Literature Review in Mobile Technologies and Learning

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FUTURELAB SERIES

REPORT 11:

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FOREWORD

Mobile technologies are a familiar part of the lives of most teachers and students in the UK today. We take it for granted that we can talk to other people at any time, from wherever we may be; we are beginning to see it as normal that we can access information, take photographs, record our thoughts with one device, and that we can share these with our friends, colleagues or the wider world. Newer developments in mobile phone technology are also beginning to offer the potential for rich multimedia experiences and for location-specific resources.

The challenge for educators and designers, however, is one of understanding and exploring how best we might use these resources to support learning. That we need to do this is clear – how much sense does it make to continue to exclude from schools, powerful technologies that are seen as a normal part of everyday life? At the present time, however, the models for using and developing mobile applications for learning are somewhat lacking.

This review provides a rich vision of the current and potential future developments in this area. It moves away from the dominant view of mobile learning as an isolated activity to explore mobile learning as a rich, collaborative and conversational experience, whether in classrooms, homes or the streets of a city. It asks how we might draw on existing theories of learning to help us evaluate the most relevant applications of mobile technologies in education. It describes outstanding projects currently under development in the UK and around the world and it explores what the future might hold for learning with mobile technologies.

We look forward to hearing your views on this review and welcome comments at research@futurelab.org.uk

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Director of Learning Research
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EXECUTIVE SUMMARY

the whole world is going mobile

EXECUTIVE SUMMARY

The whole world is going mobile. Phones, computers and media devices now fit in our pockets and can connect us to a variety of information sources and enable communication nearly everywhere we go. There is considerable interest in exploiting the almost universal appeal and abundance of these technologies for their educational use.

The following issues are the most salient:

WHAT ARE THE NEW MOBILE TECHNOLOGIES, AND WHY ARE THEY RELEVANT TO LEARNING?

With respect to technologies, 'mobile' generally means portable and personal, like a mobile phone. Many examples of learning with mobile technologies fit in to this description. Personal digital assistants and mobile phones are the most commonly used technologies for mobile learning, but they exist within the larger space of possible mobile technologies that can be broadly categorised on the two dimensions of personal vs shared and portable vs static.

NEW LEARNING AND TEACHING PRACTICES AND MOBILE TECHNOLOGIES

Most previous reviews of mobile technologies and learning have been concerned with the use of these technologies to address specific curriculum areas. In this review, we take an activity-centred perspective, considering new practices against existing theories. Our review of the literature reveals six broad theory-based categories of activity, and identifies a number of examples of the use of mobile technology in each of them:

1 **Behaviourist –** activities that promote learning as a change in learners' observable actions
In the behaviourist paradigm, learning is thought to be best facilitated through the reinforcement of an association between a particular stimulus and a response. Applying this to educational technology, computer-aided learning is the presentation of a problem (stimulus) followed by the contribution on the part of the learner of the solution (response). Feedback from the system then provides the reinforcement. In a mobile learning context, classroom response systems like 'Classtalk' (Dufresne et al 1996) and 'Qwizdom' (Qwizdom: Assessment for Learning in the Classroom 2003) fall in this category, as well as examples of content delivery by text messages to mobile phones (BBC Bitesize 2003, 2004; Thornton and Houser 2004).

2 **Constructivist –** activities in which learners actively construct new ideas or concepts based on both their previous and current knowledge
In the constructivist approach, learning is an active process in which learners construct new ideas or concepts based on both their current and past knowledge. Learners are encouraged to be active constructors of knowledge, with mobile devices now embedding them in a realistic context at the same time as offering access to supporting tools. The most compelling examples of the implementation of constructivist principles with mobile technologies

come from a brand of learning experience termed 'participatory simulations', where the learners themselves act out key parts in an immersive recreation of a dynamic system. Examples include the Virus Game (Collella 2000), Savannah (Facer et al in preparation), and the Environmental Detectives (Klopfer and Squire in preparation).

3 **Situated –** activities that promote learning within an authentic context and culture
Situated learning posits that learning can be enhanced by ensuring that it takes place in an authentic context. Mobile devices are especially well suited to context-aware applications simply because they are available in different contexts, and so can draw on those contexts to enhance the learning activity. The museum and gallery sector has been on the forefront of context-aware mobile computing by providing additional information about exhibits and displays based on the visitor's location within them. Examples of mobile systems that situate learning in authentic contexts include the Ambient Wood (Rogers et al 2002), MOBIlearn (Lonsdale et al 2003, 2004), and the multimedia tours offered at the Tate Modern (Proctor and Burton 2003).

4 **Collaborative –** activities that promote learning through social interaction
Collaborative learning has sprung out from research on computer-supported collaborative work and learning (CSCW/L) and is based on the role of social interactions in the process of learning. Many new approaches to thinking about learning developed in the 1990s, most of which are rooted in Vygotsky's socio-cultural psychology (Vygotsky 1978), including activity theory (see for example Engeström 1987). Though not traditionally linked with collaborative learning, another theory that is particularly relevant to our consideration of collaboration using mobile devices is conversation theory (Pask 1976), which describes learning in terms of conversations between different systems of knowledge. Mobile devices can support mobile computer-supported collaborative learning (MCSCL) by providing another means of coordination without attempting to replace any human-human interactions, as compared to say, online discussion boards which substitute for face-to-face discussions (Zurita et al 2003; Cortez et al 2004; Zurita and Nussbaum 2004).

5 **Informal and lifelong –** activities that support learning outside a dedicated learning environment and formal curriculum
Research on informal and lifelong learning recognises that learning happens all of the time and is influenced both by our environment and the particular situations we are faced with. Informal learning may be intentional, for example, through intensive, significant and deliberate learning 'projects' (Tough 1971), or it may be accidental, by acquiring information through conversations, TV and newspapers, observing the world or even experiencing an accident or embarrassing situation. Such a broad view of learning takes it outside the classroom and, by default, embeds learning in everyday life, thus emphasising the value of mobile technologies in supporting it. An example in this category is the system

mobile devices are especially well suited to context-aware applications

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described by Wood et al (2003) where breast cancer patients are enabled to access trustworthy information about their condition, to communicate with other patients, and to keep track of the issues that concern them.

6 **Learning and teaching support –** activities that assist in the coordination of learners and resources for learning activities
Education as a process relies on a great deal of coordination of learners and resources. Mobile devices can be used by teachers for attendance reporting, reviewing student marks, general access of central school data, and managing their schedules more effectively. In higher education, mobile devices can provide course material to students, including due dates for assignments and information about timetable and room changes. Examples of using mobile technologies in this context include a mobile learning organiser which has been developed and tested at the University of Birmingham (Holme and Sharples 2002; Sharples et al 2003; Corlett et al 2004), and the use of mobile phone technologies to support computing students (Riordan and Traxler 2003; Traxler and Riordan 2003).

a blended approach to enabling learning with mobile technologies is necessary

A blended approach to enabling learning with mobile technologies is necessary as successful and engaging activities draw on a number of different theories and practices.

WHAT ARE THE IMPLICATIONS FOR LEARNERS, TEACHERS AND CURRICULUM DEVELOPERS?

Learning and teaching with mobile technologies is beginning to make a breakthrough from small-scale pilots to institution-wide implementations. In order for these implementations to be successful, educators and technology developers must consider the following key issues:

- **Context:** gathering and utilising contextual information may clash with the learner's wish for anonymity and privacy.
- **Mobility:** the ability to link to activities in the outside world also provides students with the capability to 'escape' the classroom and engage in activities that do not correspond with either the teacher's agenda or the curriculum.
- **Learning over time:** effective tools are needed for the recording, organisation and retrieval of (mobile) learning experiences.
- **Informality:** students may abandon their use of certain technologies if they perceive their social networks to be under attack.
- **Ownership:** students want to own and control their personal technology, but this presents a challenge when they bring it in to the classroom.

Research-informed guidelines can help to address these issues along with more practical concerns such as cost, usability, technical and institutional support. A set of such guidelines (O'Malley et al 2003) is presented in Section 4.1 and outlined here:

1 Investigate a cost model for infrastructure, technology and services.

2 Study the requirements of all those involved in the use of the technology (learners, teachers, content creators) to ensure it is usable and acceptable.

3 Assess that the technology is suited to the learning task and examine advantages and disadvantages of each technology before making a decision on which one to use.

4 Assign the necessary roles for initiating and thereafter supporting mobile learning.

5 Develop procedures and strategies for the management of equipment when it is provided by the institution.

6 Provide training and (ongoing) technical support to the teachers to enable them to use mobile technologies to enhance current and to enable new instructional activities.

7 Consider the use of mobile technologies for student administration tasks.

8 Consider the use of mobile technologies to support collaborative and group learning.

9 Discover and adopt suitable applications that match the needs of your specific classroom and map directly to your curriculum needs.

10 Ensure security and privacy for the end users.

WHAT IS THE FUTURE OF MOBILE TECHNOLOGY IN EDUCATION?

Mobile technologies are becoming more embedded, ubiquitous and networked, with enhanced capabilities for rich social interactions, context awareness and internet connectivity. Such technologies can have a great impact on learning. Learning will move more and more outside of the classroom and into the learner's environments, both real and virtual, thus becoming more situated, personal, collaborative and lifelong. The challenge will be to discover how to use mobile technologies to transform learning into a seamless part of daily life to the point where it is not recognised as learning at all.

learning and teaching with mobile technologies is beginning to make a breakthrough

1 INTRODUCTION

Today we are witnessing the emergence of a connected, mobile society, with a variety of information sources and means of communication available at home, work, school and in the community at large. Some even describe this as the beginning of the next social revolution (for example, Rheingold 2003). A high proportion of UK residents have mobile phones (75% general population, 90% young adults; Crabtree et al 2003) that can handle both voice calls and the display of textual information. Many newer phones also have the ability to connect wirelessly to the internet. Hand-held computers, otherwise known as personal digital assistants (PDAs), are also becoming more widespread (BBC 2004), being distributed by employers who are eager to keep their workforce productive whilst on the move. Laptops, though already a well-established technology, have gained new appeal when combined with the connectivity of newer mobile phones – a laptop can now use a mobile phone as a means to dial-up the internet and in doing so offer a truly mobile web experience. Furthermore, kiosks and information screens are appearing all around the country, and both researchers and industry are keen to exploit the potential of these 'ambient' approaches to providing rich information spaces.

There is considerable interest from educators and technical developers in exploiting the unique capabilities and characteristics of mobile technologies to enable new and engaging forms of learning. This review explores the use of these mobile technologies for learning, considered against a backdrop of existing learning theories that have been applied to the use of computers in education.

The specific aims of this review are:

- to identify the different types of mobile technologies that are applicable to learning
- to explore new and emerging practices relating to the use of mobile technologies for learning
- to identify the learning theories that are relevant to these new practices
- to present a set of exemplary case studies demonstrating uses of mobile technologies for learning
- to present key issues and guidelines to inform current educational practice and policy
- to encourage educators and technical developers to rethink their roles for the future of learning with mobile technologies.

1.1 MOTIVATION FOR THIS REVIEW

The prevalence of mobile technologies is in itself a motivator to exploit them for learning. Mobile technologies are already widespread among children (NOP 2001). It makes sense, then, for an educational system with limited information and communication technology (ICT) resources to make the most of what children bring to the classroom. Sharples (2003) suggests that rather than seeing them as disruptive devices, educators should seek to exploit the potential of the technologies children bring with them and find ways to put them into good use for the benefit of learning practice. Mobile technologies provide an opportunity for a fundamental change in education away from occasional use of a computer in a lab towards more embedded use in the classroom and beyond (Hennessy 1999). Soloway et al (2001) have further argued that to make any difference in the classroom at all, computers must be mobile and within 'arm's reach'.

The nature of learning is closely linked to the concept of mobility. Vavoula and Sharples (2002) suggest that there are three ways in which learning can be considered mobile:

"learning is mobile in terms of space, ie it happens at the workplace, at home, and at places of leisure; it is mobile between different areas of life, ie it may relate to work demands, self-improvement, or leisure; and it is mobile with respect to time, ie it happens at different times during the day, on working days or on weekends" (p152).

The close relation of learning to the context and the situation in which the learning need arises has been widely discussed in the literature (Brown et al 1989; Lave and Wenger 1991) and the benefits of just-in-time, situated learning have been explored (Goodyear 2000). Nyiri (2002) notes that knowledge is information in context and since mobile devices enable the delivery of context-specific information they are well placed to enable learning and the construction of knowledge.

Mobile technologies offer learning experiences which can effectively engage and educate contemporary learners and which are often markedly different from those afforded by conventional desktop computers. These devices are used dynamically, in many different settings, giving access to a broad range of uses and situated learning activities. The personal nature of these technologies means that they are well suited to engaging learners in individualised learning experiences, and to giving them increased ownership (and hence responsibility) over their own work.

Most previous reviews of mobile technologies for learning categorise examples of use according to curriculum area. We believe that the benefits of mobile technologies for learning encompass more than just what an individual can do with a device, and that there is thus a need for a wider review of new and emerging practices and how these relate to theories and paradigms previously established for the use of computers in education.

1.2 CLASSIFICATION OF MOBILE TECHNOLOGIES

There are many different kinds of technology that can be classed as 'mobile'. Mobile, to most, means 'portable' and 'movable'. It also seems to implicate a 'personal' as opposed to 'shared' context of use, and the terms 'mobile' and 'personal' are often used interchangeably – but a device might be one without necessarily being the other.

We can classify the range of mobile technologies using the two orthogonal

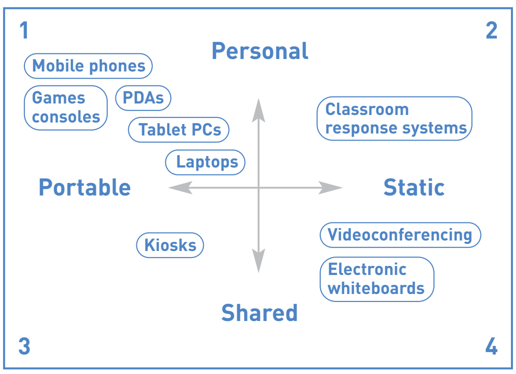

Fig 1: Classification of mobile technologies

dimensions of personal vs shared and portable vs static, as outlined in Fig 1. Quadrant 1 shows devices that can be classified as both portable and personal. These kinds of devices are what people most commonly think of in relation to mobile technologies: mobile phones, PDAs, tablet PCs and laptops. It also includes hand-held video game consoles, with Rosas et al (2003) and Lee et al (2004) reporting on early evaluations of their educational use. Since these devices normally support a single user, they are generally perceived as being very personal. The networked nature of such devices affords communication and information sharing, meaning that while the devices themselves are personal, the information within them can be shared easily. These devices are portable because they are taken from place to place and hence they can be available in many different locations. These are personal portable technologies.

Some other technologies, less portable than mobile phones and PDAs, can still offer personal interactions with learning experiences. Classroom response systems, shown in quadrant 2, consist of individual student devices that are used to respond anonymously to multiple choice questions administered by a teacher on a central server. This technology is static in the sense that it can only be used in one location, but remains personal because of its small size and allocation to (typically) one single user. These are personal static technologies.

Being physically moved from one place to another is not the only way in which mobile technologies can be 'portable'. In quadrant 3, there are examples of technologies that can provide learning experiences to users on the move, but the devices themselves are not physically movable. Street kiosks, interactive museum displays and other kinds of installations offer pervasive access to information and learning experiences, but it is the learner who is portable, not the delivery technology. Such devices are typically seen as being less personal, and are likely to be shared between multiple users. Their larger size means they are also better suited to multiple-user interactions. These are shared portable technologies.

For more shareable interactions, the devices themselves must become larger and hence less portable. Examples include interactive classroom whiteboards and video-conferencing facilities, as shown in quadrant 4. These technologies have been included to show the complete space of possibilities engendered by our classification, but they would generally not be classed as mobile technologies.

We believe that 'mobile technologies' comprise all devices from quadrants 1-3, and those from quadrant 4 that are not at the extreme end of the 'static' dimension.

1.3 SCOPE OF THIS REVIEW

In this review we will primarily be considering personal portable technologies. We shall focus on hand-held devices including PDAs and mobile phones. Many of the implications for learning are shared by other portable devices such as tablet PCs and laptops.

Even within the narrow range of devices considered there is a variety of capabilities and features. Appendix 1 presents an overview of features and specifications. Further discussion of mobile device characteristics can be found in Sharples and Beale (2003) and Becta (2004).

This review advocates an activity-focused perspective on the use of mobile technologies for education, and presents these activities along with relevant learning paradigms and theories in Section 2. In Section 3, we illustrate the categories of practice through case studies drawn from the literature. In Section 4, we consider the implications for policy and educational practice, and present research-informed guidelines as to how these can be addressed. Finally, with reference to both emerging trends in mobile technology and learning research, we speculate on the future of mobile technologies and learning and the implications this will have for today's educators and technology developers.

2 AN ACTIVITY-BASED APPROACH TO CONSIDERING LEARNING WITH MOBILE TECHNOLOGIES

Much of the research into the use of mobile technologies for learning is driven by the technical capabilities of new devices. This is not unexpected, given the rapidly changing face of mobile computing. These new capabilities inspire new practices which can lead to valuable outcomes, but, to date, application of theory to the use of these technologies for educational purposes is lacking. In this section we consider the kinds of activities that can be enabled through the use of mobile devices under the categorisation of relevant theories from the study of learning and, in particular, learning with technology.

Mobile technologies are computers, but that does not mean that they should be viewed as simply providing more portable versions of the learning activities that are currently supported on more static machines. Being mobile adds a new dimension to the activities that can be supported, both because of the personal and portable nature of the devices themselves, and because of the kinds of interactions they can support with other learners and the environment.

Klopfer et al (2002) identify five properties of mobile devices (PDAs in this case) that produce unique educational affordances:

- **Portability –** the small size and weight of mobile devices means they can be taken to different sites or moved around within a site.
- **Social interactivity –** data exchange and collaboration with other learners can happen face-to-face. Nyiri (2002), with

being mobile adds a new dimension to the activities that can be supported

AN ACTIVITY-BASED APPROACH TO CONSIDERING LEARNING WITH MOBILE TECHNOLOGIES

reference to Dewey's emphasis on the need to facilitate face-to-face interactions, posits a new philosophy of mobile learning that points to mobile technologies as facilitators for the innate anthropological need to communicate.

- **Context sensitivity –** mobile devices can both gather and respond to real or simulated data unique to the current location, environment and time.
- **Connectivity –** a shared network can be created by connecting mobile devices to data collection devices, other devices or to a common network.
- **Individuality –** scaffolding for difficult activities can be customised for individual learners.

To fully appreciate the potential of mobile technologies for learning, we must look beyond the use of individual devices and consider their use embedded in classroom practice, or as part of a learning experience outside the classroom.

2.1 CLASSIFICATION OF ACTIVITIES

We have structured the classification of activities around the main theories and areas of learning relevant to learning with mobile technologies.

The six main themes we have identified are:

1. **Behaviourist –** activities that promote learning as a change in observable actions.
2. **Constructivist –** activities in which learners actively construct new ideas or concepts based on both their previous and current knowledge.
3. **Situated –** activities that promote learning within an authentic context and culture.
4. **Collaborative –** activities that promote learning through social interaction.
5. **Informal and lifelong –** activities that support learning outside a dedicated learning environment and formal curriculum.
6. **Learning and teaching support –** activities that assist in the coordination of learners and resources for learning activities.

Note that these categories are by no means mutually exclusive, but are intended to provide a loose theoretical background for reviewing the case studies presented in Section 3.

2.2 BEHAVIOURIST LEARNING

The use of mobile devices to present learning materials, obtain responses from learners, and provide appropriate feedback, fits within the behaviourist learning paradigm. This paradigm draws on Skinner's work on operant conditioning and behaviourism (Skinner 1968; itself based on Pavlov's work on classical conditioning). Within this paradigm, learning is thought to be best facilitated through the reinforcement of an association between a particular stimulus and a response. Applying this to educational technology, computer-aided learning is the presentation of a problem (stimulus) followed by the contribution from the part of the learner of the solution (response). Feedback from the system then provides the reinforcement. This type of learning adopts a transmission model – learning takes place through the transmission of information from the tutor (the computer) to the learner.

Despite a move away from the behaviourist perspective within the field of learning theory, many e-learning systems still rely heavily on this approach. Computers provide the ideal opportunity to present content, gather responses, and provide appropriate feedback. It would seem that this approach has lost none of its momentum in transferring to the use of mobile devices instead of desktop PCs; there is currently a great deal of interest in the use of mobile devices as a means to deliver such content, as the case studies in the next section will demonstrate.

With regard to mobile delivery, we find that we are faced with challenges similar to those faced by early designers of computer-assisted learning (CAL) systems, when the technology was more limited. Compared to today's desktop computers, mobile devices have limited displays, restricted input methods, and low rates of connectivity.

Despite these problems, 'drill and feedback' activities still offer a number of advantages:

- content and feedback can be tailored to suit particular curriculum areas
- valuable data can be gathered about the progress of individual students.

The use of mobile devices also means that even the most basic of such activities can be embedded within a meaningful learning context, as exemplified by classroom response systems.

2.2.1 Classroom response systems – hybrid drill and feedback

The use of mobile devices to gather feedback from learners during a session being delivered by a teacher employs a hybrid model that emphasises the integration of mobile devices into existing teaching practice, not the replacement of it.

Classroom response systems facilitate whole-class drill and feedback activities by allowing teachers to:

- Present content-specific questions. These questions can range from simple review to probing questions at the heart of the subject matter. Suggested solutions are invited by way of multiple choice options on the students' devices.
- Gather student responses rapidly and anonymously.
- Quickly assemble a public, aggregate display to show the variation in the group's ideas while maintaining individual anonymity (Roschelle et al 2004).

The underlying principle is simple, but there appear to be a number of gains over traditional methods of classroom interaction. Roschelle (2003) reports the following benefits for classroom response systems:

- **Formative assessment/peer feedback and the benefit of anonymity:** students can see that others share their own misconceptions, but this information is anonymous, which means there is no potential loss from answering incorrectly. This also aids the teacher in assessing the current level of understanding in the class as a whole.

even the most basic of activities can be embedded within a meaningful learning context

AN ACTIVITY-BASED APPROACH TO CONSIDERING LEARNING WITH MOBILE TECHNOLOGIES

- **The use of devices for responses gives rise to a change in the nature of the teaching,** as the responses themselves can serve as a catalyst for richer discussion of the pertinent topics.

- **The role of the technology is small but valuable:** it provides anonymity, speed of response collection, and shared visualisations that enhance mutual pattern recognition.

These advantages give an indication of the ways in which mobile devices in particular can enhance the behaviourist learning process. This remains, however, a fairly basic application of mobile devices in learning. As explored in the subsequent sections, mobile devices can provide more direct ways for learners to interact with materials in an authentic learning context.

mobile devices can provide more direct ways for learners to interact with materials in an authentic learning context

2.3 CONSTRUCTIVIST LEARNING

Constructivist theories of learning were developed during the 1960s and 70s, inspired by the rise in cognitive theories of learning. Bruner, a principal contributor, theorised that learning was an active process in which learners construct new ideas or concepts based on both their current and past knowledge (Bruner 1966). The use of a cognitive structure to select and transform information, construct hypotheses and make decisions was heavily based on Piaget's descriptions of the patterns of physical or mental action that underlie specific acts of intelligence and correspond to stages of child development (Piaget 1929).

The personal home computer of the 1980s offered tremendous advances in terms of display capabilities (text, graphics, video and sound were now possible) and interaction methods. The computer was no longer just a conduit for the presentation of information; it was a tool for the active manipulation of that information. The user or learner gained a locus of control in the learning activity that was missing from behaviourist approaches, and so dawned the era of 'Powerful Ideas' (Papert 1980).

For Papert, and others of the time, the computer became the tutee, rather than the tutor, and the learner engaged in the learning process through instructing the computer how to perform tasks and solve problems. This was accomplished through a specially designed computer programming language called Logo. Papert termed this alternative approach to constructivist learning constructionism, as learners were actively constructing their own knowledge and learning by building interactive models.

Within a constructivist learning framework, instructors should encourage students to discover principles for themselves. In order to transform learners from passive recipients of information to active constructors of knowledge we must give them an environment in which to participate in the learning process, and the appropriate tools to work with that knowledge. Mobile devices give us a unique opportunity to have learners embedded in a realistic context at the same time as having access to supporting tools.

The most compelling examples of the implementation of constructivist principles with mobile technologies come from a brand of learning experience termed participatory simulations.

2.3.1 Participatory simulations

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 (in preparation) and Klopfer and Squire (in preparation). Further details of these studies will be reported in Section 3.

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 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.

2.4 SITUATED LEARNING

The situated learning paradigm, as developed 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.

Three 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, case-based learning, and context-aware learning.

2.4.1 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 practicing professional. The problem is used as a basis for "learning by analogy and abstraction via reflection" (O'Malley et al 2003) .

in participatory simulations, the learners themselves act out key parts in an immersive recreation of a dynamic system context-aware computing represents a relatively new area of research

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 five to six) 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 (eg 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).

2.4.2 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.

2.4.3 Context-aware learning

Context-aware computing represents a relatively new area of research. Context awareness means gathering information from the environment to provide a measure of what is currently going on around the user and the device. Activities and content that are particularly relevant to that environment can then be made available. Mobile devices are especially well suited to context-aware applications simply because they are available in different contexts, and so can draw on those contexts to enhance the learning activity. Context-aware mobile devices can support learners by allowing a learner to maintain their attention on the world and by offering appropriate assistance when required. This kind of appropriate support can be seen as a form of scaffolding (Wood et al 1976).

The museum and gallery sector has been on the forefront of context-aware mobile computing by providing additional information about exhibits and displays based on the visitor's location within them.

2.5 COLLABORATIVE LEARNING

Both the capabilities of mobile devices and their wide context of use contribute to their propensity to foster collaboration. Mobile devices can easily communicate with other devices of the same or similar type, enabling learners to share data, files and messages. They can also be connected to a shared data network, further enhancing possibilities for communication. These devices are also typically used in a group setting, and so interactions and collaboration will tend to take place not just through the devices but also at and around them as well.

Research into collaborative learning with mobile devices is greatly informed by previous research on computer-supported collaborative learning (CSCL). In reality, much current research into mobile learning can be classed as mobile-CSCL or MCSCL, and there is a specific focus on the use of mobile technologies to promote, facilitate and enhance interactions and collaborations between students.
CSCL draws on many different learning theories. Situated learning theories emphasise the role of social interactions in the process of learning. Many new approaches to thinking about learning developed in the 1990s, most of which are rooted in Vygotsky's socio-cultural psychology (Vygotsky 1978), including activity theory (see for example Engeström 1987).

Though not traditionally linked with collaborative learning, another theory that is particularly relevant to our consideration of collaboration using mobile devices is conversation theory (Pask 1976), which describes learning in terms of conversations between different systems of knowledge. Pask was careful not to make any distinction between people and interactive systems such as computers, with the great advantage that the theory can be applied equally to human teachers and learners, or to technology-based teaching or learning support systems.

In order to constitute a 'conversation', the learner must be able to formulate a description of himself and his actions, explore and extend that description and carry forward the understanding to a future activity. In order to learn, a person or system must be able to converse with itself about what it knows.

Learning can be even more effective when learners can converse with each other, by interrogating and sharing their descriptions of the world. We can say that the two people share an understanding if Person A can make sense of B's explanations of what B knows, and person B can make sense of A's explanation of what A knows. Thus, it is through mutual conversation that we come to a shared understanding of the world. Learning is a continual conversation; with the external world and its artefacts, with oneself, and also with other learners and teachers.
The most successful learning comes when the learner is in control of the activity, able to test ideas by performing experiments, ask questions, collaborate with other people, seek out new knowledge, and plan new actions.

Laurillard (1993) relates Pask's theory to the realm of academic knowledge. Though primarily concerned with the application of educational technology to university-level teaching, the 'conversational framework' she puts forward can be applied to the full range of subject areas and topic types.

AN ACTIVITY-BASED APPROACH TO CONSIDERING LEARNING WITH MOBILE TECHNOLOGIES

The learning process includes the following aspects: apprehending structure, integrating parts, acting on descriptions, using feedback and reflecting on goal-action-feedback. As illustrated in Fig 2, technology may play multiple roles within the conversation space.

Technology may take the place of the teacher, as in drill and feedback. The difficulty here is that the computer can hold a limited dialogue at the level of actions - "look here", "what's this?", "do that" - but is not able to reflect on its own activities or its own knowledge. And because it cannot hold a conversation at the level of descriptions, it has no way of exploring students' misconceptions or helping them to reach a shared understanding. Technology can also demonstrate ideas or offer advice at the level of descriptions, as with the world wide web or online help systems, but their practical advice, at the level of actions, is limited.

Alternatively, the technology may provide the environment in which conversational learning takes place. It can extend the

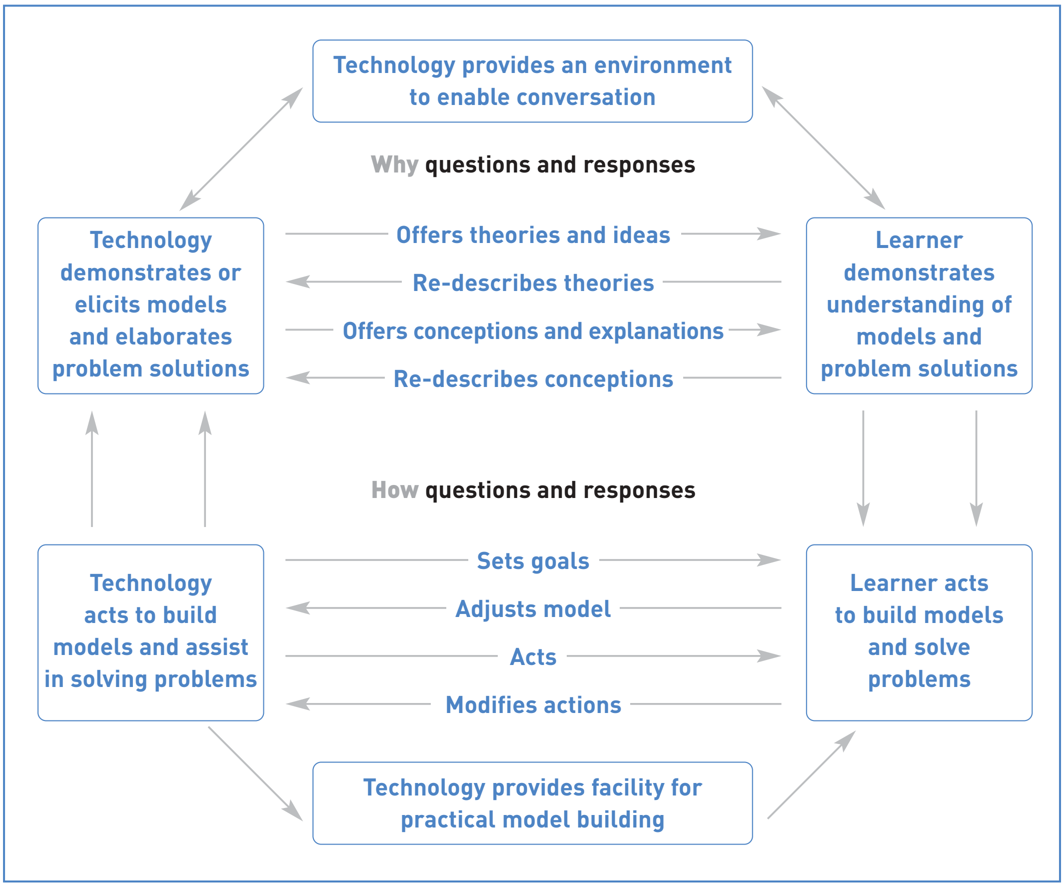

Fig 2: Role of technology in supporting conversational learning

the technology may provide the environment in which conversational learning takes place range of activities and the reach of a discussion into other worlds through games, and to other parts of this world by mobile phone or e-mail. The technology provides a shared conversational learning space, which can be used not only for single learners but for groups of learners.

2.5.1 Small group collaboration

Mobile devices can support MCSCL by providing another means of coordination without attempting to replace any human-human interactions, as compared to say online discussion boards which substitute for face-to-face discussions.

Hand-helds support MCSCL activities by directly addressing usability problems with conventional CSCL activities. The hand-held stores all of the material and information necessary to organise the activity, and the user interface addresses coordination by forcing the participants to perform one task at a time in a specific sequence. Communication is supported by making messages about activity status, data, error or results available to all participants, and synchronisation is supported as each hand-held has to wait for the action of the other hand-helds before moving to the next stage of the activity. By requiring all participants to agree on an answer before proceeding, the application facilitates interactivity and provides a negotiation space. Finally, the hand-helds support mobility by allowing the participants to take the technology anywhere, and by allowing for natural social interactions. By effectively coupling an informatic layer with the social network layer, learning gains can be significant (Zurita and Nussbaum 2004).

2.6 INFORMAL AND LIFELONG LEARNING

Learning happens all of the time and is influenced both by our environment and the particular situations we are faced with. Informal learning may be intentional, for example through intensive, significant and deliberate learning 'projects' (Tough 1971), or it may be accidental by acquiring information through conversations, TV and newspapers, observing the world, or even by experiencing an accident or embarrassing situation. Eraut (2000) classifies these 'non-formal' learning activities along a continuum of the learner's intent, with the former activities representing deliberate learning and the latter activities representing implicit learning. Activities in the middle of the continuum are described as reactive learning, which occurs in response to changing circumstances such as career promotion or parenthood.

Indeed, studies of informal learning (Tough 1971; Livingstone 2001) show that most of adults' learning happens outside formal education. While informal learning is a reality in people's lives, they may not recognise it as learning.

Tough (1971) notes:

"...when the person's central concern is a task or decision, he will not be very interested in learning a complete body of subject matter. Instead, he will want just the knowledge and skill that will be useful to him in dealing with the particular responsibility of the moment" (p51).

by effectively coupling an informatic layer with the social network layer, learning gains can be significant

the use of mobile technologies in education is not restricted to exploiting them for learning activities

Thus, people learn in order to be able to perform a new task, or even to be able to carry out a routine task in a better, more efficient or elegant way. Technology that is used to support learning should be blended with everyday life in the same way that learning is blended with everyday life: seamlessly and unobtrusively. Mobile technologies, with their reduced size and ease of use, provide the potential to support such activities.

With regard to accidental learning, learning episodes are impossible to predict. The personal and portable nature of mobile technologies makes them very strong candidates for recording, reflecting on and sharing this type of informal learning.

2.7 LEARING AND TEACHING SUPPORT

The use of mobile technologies in education is not restricted to exploiting them for learning activities. Education as a process relies on a great deal of coordination of learners and resources. Mobile technologies can help in supporting teaching and learning without explicitly being part of the learning activity themselves.

There is scope for supporting both students and teachers, and also for supporting administration more generally. Perry (2003) reports on the successful use of PDAs for administration and supporting classroom management.

Theme	Key Theorists	Activities
Behaviourist learning	Skinner, Pavlov	• drill and feedback • classroom response systems
Constructivist learning	Piaget, Bruner, Papert	• participatory simulations
Situated learning	Lave, Brown	• problem and case-based learning • context awareness
Collaborative learning	Vygotsky	• mobile computer-supported collaborative learning (MCSCL)
Informal and lifelong learning	Eraut	• supporting intentional and accidental learning episodes
Learning and teaching support	n/a	• personal organisation • support for administrative duties (eg attendance)

Table 1: An activity-based categorisation of mobile technologies and learning

Mobile devices can be used by teachers for attendance reporting, reviewing student marks, general access of central school data, or managing their schedules more effectively. In higher education, mobiles can provide course material to students including due dates for assignments and information about timetable changes or room changes.

The informal nature of the devices can lead to positive rewards; Strom and Strom (2002) report that PDAs helped with teacher-parent communication, enabling a means for teachers to inform parents of absenteeism and thus manage this problem more effectively.

2.8 SUMMARY

Table 1 summarises the main activity themes discussed in this section.

While mobile devices are not necessarily required to support these activities, their use affords a highly personal experience embedded within an authentic context of use. The range of activities for which mobile devices are being used suggests that these technologies are fundamentally changing the nature of learning provision.

It is beyond the scope of this review to attempt a synthesis of the theories presented here and elsewhere that are relevant to learning with mobile technologies. There is, as yet, no over-arching 'theory of mobile learning', but what we can work towards is an integrated pedagogy for the use of mobile devices that draws on a number of areas. What is needed is a blended, integrated approach – as explored in the next section, the power of mobile devices in the classroom and beyond comes from being able to combine different elements in ways that are appropriate to the learning activities to be supported.

the informal nature of the devices can lead to positive rewards

3 TEACHING AND LEARNING WITH MOBILE TECHNOLOGIES – CASE STUDIES

This section presents both current and recent examples of teaching and learning with mobile technologies, categorised under the themes introduced in Section 2. The particular examples were chosen because they possess one or more of the following key characteristics:

- broad impact, mainly inferred from the number of learners supported
- strong theoretical basis
- support of an interesting or novel activity
- inclusion of both qualitative and quantitative evaluation results.

3.1 BEHAVIOURIST LEARNING

The following case studies demonstrate the unique capabilities for anytime, anywhere learning that mobile devices can offer, even for the most straightforward 'drill and feedback' activities.

3.1.1 Skills Arena

Skills Arena (Lee et al 2004) is a mathematics video game, implemented using the Nintendo Game Boy Advance system, that supplements traditional curricula and teaching methods. Drills in addition and subtraction are presented as a game with advanced scoring and record-keeping, character creation and variable difficulty level. Students can select the name and physical traits of their character, which they use to compete in 'matches' against computer-generated opponents, ranked by difficulty. Difficulty is increased by increasing the speed at which the problems display on the screen.

Compared to traditional worksheets, Skills Arena was designed to offer faster feedback, the ability for each student to select the appropriate difficulty level and to provide increased motivation.

An initial pilot study of Skills Arena was tested with two classes of second grade students (39 students in total) over 19 days. Students completed an average of 1,296 problems each during this period, three times what would be expected with traditional worksheets. Skills Arena also had a significant impact on the classroom culture. Both teachers found the activity was easy to administer and control, and one teacher even used Skills Arena as a reward for good behaviour. Students' active engagement with Skills Arena extended beyond the time allotted in the classroom, as they were inspired to create stories about both their experience and their characters.

Based on the results of the pilot study, additional classroom studies are planned to quantify whether using Skills Arena improves student's performance in addition and subtraction, and to compare the impact with traditional drill activities such as worksheets.

3.1.2 BBC Bitesize

BBC Bitesize (2003; 2004) is an initiative to provide revision materials via mobile phones, using a downloadable Java game and SMS text messages. 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 cross-platform 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.

3.1.3 Mobile phones for language learning

Two mobile language learning systems for mobile phones were implemented and tested in 2003 (Thornton and Houser 2004). SMS was used as part of an English language course, where students were sent frequent vocabulary messages, which also act as reminders to revise. The lessons proved effective and were well received by the students. The system takes advantage of 'push' technologies and promotes regular study. Researchers did note, however, that students were postponing study until they would have the time to concentrate on the task.

Video delivered on mobile platforms (both mobile phone and PDA) was used to demonstrate the literal meaning and the special use of English idioms. Students found the video quality low, but the experience of using the videos engaging.

A related commercial application is Pocket Eijiro [1], started in December 2002 as an English-Japanese, Japanese-English dictionary. The site now receives more than 100,000 hits per day and subscribers number in the hundred thousands.

3.1.4 Classroom response systems

Classroom response systems can be implemented as either specialist systems, comprising both the hardware and software such as Educue [2], or as software-only systems that can be installed on mobile devices, such as Discourse [3].

Dufresne et al (1996) report on the use of a classroom response system called 'Classtalk' with first year physics students at the University of Massachusetts, USA.

1 http://ojr.org/japan/wireless/1080854640.php
2 http://www.educue.com
3 http://www.ets.org/discourse/about.html

Classtalk helped to clarify the students' conceptual understanding of the material by allowing them to articulate and elaborate their ideas, reflect on both their own ideas and the ideas of others, and evaluate the usefulness of having a number of different perspectives. The key benefit of a technology-supported system was that it afforded all the students the opportunity to present a viewpoint, whether or not they were comfortable presenting their ideas to the entire class. In addition to engaging students in active learning during the lectures, Classtalk also enhanced the overall communication within the classroom.

A more recent example of a classroom response system implementation is the Northern Ireland e-Learning 'Assessment for Learning' project, which evaluated the Qwizdom Classroom Response System (2003) with 114 students and four teachers at three schools.

a technology-supported system afforded all the students the opportunity to present a viewpoint

3.2 CONSTRUCTIVIST LEARNING

As introduced in the previous section, participatory simulations are games where learners play an active role in the simulation of a dynamic system or process. The key challenge is to make sure the technology is unobtrusive, so that it facilitates rather than hinders interactions between the learners.

3.2.1 The virus game

Collella (2000) describes a study where learners took part in a participatory simulation about the spread of a virus. Students were asked to simulate and observe the spread of a virus in a population by moving around the classroom meeting each other face to face. Each student wore a custom-built 'thinking tag' that showed whether or not they were infected by means of coloured lights. These tags were worn like badges, and would communicate with other tags whenever they were in range; in this way, meetings between learners were tracked by the tags, and the virus, which started in just one person, could spread to other people as they met and their tags communicated. The students were able to take part in a simulation without worrying about underlying rules of that simulation – their tags did all the thinking about rules for them, and the students could concentrate on the important questions: "Where did the disease start?" "How does it get spread?" "Who can catch it?"

Key findings include:

- students readily engaged with the simulation, and found it to be a rewarding and stimulating experience
- students successfully collaborated to answer the relevant questions about the simulation
- the technology facilitated, rather than hindered, normal interactions between the students – the devices augmented rather than replaced normal channels of communication, and hence provided unobtrusive technology support
- students were able to test out experimental hypotheses within the simulation after observing specific behaviours.

This simulation has been re-created for the PalmOS PDA, and is freely available from http://education.mit.edu/pda/games.htm.

3.2.2 **Savannah**

Savannah (Facer et al in preparation) was a collaboration between NESTA Futurelab, BBC NHU, the Mixed Reality Lab (Nottingham University) and Mobile Bristol (Hewlett-Packard and University of Bristol). This pilot study explored 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 more reflective learning 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 (ie "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:

- 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.

- 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 and the rules of the game in order to play better - and needed support in transitioning between these roles.

- Despite suspending their disbelief, children had high expectations of the system; they 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.

3.2.3 **Environmental Detectives**

The MIT Games-to-Teach project seeks to further explore the development of 'augmented reality educational gaming'

(Klopfer and Squire in preparation). Augmented reality educational gaming builds on recent developments in hand-held 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 two 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.
The researchers have designed a toolkit for implementing customised scenarios, available through the Games-to-Teach website at http://www.educationarcade.org/gtt/Hand-held/Intro.htm.

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.

3.3 SITUATED LEARNING

The portability of mobile technology allows the learning environment to be extended beyond the classroom into authentic and appropriate contexts of use. This is cited in Juniu (2002) as the most important benefit of the PDA for educators and students.

3.3.1 Ambient Wood

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 portability of mobile technology allows the learning environment to be extended beyond the classroom 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 three 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 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 had 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, or changing moisture and light levels, were introduced into the habitat. The children tried to predict the outcomes, and they could use the periscope to get feedback and answers to their hypotheses in the form of animations.

The Ambient Wood was trialled with 16 11 year-olds, who worked in pairs. They spent 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 they were too engrossed with their activities to notice sounds, voice-over and PDA display.

the most effective design approaches that incorporated audio-visual coherence and interactive messages

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.There are currently no reports on how the Ambient Wood experience compared with more traditional field trips.

3.3.2 Natural science learning in Taiwan

A butterfly-watching system was implemented and tested at an elementary school in Taiwan (Chen et al 2004). The objective was for the students to learn about natural sciences, and more specifically about the different kinds of butterflies in the region.

The project was based on the premises of independent learning, with the assumption being that providing appropriate mobile tools would help students to become capable, self-reliant, self-motivated and independent. The system was implemented using a wireless ad-hoc networking environment, comprising of a (teacher's) notebook with a WiFi wireless LAN card that acted as the local server, and student PDAs with 802.11 LAN cards and small-sized CCD cameras.

A database of different butterfly species in Taiwan was used with a content-based image retrieval system, and an online nature journal system. The students visited a butterfly farm, where the networking environment was set up and they could use their PDA cameras to take photographs of the butterflies they observed. Using the photos, they could then query the database, which would send back possible matches. The students could then decide which match was best, and the database would verify based on image content similarity. The students then made the final decision, which they recorded on their journal together with their notes of the whole experience, and posted to the teacher. The teacher in turn sent feedback to the students on their PDAs.

In the evaluations, a control group used a text-based butterfly guidebook and the experimental group used the system described above. Multiple choice tests on the key features of the butterfly species were administered before and after the trial. Six field trips were conducted in total, with students encountering three new species and three old species at each trip. In four out of the six field trips, the experimental group was able to more correctly identify the key features than the control group.

3.3.3 Multimedia tours at the Tate Modern

The Tate Modern museum in London (Proctor and Burton 2003) launched an interactive audio-visual tour in July 2002. A wireless network implementation allowed visitors using iPAQ 3850 Pocket PCs to view video and still images, listen to expert commentary and reflect on their experience by answering questions or mixing a collection of sound clips to create their own soundtrack for an artwork. The wireless network was location-sensitive, which meant that they did not have to search out the information.

The pilot tour was taken by 852 visitors. Through evaluations and focus groups, visitors reported their enthusiasm for the tour and the services it provided. The average visitor spent about 55 minutes on the tour and over 70% reported that they had spent longer than they would have without the multimedia tour. Interestingly, 45% of the visitors found the system difficult to use, with older visitors reporting more technological difficulties than younger visitors.

Regarding the content itself, the most effective design approaches were those that incorporated audio, particularly audio-visual coherence and interactive messages. Visitors did not respond well to long messages, particularly those that were primarily text-based. A second phase of trials ran until May 2004, with comprehensive results expected later in the year.

3.3.4 MOBIlearn

MOBIlearn, a major European research project, is focusing on the context-aware delivery of content and services to learners with mobile devices (Lonsdale et al 2003;2004). Context awareness is being explored not just as a way to deliver appropriate content but to enable appropriate actions and activities, including interactions with other learners in the same or similar contexts.
The central aim of this project is to produce a reusable architecture for mobile learning. Researchers at the University of Birmingham are currently developing a reference context awareness module (CAM) that will facilitate context-dependent information delivery for learners on a wide variety of mobile devices (Lonsdale et al 2003). It is intended to support a range of different learners in different environments, and addresses the following specific issues:

- human interfaces adaptive to the mobile device in use and the nature (eg bandwidth, cost) of the ambient intelligence that is available in a given locations
- context-awareness tools for exploiting context and capturing learning experience
- integration of mobile media delivery and learning content management systems
- collaborative learning applications for mobile environments.

Trials of an art gallery implementation are scheduled for December 2004.

3.4 COLLABORATIVE LEARNING

The most compelling examples of conversational learning occur when mobile technology is used to provide a shared conversation space. Effective learning occurs when people can converse with each other, by interrogating and sharing their descriptions of the world.

3.4.1 Chile embraces mobile computer supported collaborative learning (MCSCL)

Researchers from the Universidad Católica de Chile are using hand-held computers to encourage face-to-face collaborative learning for both primary and secondary education (Zurita et al 2003; Cortez et al 2004; Zurita and Nussbaum 2004).

the most compelling examples of conversational learning occur when mobile technology is used to provide a shared conversation space the personal nature of mobile devices makes them well suited for learning applications outside of formal education

A general architecture for MCSCL that uses a mobile ad hoc network (MANET) has also been developed, that works over a wireless 802.11b network. The devices are set up to communicate only between each other (peer-to-peer or P2P) and have no access to either the internet or local networks. The system can thus be used independent of any other hardware infrastructure.

The MCSCL activities are distributed through the teacher's hand-held device (Pocket PCs in this case). The teacher first downloads the activity from the project website and then transmits the activity to the students using the MANET. After the teacher launches the activity, the students are automatically assigned to collaborative groups (typically three to five students per group). Upon completion of the activity, the teacher's Pocket PC collects the students work, which can then be downloaded to the school's PC for analysis.

During the MCSCL activities, students are not allowed to progress to the next question until they answer the current question correctly. If the students submit different answers, the system prompts them to come to agreement before the answer can be submitted for marking. Students have various resources available to them during the activity, including textbooks, their own notes and the guidance of their teacher. It should be noted that rather than seeking to replace the teacher, the MCSCL system attempts to support teachers by providing additional tools to support them in performing their duties.

A wide range of curriculum-based activities can be supported. Trials of the MCSCL architecture have been conducted with both primary and secondary school students. At the secondary school level, MCSCL was tested with 90 students for five weeks to teach physics (Cortez et al 2004). At the primary level, 48 children performed a trial of MCSCL for an activity on ordering numbers (Zurita et al 2003). In each case, statistically significant results showed that the MCSCL system assisted learning. Qualitative responses from students also indicated their enthusiasm to participate in such activities. The secondary school physics experiment also had a broad social impact, as it was covered extensively by the Chilean media. The experiment was expanded to cover 1,000 students during 2003.

3.5 INFORMAL AND LIFELONG LEARNING

The personal nature of mobile devices makes them well suited for learning applications outside of formal education.

3.5.1 m-learning: reaching out to disengaged youth

m-learning is a three-year pan-European research and development programme, initiated in 2001, that uses mobile technology to teach basic literacy and numeracy skills (Attewell and Savill-Smith 2003; Colley and Stead 2003; Mitchell and Doherty 2003; Traxler 2003). It is targeted at young adults aged 16 to 24, who are deemed to be 'at-risk' because they are either outside of formal education, in low-skilled employment or unemployed, in the effort to give them better future prospects.

Initial research revealed widespread use of mobile phones across the partner countries (UK, Italy and Sweden), with even

80% of young, homeless people in the UK having access to a mobile phone. Mobile phones are used to send and receive text messages, communicate with friends and play simple computer games. The fact that mobile phones are very personal in nature, have a constant presence on the user and are highly important to teenage identity and friendships indicates that this technology holds high potential for individual and collaborative learning.

The infrastructure supporting this project includes a Learning Management System and a custom designed microportal interface, m-Portal, contributed by project partner Ultralab. This facilitates access to m-learning materials and services from a variety of mobile devices plus web and TV access. Technologies such as SMS, VoiceXML and picture messaging are implemented in a device-independent way via mobile phones, smart phones, hand-held computers and networked PCs.

To ensure learning activities were relevant, custom content was created to reflect the new adult literacy standards for England and Wales. Some examples of content include an urban soap opera about two characters moving into a flat for the first time to help with language and provide advice about how to set up a home; and a referee quiz, coinciding with the World Cup, to help with literacy.

VoiceXML is used extensively with mobile phones to deliver interactive stories or quizzes, while a simple database system receives registrations and sends instructions and reminders via SMS. Compaq iPAQ Pocket PCs are used to deliver both browser-based materials and Pocket PC-specific applications, including soap opera storylines, animations, quizzes and other interactive information.

Rather than measuring specific learning gains, m-learning evaluations seek to measure changes in attitudes towards learning. In the Phase 1 trial, 34 individuals took part in one-week trials in four locations. Initial response from the participants was highly enthusiastic and believed to have helped the participants to develop a heightened interest in improving their education. Planning for Phase 2 trials is currently underway, which will concentrate on engaging a larger number of learners by with mobile phones. Twelve schemes are planned, encompassing a total of 200 learners.

3.5.2 Mobile devices for breast cancer care

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.

No evaluation is currently available.

3.6 LEARNING AND TEACHING SUPPORT

The following examples demonstrate how mobile devices can be used to support learning-related activities for students, teachers and administrators.

3.6.1 Helping university students organise their own learning

Researchers at the University of Birmingham, UK, developed and trialled a mobile learning organiser, based on a wirelessly-enabled Pocket PC, with Masters level students in 2002-2003, to determine the key tools necessary for such a learning device (Holme and Sharples 2002; Sharples et al 2003; Corlett et al 2004).

The Student Learning Organiser is an integrated suite of software tools developed at the University of Birmingham. The 'Time Manager' tool included the ability to create, delete and view timetable events and deadlines, while the 'Course Manager' tool allowed students to wirelessly download course material packages, created by a complementary desktop tool, in Microsoft Reader format.

A one-year trial was conducted with 17 MSc students in the Department of Electronic, Electrical and Computer Engineering. Each student was given a Compaq iPAQ 3760 Pocket PC 2002 hand-held with 64MB of memory. As devices with integrated wireless capabilities were not available at the time, it was necessary to provide each student with an expansion sleeve and an 802.11b wireless network card. In addition to the Student Learning Organiser tools, the students had access to cut-down versions of Microsoft Word, Excel, Outlook, Internet Explorer and Media Player, e-mail, instant messaging and two concept mapping tools. The students were encouraged to use the hand-helds for their personal activities and to install additional software as they wished.

Results were collected via questionnaires, focus groups, video recordings and log books. No single tool stood out as a 'killer app' that significantly changed students' learning or personal organisation. Communication tools and timetabling features were consistently rated by the students to be the most useful, while the course content and concept mapping tools showed a trend of decreasing usefulness over time. Little additional software was installed, with the main reasons being that students saw the value of the hand-helds being in the time management of e-mail/messaging applications provided, and that students were reluctant to invest time and money in personalising a device they had to return at the end of the year.

Significant usability issues were encountered. The students found the hand-held, expansion sleeve and wireless card too large and heavy for comfortable use, the 64MB memory size was not sufficient for their data storage requirements, and that not recharging the hand-held regularly could cause the entire memory of the device to be cleared (including any stored data). Apart from issues with the device itself, the main reported limitation was the loss of wireless connectivity outside the department.

Institutional support issues were also considerable. In addition to not having standardised provision of content and course dates by all lecturers, timetable information was not provided consistently. The hand-held became another mode of communicating information between students and departments, making it more difficult to find relevant information quickly. The students also felt that further training sessions and integration with other departmental systems would be beneficial.

While this study was not designed to gather quantitative results into specific learning gains, it did show that the students thought the technology to be useful, even though it did not revolutionise or improve their learning significantly.

3.6.2 Support for teachers and administrators

A DfES-sponsored hand-held computing pilot was conducted in 2002-2003 with 150 teachers at 30 schools (Perry 2003). The foci of the project were managing teachers' workloads and supporting teaching and learning. A number of features of mobile technologies met with universal approval. These included pragmatic features such as the small size and longer battery life than laptops. The storage capacity of PDAs was generally rated as highly favourable, along with ease of synchronising data with other devices. The relatively low price of PDAs was also cited.

As headteachers and senior managers most closely match the mobile professional profile for which hand-helds were designed, they were thus in the best position to experience immediate benefits. This group of users found the hand-helds amazingly efficient at ensuring contact lists, diaries and meeting arrangements were up-to-date, and were able to employ the facilities for rapid accrual and reporting of data to address truancy control problems. Classroom teachers were also able to benefit from the hand-helds' data administration capabilities to help record attendance and marks, and also help organise their lesson plans.

Though most users were able to benefit from the hand-helds, some were reluctant to adopt the new ways of working afforded by them. In addition to dissatisfaction with the small screens, volatile storage (some types of PDA lose their stored data when their batteries run out of charge), and a concern about the ruggedness of the design, training issues were frequently cited as an inhibiter to progress.

3.6.3 SMS supports computing students at risk

Blended learning technologies were used to support HND computing students at the University of Wolverhampton during the 2002-2003 academic year (Riordan and Traxler 2003; Traxler and Riordan 2003).

The objectives of this project were to develop, deliver and evaluate blending learning opportunities that exploited SMS, WAP and VLE technologies. Initial research indicated that students used SMS text messaging promptly and effectively, and that they would prefer to receive noticeboard information such as room changes, appointments, feedback and

head teachers and senior managers found the hand-helds amazingly efficient how can the use of mobile technologies help today's educators to embrace a truly learner-centred approach to learning?

exam tips via SMS rather than via e-mail or noticeboards. The target group was HND computing students, whose attendance and performance were considered to be at-risk due to poor literacy skills exhibited in their coursework.

SMS-based interventions took place over the second semester of the 2002-2003 academic year. Initial test messages gauged the effectiveness and the level of timeliness of student responses to SMS text messages. A second set of messages was sent as feedback following the marking and moderating of assessments. A final set of messages provided revision tips prior to the exam. The key features of the SMS interventions were timeliness and appropriateness, such that 'at-risk' learners could be directed as appropriate to either WAP-based support, VLE-based support or in-house support before their academic careers were significantly impacted.

Following the trial, final exam results for the group of students receiving SMS interventions were slightly higher than a non-SMS group taking the same module at the same time, though these results cannot be considered statistically significant.

During the trial, the students provided considerable positive informal feedback to the course leader, and a questionnaire administered to the students revealed that the majority of students thought the experiment was worthwhile. In general, the SMS interventions themselves were found to be successful if they were short, personalised and focused, but there was little take-up of the VLE technology and the WAP-based technology was vetoed as being too expensive. Access to large-scale or systematic views was limited due to poor attendance at a proposed focus group and poor response to SMS queries inviting students to comment on aspects of the trial.

Free-text responses from the student questionnaires provided a positive basis for improving the service. A large-scale pilot is planned for October 2004.

3.7 SUMMARY

Mobile technology can effectively support a wide range of activities for learners of all ages. While implementation examples can be broadly categorised within the main theories and areas of learning relevant to mobile technology, the most successful adopt a blended approach to their use.

Mobile technologies provide for each student to have a personal interaction with the technology in an authentic and appropriate context of use. This does not mean, however, that the use of mobile devices is a panacea. Significant technological and administrative challenges are encountered along with a more ill-defined challenge: how can the use of mobile technologies help today's educators to embrace a truly learner-centred approach to learning?

IMPLICATIONS FOR LEARNERS, TEACHERS AND DEVELOPERS

4 IMPLICATIONS FOR LEARNERS, TEACHERS AND DEVELOPERS

Teaching and learning with mobile technologies is beginning to make a breakthrough from small-scale pilots to large departmental and institutional implementations. This section presents both key issues for educators and technical developers, and research-informed guidelines as to how these can be addressed.

4.1 KEY ISSUES

Compared to desktop technology, learning and teaching with mobile technology presents significant new challenges including:

- **Context –** the ability to acquire information about the user and his or her environment presents a unique ability to personalise the learning opportunity. There are, however, significant ethical issues (described further in Lonsdale et al 2003). For example, context information needs to be gathered with the consent of users, and must be stored securely to prevent misuse by third parties. This is also related to the issue of coupling between the informatic layer provided by the devices and the existing communication layers of the classroom (or other environment).

- **Mobility –** the 'anytime, anywhere' capabilities of mobile devices encourage learning experiences outside of a teacher-managed classroom environment. Inside the classroom, mobile devices provide students with the capabilities to link to activities in the outside world that do not correspond with either the teacher's agenda or the curriculum (Sharples 2003). Both scenarios present significant challenges to conventional teaching practices.

- **Learning over time –** lifelong learners will need effective tools to record, organise and reflect on their mobile learning experiences (Vavoula 2004).

- **Informality –** the benefits of the informality of mobile devices may be lost if their use becomes widespread throughout formal education. Students may abandon their use of certain technologies if they perceive their social networks to be under attack.

- **Ownership -** both personal and group learning are most effectively supported when each student has access to a device. The ownership of the devices is thus a key consideration. According to Perry (2003), both tangible and intangible benefits can accrue through the use of mobile devices. Intangible benefits include a sense of belonging with the device and personal commitment and comfort. Ownership is stated as a prerequisite for engagement, where students have the potential to go "beyond the necessary and play with it to explore its potential". Personal ownership does, however, present a challenge to the institutional control of the technology (Savill-Smith and Kent 2003).

4.2 GUIDELINES FOR EFFECTIVE IMPLEMENTATION

The following guidelines for implementing mobile learning were developed through

mobile technology presents significant new challenges

the MOBIlearn project (O'Malley et al 2003) and have been extended in this report. Each guideline has been based on theory and practice of learning with conventional tools, evidence from desktop e-learning or findings from the available studies of mobile learning. While intended primarily for direct users of mobile learning technologies, these guidelines may also be useful in informing policy initiatives.

1 Investigate a cost model for infrastructure, technology and services.
Various costs must be considered when implementing mobile learning. In addition to the significant initial capital expenditure required to purchase devices and networking equipment, there is the ongoing cost of technical support and also various 'hidden' costs. The 'Costs of Networked Learning' project (Bacsich et al 1999; Bacsich et al 2001), though targeted at wired networking, is helpful in assessing the extent of these hidden costs and provides a useful tool to support activity-based costing.

Different options for infrastructure and services imply different cost models. In general, institutions should try and make use of their existing facilities and services in order to keep costs down. It should be noted that it is generally less costly to equip each student with a hand-held computer than with a desktop or laptop computer. Indeed, mobile technology can be used to address the 'digital divide', as mobile devices are the cheapest way of providing pupils with a computing device that can be taken home and through which they can connect to the internet (Perry 2003).

There may also be some hidden benefits, when compared to other ICT initiatives (Traxler 2004). The personal and collaborative nature of mobile devices can encourage participation and build social capital, which can be used to motivate disengaged or at-risk students. As the education marketplace becomes increasingly competitive, institutions can offer mobile learning opportunities as a competitive edge over other institutions. Mobile learning can fit training niches, such as in medical training, where significant costs are incurred for students who drop out or fail. Finally, there may also be an opportunity to leverage technologies that students already own such as mobile phones for SMS messaging.

2 Study the requirements of all those involved in the use of the technology (learners, teachers, content creators) to ensure that it is usable and acceptable.
Usability should account for both the set of users that will be creating the mobile content and those who will be using the mobile applications to learn from or teach with.

3 Assess that the technology is suited to the learning task and examine advantages and disadvantages of each technology before making a decision on which one to use.
The effective implementation of mobile learning requires a clear pedagogical approach, identification of specific learning needs/goals and teachers to be directly involved in decisions on planning and curriculum use (Perry 2003).

4 Assign the necessary roles for initiating and thereafter supporting mobile learning.
The following roles (which may be filled by the same person) are helpful:

- a technical promoter to demonstrate the capabilities of the system
- a promoter in power to make sure the technical promoter's views are heard by those in charge
- once mobile technologies are in place, institutions can also benefit from technical experts to deal with equipment failures and ongoing system improvements.

5 Develop procedures and strategies for the management of equipment when it is provided by the institution.
These procedures include the need to develop strategies for assigning equipment to students, restricting students' off-task use (if desired), synchronising hand-held to desktop, tracking, reviewing and collecting students' work, devising and implementing parental agreements for managing loss and theft, hardware management and routine backup procedures.

6 Provide training and (ongoing) technical support to the teachers to enable them to use mobile technologies to enhance current and to enable new instructional activities.
Almost all respondents in the DfES-sponsored hand-held computing pilot (Perry 2003) were dissatisfied with the amount of training they received. Specialist training and dissemination of good practice is necessary in order for staff to exploit the whole range of capabilities that mobile computing can offer. Both staff and students must have sufficient time to familiarise themselves with new devices.

7 Consider the use of mobile technologies for student administration tasks.
Mobile devices can be used to maintain accurate lists of classes which can be used in conjunction with rich information sets about students to help to draw out individual students' needs. Applications that could be supported include truancy control, classroom monitoring and marking with immediate feedback.

8 Consider the use of mobile technologies to support collaborative and group learning.

9 Discover and adopt suitable applications that match the needs of your specific classroom and map directly to your curriculum needs.

10 Ensure security and privacy for the end users.
Privacy protection includes both the student's personal data and the student's current location.

THE FUTURE OF TEACHING AND LEARNING WITH MOBILE TECHNOLOGIES

mobile devices are finding their way into classrooms in children's pockets

5 THE FUTURE OF TEACHING AND LEARNING WITH MOBILE TECHNOLOGIES

The current trends in mobile computing are towards devices that are even more embedded, ubiquitous and networked than those available today. The capabilities of mobile phones, PDAs, games consoles and cameras will likely merge within the next five to ten years to provide a networked, multimedia device that is always with you. Integrated context-aware capabilities will transform everyday activities by providing the ability to capture details about the time, location, people around you and even the weather. The entire internet will become both personal and portable.

Such technologies can have a great impact on learning. Learning will move more and more outside of the classroom and into the learner's environments, both real and virtual. Learning will involve making rich connections within these environments to both resources and to other people. In addition to consulting internet-based resources on the move, learners will be able to manage the administration of their learning through consultations with their personal diaries and institution-based virtual learning environments. The ability to instantly publish their observations and reflections as digital media will empower them to be investigators. Context-aware applications will enable learners to easily capture and record events in their life to both assist later recall and share their experiences for collaborative reflection. Opportunities for distributed collaboration and mobile team working will be greatly enhanced.

The challenge for the educators and technology developers of the future will be to find ways to ensure that this new learning is highly situated, personal, collaborative and long term; in other words, truly learner-centred learning. Educators will need to adapt from a role as transmitters of knowledge to guiders of learning resources. Technology developers will need to respond to concerns of security and privacy while designing devices and services that learners both want and will pay for.

Whether they are welcome right now or not, mobile devices are finding their way into classrooms in children's pockets, and we must ensure that educational practice can include these technologies in productive ways. In the future, the success of learning and teaching with mobile technologies will be measured by how seamlessly it weaves itself into our daily lives, with the greatest success paradoxically occurring at the point where we don't recognise it as learning at all.

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APPENDIX 1: CHARACTERISTICS OF MOBILE TECHNOLOGIES TYPES OF DEVICES

Personal digital assistants (PDAs)

These devices are small and lightweight and are variously referred to as hand-helds, palmtops, PDAs, Palm Pilots, Palms and iPAQs.

PDAs are hand-held computers that have touch-sensitive LCD screens, with pen/stylus input, and moderate processing power (can run cut-down versions of Word, Excel etc or their non-Microsoft equivalents). Manufacturer-provided memory is usually limited, though this can be expanded with additional memory. The most popular formats of memory supported are Secure Digital (SD) and Compact Flash (CF), though some manufactures such as Sony use a proprietary memory format.

The two main varieties of PDAs are distinguished by their operating system (OS). Pocket PC PDAs run a cut-down version of Windows specially designed for mobile devices. PalmOS PDAs (eg Palm Pilots, Palm Zire) run the PalmOS operating system. Software is not interoperable between the two operating systems.

PDAs normally include a docking and synchronisation cradle for battery charging, administration of application software and data transfer and backups.

Mobile phones

This class of device includes basic handsets, and also so-called 'smart phones' which offer limited PDA-like capabilities, but usually without a pen/stylus interface. Smart phones usually include a means of connecting to a desktop PC to perform the same functions as a PDA docking and synchronisation cradle.

Hand-held games consoles

These lightweight, portable devices include in-built screens, games controls and speakers. The dominant manufacturers include Nintendo (Game Boy Advance) and Nokia (N-Gage).

Connectivity

The mobile devices described here typically have some means of connecting wirelessly to the internet or other network. Most devices can also communicate directly with other devices of the same or similar type. This means that files, messages and programs can be directly transferred between devices without the need for any mediating device or technology. A brief overview of popular connection methods is presented in Table A1.

APPENDIX 2: MAJOR MOBILE LEARNING RESEARCH PROJECTS

Mobilearn

24 partners from Europe, Israel, Switzerland, USA and Australia
www.mobilearn.org

'MOBIlearn is a worldwide European-led research and development project exploring context-sensitive approaches to informal, problem-based and workplace learning by using key advances in mobile technologies.'

Technology	Transmission protocols	Transmission speed	Range	Security	Additional requirements	Notes
Wireless LAN (WiFi)	802.11a 802.11b 802.11g	Fast: 802.11b – 11Mbps, 802.11a – 54 Mbps, 802.11g – 54 Mbps	Mid Range – 802.11b – 300 feet, 802.11a – 100 feet, 802.11g – 300 feet. Range can be extended by providing multiple access points.	Dependent on network configuration.	Expansion cards readily available, though most hand-helds now offer built-in capabilities. Wireless LAN networks must be set up, installed and configured by the institution[2].	The most flexible solution for allowing multiple devices to access networked resources (internet, e-mail, filestores). Can also be used to network desktop PCs, printers and other traditionally 'wired' devices.
Cellular	GSM/GPRS CDMA/1xRTT	Slow: 13.4 -14.4 Kbps per channel (multiple channels may be available)	Long Range – continent wide.	Secure	Subscription to a data access provider necessary. May be combined with cellular voice service. Monthly charges incurred per device.	Rural areas may not provide suitable coverage. Not possible to set up your own cellular network.
Bluetooth		Fast: 1 Mbps	Short Range – 30 feet. Range can be extended by piggybacking multiple devices.	Dependent on network configuration.	Expansion cards readily available, though many devices now offer built-in Bluetooth capabilities. Bluetooth networks must be setup, installed and configured by the user.	Suitable for device-device connections, though possible to connect to the internet through another device.
Infrared		Fast: up to 16 Mbps	Short Range – 3 feet, line of sight.	Secure	Capabilities built-in to most hand-helds.	Suitable for device-device communication. Does not support internet connection.

1 The Getting Started Guide to Wireless Networks (Ting et al 2003) provides practical advice on setting up and configuring wireless LANs for IT managers in universities, colleges and schools.

Table A1 : Comparison of networking technologies

m-learning

Europe – UK, Sweden, Italy
www.m-learning.org

'm-learning is a pan-European research and development programme. It is aimed at young adults, aged 16 to 24, who are most at risk of social exclusion in Europe.

m-learning's aim is to develop prototype products and services which will deliver information and learning experiences via technologies that are inexpensive, portable and accessible to the majority of EU citizens.' (primarily mobile phones)

The University of Birmingham

Birmingham, UK
www.mobile.bham.ac.uk

The University of Birmingham was designated Microsoft's European Reference Centre for Research into Mobile Learning in 2003.

Pontificia Universidad Católica de Chile

Santiago, Chile
www.mobilelearning.cl/eng/index.html

'The objective of the project is to improve the quality of education, by incorporating mobile technology in the classroom, to support the instructional process, the assessment of educational contents included in the school curriculum and the teacher's role regarding the classroom management.

Mobile technology allows to increase coverage, that is, the access that teachers and students have to it in terms of the amount of hours they can spend using it, as well as the amount of students that may use this device individually during the day.'

National Central University

Taiwan
www.cl.ncu.edu.tw/en_web/research.htm

Global Public & Private Partnership Platform (G4P) for Mobile Learning Technologies is a collaboration between the Ministry of Education, the National Central University and local device and software makers. Currently, over 100 schools with 35,000 primary and junior high school students are involved in the project.

Center for Highly Interactive Computing in Education (Hi-Ce), University of Michigan

Ann Arbor, Michigan, USA
www.hand-held.hice-dev.org (including downloads and discussion forums)

'The Center for Highly Interactive Computing in Education (Hi-Ce) develops learner-centered software tools and curriculum founded on the pedagogy of inquiry, or project-based science. Researchers work as partners with teachers and administrators to integrate technology into K-12 classrooms.'

University of South Dakota

South Dakota, USA
www.usd.edu/pda

First HE institution in the USA to require incoming students to use hand-held computers (Palm).

Pocket Eijiro

Japan
http://ojr.org/japan/wireless/1080854640.php

'The Pocket Eijiro site started in December 2002 with an English-Japanese, Japanese-English dictionary. Now the site gets more than 100,000 hits per day (data on individual visits were not available), and its subscribers number in the hundred thousands. The service costs $1.53 per month, plus tax and packet charges.'

Designed for mobile phones and consists of a dictionary and quizzes designed to take no more than five minutes.

Dudley Local Education Authority (LEA)

United Kingdom

Ambitious project to equip 20,000 school children with Palm hand-helds and wireless internet connections.

Reviews available from Futurelab:

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Report 8: Games and Learning
Report 9: Learning with Digital Technologies in Museums, Science Centres and Galleries
Report 10: Assessment and Digital Technologies
Report 11: Learning with Mobile Technologies
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