Ubiquitous Computing for Mobile Learning

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The trend toward miniaturization and wireless communication offers the prospect of ubiquitous computing, that is computing available everywhere, all the time. As communication devices become more and more mobile, and as life styles adapt to this mobility, education must adapt also. A host of new and rapidly changing applications is emerging, wrapped around handheld information and communication technology (ICT) devices and the software and services on which they run. Users expect to always remain connected during their nomadic roaming, and this expectation is beginning to include students. Information technology managers are searching for ways to meet the mobile technology and ubiquitous computing demands of students while educators are seeking ways to exploit this new communication life style for positive pedagogical purposes.

The new mobile technologies seem well suited to support contemporary theories of learning that emphasize active engagement, collaboration, information-seeking, and reflection. All of these qualities can be achieved in mobile learning (“m-learning”) but only after overcoming significant constraints related to the technical and physical limitations of mobile technologies. Some design guidelines are offered to help educators cope with these limitations.

Introduction

The trend in computing hardware toward miniaturization and wireless communication is creating a new genre of mobile technologies; notebook and tablet PCs, cell phones, digital audio players, handheld game consoles, and personal digital assistants (PDAs) which can include the functionality of a computer, a cell phone, a music player, a camera, and various other combinations of these functions. Connected to the Internet, they give users, in effect, a high-end computer workstation in their hands. Users can talk or text-message with others and navigate the Web from anywhere (as long as they are in range of a wireless access point). As this trend continues, we enter the era of ubiquitous computing when information and communication technologies (ICT) are available all the time and everywhere.

In the economies in which these mobile media devices are already widely disseminated, habits of communication have already changed drastically. In the new, “plugged-in” lifestyle, people expect to be able to send and receive information continuously as they move about, reinventing the nomadic lifestyle. As ICT becomes more ubiquitous and as communication habits change, it is inevitable that educational applications will also evolve, with pressure coming both from the demand side and the supply side. That is, consumers of education will increasingly demand access to learning through the new mobile ICT delivery systems and providers of education, that is corporations, governments, and educational institutions, will seek ways to offer their instructional services to the broadest audience in the
most convenient fashion, and at the lowest price.

Some foresee the emergence of a new paradigm of education: mobile learning (“m-learning”). It is difficult to see very far into the future at a time when technologies and usage patterns are changing at an accelerating rate, but this article explores some of the possible implications of the coming age of mobile learning or m-learning. First, it reviews how mobile technology is emerging, evolving, and expanding and how it impacts individuals and society. Second, it inquires specifically into the influences of mobile technology on education. Third, it reviews the concepts and features of mobile learning and its theoretical underpinnings. Finally, it recommends guidelines for designing mobile learning, after discussing the current constraints of mobile technology.

**Emergence and Convergence of Mobile Technologies**

*The Range of Mobile Technologies*

A technological revolution through the emergence and convergence of various mobile technologies introduces a promising potential for less expensive and more equitable access to ICT than were possible with desktop computers and wired networking.

*Mobile appliances*

What comprises mobile technology? Mobile means that “the device is small enough to fit comfortably into a purse, pocket, or holster so you can conveniently keep it with you at all times” (Livingston, 2004). A number of recent reports identify the different technologies available (Rainger, 2002; Perry, 2003; Smith, 2003). First, there is a broad range of hardware systems that comprise the mobile technologies: mobile phones, laptops and tablet PCs with wireless cards, personal digital assistants (PDAs) including Pocket PCs, MP3 players, digital cameras both still and motion which are increasingly found in cellular phones, handheld
Figure 4. LG-lp5500 digital cameras with still and motion/MP3 (Source:http://www.cyon.co.kr/good/product/product_view1.jsp?product_id=163)

Figure 5. Nokia N-Gage smart phone protocol (Source:http://www.slashphone.com/87/1943.html)

Figure 6. LG-sv360: Phone/Camera/Gaming tool (Source:http://www.cyon.co.kr/good/product/product_view1.jsp?product_id=164)

Figure 7. LG-sb120(DMB Phone/Camera/Receiving digital Satellite Broadcasting) (Source:http://www.cyon.co.kr/good/product/product_view1.jsp?product_id=154)

Figure 8. Digital Door Lock (with RFID Tag) (Source:http://www.thinkgeek.com/gadgets/security/77af?cpg=cj)

Figure 9. Bluetooth-enabled devices: Keyboard and Mouse Logitech® Cordless Desktop® MX™ (Source:http://blog.naver.com/z_ag.do?Redirect=Log&logNo=4923456)
gaming tools such as the NGage, and fusion devices, such as combination of phone + PDA + MP3 players. These appliances are accompanied by USB drives, wireless connectivity detectors, Bluetooth-enabled devices, and wireless access points, not to mention the RFID tags that are proliferating rapidly. See Figures 1 - 9 for sample images of mobile technologies.

**Mobile software**

Mobile technologies also include the software and services that give the hardware special functionalities. For example, Short Message Service (SMS) is a service that allows cell phone users to send short text messages to each other. Multimedia Messaging Service (MMS) enables the transmission of images, audio, and video as well as text messages. One of the most common services is VoiceXML, which allows a direct interface between the human voice and a computer using speech recognition and speech synthesis; people encounter it when using voice mail, tracking packages, refilling prescriptions, and getting wake-up calls. Java Platform, Micro Edition (Java ME), is a collection of programming interfaces that allows games to be developed on a computer and then uploaded to a cell phone, making it easy to store numerous small games on mobile devices. Minibrowser is the wireless Internet service that allows users to navigate the Web on a cell phone, using a small LCD screen.

**Rapid Growth in Adoption**

By 2006, in Europe and Asia these functionalities were rapidly migrating toward convergence in a cell phone type device, but this movement was emerging more slowly in the United States and other countries. For example, by February of 2005 mobile phone users in the Republic of Korea had grown to about 37 million, about 80% of the total population (NCA, Republic of Korea, http://www.nca.or.kr/). Mobile phone users worldwide, as of 2004, had reached over 1.5 billion with growth expected to reach 2 billion during 2006. Figure 10 indicates the increase of mobile phone users worldwide.

**Impact of Mobile Technologies on Society**

**Nomadicity**

The Internet has evolved into an environment of mobility and will "accelerate the pace at which nomadicity will evolve" (Hitch & McCord, 2004). As early as 1996 Kleinrock was pointing out that the perception of "always being connected" was quite

![Figure 10. The Worldwide Trends of Mobile Phone Service Users (In-Stat/MDR, 2004)](image)
false, in that we spend much of our time away from fixed, wired stations. We roam, like nomads, from place to place, office to conference room, home to work, to and from hotels or dormitories, through airports, railroad stations, and subways, and so on. In 1996 it was very difficult to stay connected to the Internet grid during such nomadic roaming. Kleinrock (1996) presented a vision of a “transparent virtual mobile environment,” which he labeled “nomadicity,” and he outlined the technology solutions to the problem of creating such a seamless network that would allow people to stay connected without conscious awareness.

By 2006 it was becoming easier, thanks to developments in both hardware and software. Mobile devices are small enough to be carried conveniently at all times. However, mobility implies more than this technical conception as we consider its potential functionality and influence on the nomadic lifestyle. This nomadic phenomenon stems not only from a multiplicity of devices but also from the immediacy that the Internet itself has facilitated. In a broader sense, mobile and wireless computing technology has changed the rhythms of social time and the uses of social space.

Swarming

Bees and some other social animals swarm, moving in an amorphous but synchronized fashion to achieve some goal. This concept has been adapted to human purposes, largely because of the new communications capabilities offered by mobile technologies. Military strategists have advocated swarming as a method of striking the enemy force from all directions in a coordinated attack (Arquilla and Ronfeldt, 2000). Effective swarming requires close and constant communication, which is becoming feasible for large groups through devices such as cell phones, especially when equipped with LCD screens and even Global Positioning System (GPS) applications. Applied to civilian life, social swarming appeared as a phenomenon in the early 2000s, as a way of simply bringing groups of like-minded people together spontaneously and almost instantaneously (“smart mobs”). Swarming was quickly adapted to political purposes, being used to quickly mass a large number of protesters to surround a target and change directions quickly if necessary to stay ahead of the forces trying to control them. Some envision possible applications of swarming to education, creating temporary groups of people with common learning interests, as is discussed below.

Applications of Mobile Technologies in Education

Since mobile technology has not matured, there are presently more possibilities relating to what could be done with this technology for learning than concrete or successful implementations. We are beginning to see the potential of mobile devices in training and performance support, however, with the number of mobile devices and bandwidth for mobile devices predicted to increase dramatically in the short term, mobile e-learning appears certain to become an important part of training in the future (Lee, 2003; Avellis, Scaramuzzi, & Finkelstein, 2004).

There are various educational benefits of handheld mobile technology; the most often cited include portability and ease of access, the integration of computing into a wide variety of educational activities, promoting autonomous learning and student organization, promoting student collaboration and communication, and supporting inquiry-based instructional activities (Roschelle & Pea, 2002). However, as mobile technologies evolve they may become integrated into training and education environments in ways that are qualitatively different from today’s paradigm. The concepts of nomadicity and swarming are examples of new ways to think about educational applications.

Nomadicity in Education

Studies done on college campuses in the United
States illustrate how higher education is already going nomadic. Hitch and McCord (2004) report that students are arriving on campus armed with an array of mobile technologies, PDAs, MP3 players, game devices, laptop and tablet PCs, and with a strong expectation that all of these technologies will be supported by the university information technology (IT) infrastructure. The most frequently recurring image is of the college student seated in the library in front of her laptop computer with an MP3 player plugged into her ears as she thumb-types a text message on her cell phone. This phenomenon is fueling an explosive demand for 24-hour-a-day support of a bewildering assortment of devices and computing platforms. Of course, the students and IT administrators all understand that these wireless resources must be supported in addition to the existing wired network.

The challenges

Hitch and McCord (2004) maintain that this mobile and nomadic style will confront higher education with three significant challenges: how to build and support the infrastructure, how to staff IT organizations and provide IT services to the campus community, and how to fund IT infrastructure and services. It is especially a major task to maintain an open, flexible network that needs security and protection against malware and other vicious attacks (Hitch & McCord, 2004). Kleinrock (2001) recognizes that we need to support an infrastructure that deals with the issues of the usual problems of bandwidth, latency, reliability, error rate, delay, storage, processing power, component to component interface, interoperability, user interface and cost. In addition, IT administrators need to monitor and establish governance for or control over synchronization, directory information, access, privacy, partnerships of services, maintenance of geographically dispersed computing resources, regulatory policy, shared social ontologies, business frameworks, surveillance, privacy and even ‘new time regimes of work’, suggest Lytyinen and Yoo (2002).

The opportunities

On the positive side, the potential for ubiquitous ‘ready-at-hand’ technology is great. Ubiquitous computing, by facilitating collaboration and sharing, can contribute to increased learning (Savill-Smith & Kent, 2003; Soloway, Norris, Jansen, Krajcik, Fishman & Blumenfeld, 2001; Inkpen, 1999; Gay, Rieger, & Bennington, 2002). In an experiment using radio-based wireless technology (Bluetooth™) at the school level by Pfieffer and Robb (2001) notes the extended possibilities for collaboration using portable keyboards. Infra-red beaming can also be used by students to exchange concept maps for peer critiques in which students can demonstrate their understanding of a topic, for example, the weather in the MaLTS project using the PiCoMap program (Luchini, Quintana, Krajcik, Farah, Nandihalli, Reese, Wieczorek, & Soloway, 2002).

Together with web-based services, mobile technologies can enhance access to different real-world information sources and intentionally designed problem-solving scenarios (Jonassen, 1995; Sharples, 2000; Leino, Turunen, Ahonen, & Levonen, 2002). Consistent with the nomadic style, Crawford and Staudt (1999) foresee that “new handheld technologies...could enable students to carry personal tools of inquiry into the field, between their classes, and between school and home. They could empower collaboration and networking regardless of location.”

Swarming in Education

Applications that are specific to mobile technologies may evolve to fit with their special adaptability to interpersonal communications. Alexander (2000, p. 32) borrows the concept of “swarming” to speculate about “learning swarms” or ad hoc, temporary learning groups. Similar to the groups that form on social networks like Facebook.com, students who develop curiosity about a topic might talk or exchange text messages with others and form a virtual discussion group, which might meet face-to-face at some times. Or they might simply use the mobile tools to carry out group
work assigned in class. In this sense, swarming could be viewed as one way in which mobile technologies can support collaborative work.

**Promoting “Doing and Reflecting”**

Handheld devices can be used anywhere inside an educational institution or outside, for example on field trips. One vision of ubiquitous computing is that of augmented reality, in which, for example, buildings on a campus or objects in a museum will be able to ‘talk’ and offer information about themselves to the pocket computers of passers-by and museum visitors. Such information can be tailored to the native language or reading level of the user based on information programmed into the handheld device.

An inexpensive handheld unit eases the problems of access to powerful representational tools, such as graphing calculator, tools for mapping concepts, running simulations, and gathering data (Roschelle, 2003). Handheld technologies can provide access to computing at the places where children’s activities and learning occur, unlike desktop computers, which are often segregated from other learning activities in the classroom (Inkpen, 1999). Flexible access means opportunities to integrate learning technology into children’s daily activities (e.g., the success of handheld toys like Gameboy™ and Tamagotchi™), where the products themselves become part of the children’s culture.

Handhelds support flexible ‘cycles of doing and reflecting,’ not tied to infrequent, timetabled access to a computer laboratory, and direct and immediate ‘collaboration and sharing,’ especially via infrared ‘beaming’ between palmtops. However, both these aspects pose the challenge of revising the curriculum to exploit them (Soloway et. al., 2001). They allow students to record their experiences, both to report back information to their tutors, to be assessed about their performance in practice, and to encourage students to be reflective about their learning experiences (Alderson and Oswald, 1999; Sommers, Hesler, & Bostick, 2001). They also appear to encourage the students to work collaboratively in a clinical environment by taking notes (Ubaydli and Dean, 2001).

Development in pedagogy has moved away from the transmissive mode of teaching and learning toward the constructivist or socio-cognitive models. The focus of constructivism (see Duffy & Jonassen, 1992) and the socio-cognitive view (see Rogers, 2002) is on learner control. A few examples of applying those concepts include collaboration, sharing, communication, contextual learning, and reflection through experiences.

Although the use of a mobile technology might seem, on the surface, to be an extremely isolated, individualistic activity, young people can communicate with each other quite successfully in the process of using the devices (Colley and Stead, 2004). Collaborative group work and sharing with peers and others can be a powerful way of confronting one’s own pre-conceptions and contributing to restructuring one’s cognitive schemas or creating new conceptions.

Educational research into situated learning has also noted the importance of giving learning a ‘context’. In the situated learning approach, knowledge and skills are learned in the contexts that reflect how knowledge is obtained and applied in everyday situations (Lave and Wenger, 2001). Situated cognition theory conceives learning as a socio-cultural phenomenon rather than an individual phenomenon of decontextualized knowledge acquisition. In that sense, mobile materials, especially games can be developed that are usable by groups as well as by individuals (Colley and Stead, 2004).

**A Cautionary Note: Fragmentation**

Sociological research on mobile use indicates the growth of flexibility but also of the micro-level inefficiency, for example when meetings are cancelled at the last minute (Cooper, 2002; Kopomaa, 2000; Laurier, 2002). Therefore, the promise to work or learn regardless of time and place should not automatically be included in the definition of mobility or mobile learning (Syvanen,
Learning with mobile devices is a highly fragmented process which should be taken into account in designing as well as in developing evaluation methods for mobile learning materials and environments (Regan, 2000; Syvanen et. al., 2004). According to Cowan (1995), the presence of attention is a key element at the time of both information processing and recall.

Fragmentation in learning is understood as when the learning experience does not form a meaningful continuum because of the environmental disturbances, poor concentration of the learner, and technical problems, such as bad network connections or problems with the devices and applications (Syvanen, et. al., 2004). Regan (2000) raised the issue that on-the-go learning situations are often disrupted or take place unexpectedly, and the focus of attention in this situation can easily be distracted. It can be questioned whether these on-the-go situations form a strong foundation for meaningful m-learning (Leino et. al., 2002). Moreover, when people access information sources and learning objects via different devices from different locations, there are still many usability, compatibility, and accessibility related questions that hinder seamless mobility and mobile learning (Syvanen, et. al., 2004).

**The Design of M-Learning**

*Technical Considerations*

The most significant design restrictions of handheld devices, according to Hayhoe (2001), are the small display screen and the limited brightness and contrast. Considering these restrictions, he suggests:

- Realize that reading online at low resolution reduces reading comprehension significantly
- Think in terms of nuggets or specks, not chunks
- Be prepared to display text in larger type than you are accustomed to seeing in documents designed to be read on the desktop
- Apply bold, italics and color with caution
- Do not expect to have access to a large variety of fonts
- Employ graphics in very minor supporting roles rather than as a primary means of communicating information
- Do not assume that other supporting media will be available
- Remember that most of the current installed base of handheld and wireless devices have very modest capabilities
- When designing for a particular installed base, consider the capabilities of the standard device in design decisions
- When designing Webpages for reading on handheld devices, remember that the screen orientation is portrait not landscape, and that the screen width is very narrow.

*Conceptual Considerations*

Based on the nature of mobile devices, with their small screens and poor input capabilities, Anna Trifonova (2003) also suggests instructional design tips in light of these constraints:

- Short, no more that 5-10 minutes long, modules: The participants should be able to use their small fragments of waiting time (i.e. waiting for a meeting or while traveling in a train) for learning, like reading small pieces of data, doing quizzes, or using forums or chat for finding answers to questions
- Simple, funny, and added-value functionality: The computational power and other properties of mobile devices make it difficult to use complex and multimedia content. It should be possible to use an m-learning system without having to read a thick user manual, and it should be as compelling as playing a game
- Area and Domain specific content, delivered just in time and place: The mobility should bring the ability to guideline and support students and teachers in new learning situations when and where it is necessary.
The dependency of the content can be relative to location context (i.e., the system knows the location where the learner resides and adjusts to it), temporal context (i.e., the system is aware of time dependent data), behavioral context (i.e., the system monitors the activities performed by the learner and responds to them adjusting its behavior) and interest specific context (i.e., the system modifies its behavior according to the user’s preferences). Of course a mix of the contextual dependencies is possible and likely.

Environmental Considerations

Finally, considering that user environments for handhelds are very diverse, Hayhoe (2001) makes the following suggestions for designers relating to users’ environments and the tasks the users perform:

- Always analyze users, their tasks, and their environments when designing online documents for wireless and handheld platforms
- When applying the results of your analysis to the design, be sensitive to the wide range of places, times, atmospheric conditions, lighting, and noise levels in which your electronic documents will be used
- Minimize file sizes to ensure quick loading of documents and to reduce the space required to store the document and load it in working memory
- Limit the amount of interactivity and scrolling required avoiding user annoyance and frustration
- Recognize that these devices are almost always held in one hand, so the user has only one hand free for interaction with the device
- Be aware of a variety of user postures
- Limit the use of sound and allow the user to mute it easily.

Conclusion

Wireless technology now encompasses a broad spectrum of mobile devices, software, and services. However, none of these technologies is particularly rich in itself, but combined appropriately they can provide an engaging and beneficial experience for even the most resistant learner. Mobile devices are small, portable, compact, lightweight, relatively low cost, and are powered by batteries that have an increasingly long endurance. However, there is concern about the small screen size, which is not so well suited to e-learning delivery and restricted input capabilities.

Mobile technology, with its adaptability to the nomadic style, has already had a significant influence on higher education in various ways. Ubiquitous computing can increase collaboration and sharing. Handhelds also support flexible ‘cycles of doing and reflecting’ by tapping into real-world databases and allowing users to keep notes and journals. However, both these aspects pose the challenge of revising the curriculum to exploit them.

Mobile devices have generally received a positive expectation in education. However, there are several technical constraints facing effective m-learning and they have quite profound design implications. Further research is required to find ways to circumvent these limitations and tap the potential for incorporating m-learning into the emerging lifestyles of 21st century learners.

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