TSW 03-05
June 2003

Evaluating the development of wearable devices, personal data assistants and the use of other mobile devices in further and higher education institutions.

By S. de Freitas and M. Levene

Part One: Technological and technical evaluation of current wearable and mobile technologies

Information and Communication Technologies, known as ICT, have undergone dramatic changes in the last 25 years, each time producing new and exciting opportunities for the education sector. The 1980's was the decade of the Personal Computer (PC), which brought computing into the home, and in an educational setting, into the classroom. The 1990's gave us the World-Wide-Web (the web), building on the infrastructure of the Internet, which has revolutionised the availability and delivery of information. The implications of web technologies on education, often described in terms of e-learning, are potentially far reaching and are still being explored and debated. In the midst of this information revolution, we are now confronted with a third wave of novel technologies, that of mobile and wearable computing, where computing devices are already becoming small enough so that we can carry them around on us at all times, and, in addition, they have the ability to interact with devices embedded in the environment. The emergence of this new wave of technologies offer many opportunities in the education sector, some of which we will explore, with special emphasis given to Further and Higher Education (FE/HE).

The development of wearable technology is perhaps a logical product of the convergence between the miniaturisation of microchips (nanotechnology) and an increasing interest in pervasive computing where mobility is the main objective. The miniaturisation of computers is largely due to the decreasing size of semiconductors and switches, molecular manufacturing will allow for "not only molecular-scale switches but also nanoscale motors, pumps, pipes, machinery that could mimic skin" [Page 2003, p. 2]. This shift in the size of computers has obvious implications upon the human-computer interface introducing the next generation of interfaces. Neil Gershenfeld the Director of the Media Lab's Physics and Media Group argues: "…The world is becoming the interface. Computers as distinguishable devices will disappear as the objects themselves become the means we use to interact with both the physical and the virtual worlds." [Page 2003, p. 3]. Ultimately this will lead to a move away from desktop user interfaces and towards mobile interfaces and pervasive computing.

Mobile computing supports the paradigm of "anytime, anywhere access" [Perry et al. 2001], meaning that users have continuous access to computing and web resources at all times and where ever they may be. In the HE context mobile computing allows:

1) The extension of the classroom beyond its normal physical location.

2) Access to electronic resources in situations when a desktop/laptop is not available (mobile eLearning).
3) Communication with a community of learners and teachers beyond the spatio/temporal boundaries of the institution.
4) The ability to do field work outside the classroom, for example data collection, experience recording and note taking.
5) Location sensing facilities and access to administrative information such as timetables and room locations.

Characteristics of mobile and wearable devices:

Our review pertains to devices such as mobile phones, personal digital assistants (PDAs) and wearable devices, and less to mobile devices such as laptops and tablet PCs which are, generally, larger in size.

Mobile devices have several limitations, due to their small size (form factor), that need to be considered when developing applications:

1) *Small screen size*, which can be very limited, for example on mobile phones. Solutions to this problem necessitate innovative human-computer interface design.
2) *Limited Performance*, in terms of processor capability, available memory, storage space and battery life. Such performance issues are continuously being improved but, to counter this, users expectations are also growing.
3) *Slow Connectivity*. Relatively slow at the moment for anywhere internet connectivity; 3G technologies promise to improve the situation. Wireless LAN connectivity, such as 802.11, provides simple and reliable performance for localised communication.

In order to take advantage of the promise of mobile computing devices, they need to have *operating systems* support such as

- A version of Microsoft windows for mobile devices.
- Linux for mobile devices.
- Palm for PDAs.
- Symbian for mobile phones.

In addition, mobile devices need to support *applications-development technologies* such as

- Wireless Application Protocol (WAP), where in the current version content is developed in XHTML, which extends HTML and enforces strict adherence to XML (eXtensible Markup Language).

- J2ME (Sun Java 2 Micro Edition), which is a general platform for programming embedded devices.
- .NET framework, which includes Microsoft's C# language as an alternative to Java.
- NTT DoComo's i-mode, which currently covers almost all of Japan with well over 30 million subscribers. Phones that support i-mode have access to several services such as email, banking, news, train schedules and maps.

Mobile devices generally support *multimodal interfaces*, which ease usability within the "anytime, anywhere" paradigm of computing. Such support should include:

- Pen input and handwriting recognition software.
- Voice input and speech recognition software.
- Touch screen, supporting colour, graphics and audio where necessary.

Standard *software tools* should also be available on mobile devices to support, amongst other applications:

- Email.
- Web browsing and other web services.
- Document and data handling, including compression software.
- Synchronisation of data with other devices.
- Security and authentication.
- Personalisation and collaboration agents.
- eLearning content management and delivery, which is normally delivered on mobile devices via its web services capability.

Apart from the last two, the above tools are widely available, although the different platforms are not always compatible. This is not a major problem, since communication occurs through standard web and email protocols. Current personalisation and collaboration tools are mainly based on static profiling, while what is needed is a more dynamic and adaptive approach; see part three. There are still outstanding issues regarding content management and delivery of eLearning materials, since these technologies, that we assume will be XML centric, are still evolving.

Wearable devices are distinctive from other mobile devices by allowing hands-free interaction, or at least minimising the use of a keyboard or pen input when using the device. This is achieved by devices that are worn on the body such as a headset allowing voice interaction and a head mounted display which replaces a computer screen. The area of wearable devices is currently a

"hot" research topic with potential applications in many fields, for example, aiding people with disabilities. As this area is still very much experimental there are not many mature commercial products with a wide user base that may be considered, at this time, in the context of FE and HE. We will now briefly review several wearable products so that their potential can be appreciated.

The IBM Linux Watch

(www.research.ibm.com/WearableComputing/factsheet.html)

Figure 1: The IBM Linux Watch (Version 1) by IBM Research. Image reproduced by kind permission of IBM research.

IBM have recently developed a wrist watch computer, which they are collaboratively commercialising with Citizen under the name of *WatchPad*. Apart from telling the time WatchPad supports calendar scheduling, address book functionality, to-do-lists, the ability to send and receive short email messages, Bluetooth wireless connectivity and wireless access to web services [Figure 1]. WatchPad runs a version of the Linux operating system allowing a very flexible software applications development platform. It is possible to design WatchPad for specific users, for example a student's watch could hold various schedules and provide location sensing and messaging capabilities.

Xybernaut Mobile Assistant

(www.xybernaut.com/Solutions/product/mav_product.htm)

Figure 2: The Xybernaut Mobile Assistant. Courtesy of Xybernaut Corporation.

This commercial product is the most widely available multi-purpose wearable device currently on the market. It is a lightweight wearable computer with desktop/laptop capabilities including wireless web connectivity and email, location sensing, hands-free voice recognition and activation, access to data in various forms and other PC-compatible software. It has a processor module, which can be worn in different ways, a head mounted display unit [Figure 2], a flat-panel display, which is touch screen activated and allows pen input, and a wrist strapped mini-keyboard. Xybernaut are currently trialling the use of the mobile assistant in an educational context concentrating on students with special needs. It allows the student full

computing access beyond the classroom, including the ability to do standard computing functions such as calculations, word processing and multi-media display, and in addition, has continuous internet connectivity and voice synthesis capabilities. It also supports leisure activities such as listening to music and playing games.

iButtons

(www.ibutton.com/ibuttons/index.html)

Figure 3: iButton can. Image reproduced courtesy of iButton, which is a registered trademark of Dallas Semiconductor/ Maxim Integrated Products.

iButtons developed by Dallas Semiconductor Corporation/Maxim are currently being piloted in a range of educational institutions. An iButton is a computer chip enclosed in a durable stainless steel can. Each can of an iButton has a data contact (called the lid) and a ground contact (called the base), which are connected to the chip inside the can [Figure 3]. By touching each of the two contacts it is possible to communicate to an iButton, and iButtons are distinguished from each other by each having a unique identification address. By adding different functionality to the basic iButton, such as memory, a real time clock, security and temperature sensing, several different products are being offered. There are many applications for this technology including: authentication and access control, eCash and a range of other services. In educational contexts, these smart buttons allow registration of students as well as access to classrooms, web pages, and computers.

MIThril: A platform for context-aware wearable computing

(www.media.mit.edu/wearables/mithril/)

MIThril is a wearable research platform developed at the MIT Media Lab. Although not a commercial product MIThril is indicative of the functionality that we can expect in next generation wearable devices. Apart from the hardware requirements, which include having a wide range of sensors with sufficient computing and communication resources, and the support for different kinds of interfaces for user interaction, including a vest [Figure 4]. There are also ergonomic requirements that include wearability, i.e. that the device should blend with the user's ordinary clothing, and flexibility, i.e. that the device should be suitable for a wide range of user behaviours and situations.

Figure 4: MIThril vest. Image reproduced by kind permission of MIT Media Lab.

As an application of this architecture a reminder delivery system, called *Memory Glasses*, was developed, which acts on user specified reminders such as "During my next lecture, remind me to give additional examples of the applications of wearable computers", and requires a minimum of the wearer's attention. Memory Glasses uses a proactive reminder system model that takes into account: time, location and the user's current activities based on daily events that can be detected such as entering or leaving an office.

Part Two: Three scenarios for further and higher education

Three Scenarios

The use of wearable and mobile devices in further and higher education contexts needs to incorporate an understanding of the technical and pedagogical considerations. Additionally, the potential applicability of usage of these devices for educational use needs deeper consideration in terms of hardware and software as well as in terms of how applications can be adapted and personalised. In order to consider these technical, pedagogic and contextual aspects in more detail, the following section will explore three possible uses of wearable and mobile devices for further and higher education: to deliver web lectures and assignments to learners, to produce a campus without walls and to supplement field study.

Scenario 1: Web lectures

The traditional lecture held in a college or university operates using a one-to-many model of communication and relies upon a didactic or instructional model of learning (Gagné et al. 1992) where information is transferred from lecturer to student. With the introduction of computers and the use of communications networks some changes to the traditional lecture have already evolved, recent innovations to the format include: e-lectures and webcasting.

Exploring the potential uses of wearable devices such as handhelds or PDAs to support learning in further and higher education institutions and building on these recent innovations, the first scenario explores the web lecture. The 3Com University Learning Assistant and IBM's Web Lectures Services provide two

examples of how web lectures and materials such as assignments and assessment can be delivered to the learner on the move. While workers and workplace learners are currently using these services this method of delivery of e-content has potential for further and higher education learners as well.

3Com University Learning Assistant

The 3Com University is a corporate university, which delivers training via networks as well as providing face-to-face training. The 3Com University has developed its Learning Assistant in order to provide training courses and modules including: wireless networking training and sales courses to its disparately located staff. In this way, handhelds are being used for the delivery of lectures on the move as well as providing greater functionality by also delivering sales information.

The 3Com Learning Assistant uses Palm's for delivering learning content to the learner [Figure 5]. Data can be delivered in text or graphical form. The assistant offers Palm Conversion Tool functionality, a simplified authoring environment and an intuitive hierarchical structure [Metcalf 2001].

Figure 5: 3COM Learning Assistant. Image reproduced courtesy of RWD Technologies

The 3Com Learning Assistant uses a blended e-learning model, which brings face-to-face training together with the use of ICT. As Perry et al. [2001] and Whittaker et al. [1994] have demonstrated, the use of mobile devices not only helps to connect disparate learning communities - but also has the potential to facilitate face-to-face interactions. In this way, rather than being desk-based the learner can be on the move meeting colleagues and learners whilst learning. The pedagogic approaches used here provide the potential to adapt and personalise learning activities more closely to the learner's requirements and everyday life. In this way, 3Com's model brings together "a combination of instructor-led training classes, live conference events, synchronous online events, self-paced WBT [Work-Based Training] courses, training manuals, and a certification process" together with 3Com's databases and modules. [Bielawski and Metcalf 2003, p. 119].

IBM's Web Lectures Services

The IBM Web Lectures Services developed out of in-house training for the sales staff as well. The main benefits for IBM have been cost savings. The system allows the company to reach 89,120 registered users simultaneously saving $80 million and 1,730 lectures have been developed to date. IBMs mobile solutions include: access to IBMs Lotus LearningSpace and SMS [Short

Messaging Services] for delivering updated activities to the learner. In this way, the IBM web lectures can be delivered to the mobile devices such as PDAs or mobile phones [Figure 6].

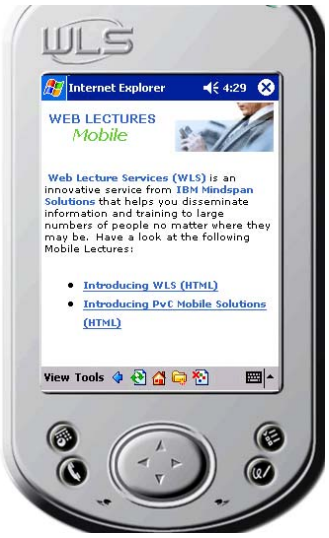

Figure 6: IBM Web Lecture services. Image reproduced courtesy of IBM.

The main technical considerations relate to the ease of access implied by the use of PDAs for dissemination of information. Learners can in this way be reached remotely, enabling access to web lectures and providing up-to-date data. Providing that the web lectures can be delivered electronically and within a formalised course context standard pedagogical considerations apply.

In the context of mobile learning, new ways of learning in terms of differing locations do need to be considered. Short learning chunks or objects for example may apply here, implying shorter learning times and cycles. There are however additional considerations implied by learning on the move which are specific to using smaller devices, including the limits of a smaller screen necessitating more summarised information, affecting course development. In an effort to overcome these considerations there is a body of work that relates to the development of new interfaces, these include 3D audio landscapes [Brewster et al 2003], concept-based navigation [Brusilovsky and Rizzo 2003] and augmented reality [Gleue and Dahne 2003].
One potential use for wearable and mobile devices in tertiary education may include supporting the development of collaborative learning - where groups of learners or 'communities of practice' [Wenger 1998] may be able to communicate synchronously (live) and non-synchronously (recorded) within groups facilitating collaborative learning on the move.

Scenario 2: Campus without Walls

The university and college campus is a mainstay of tertiary education experience bringing together learning communities to provide support and services for facilitating learning. Based on a physically located notion of a single campus increasing pressures on space - due to expanding student numbers - have been placed upon the single site. Today many universities are spread across two or more sites and this makes communications between individual student and tutor groups more problematic.

In the United States this problem of expanding student numbers and proliferating sites has led to an attempt to find new ways to support educational communities, one of which is through the use of wearable and mobile devices and selected software. Other models for the digital campus

have been provided by corporate universities and training centres where student populations are remotely located, in these cases often online universities and a virtual campus take the place of the physical campus - and computer-mediated communications have replaced seminar or lecture attendance.

This section therefore explores two examples where ICTs are being used to augment or replace the physical campus. One of the advantages of this may be greater flexibility for the learner in terms of where they choose to study, collect assignments and how they record study data. Wearable devices like handhelds or wrist computers would allow the student to interact with data in a more casual and differentiated way. The added functionality of location sensing devices using GPS and GPRS may provide information about where the learner is located, this may provide an alternative solution for bringing larger learner groups together remotely.

While the web lecture is restricted to formats and technical specification the virtual campus may incorporate a range of learner services that may include web or e-lectures, the use of e-books, accessing assignments remotely, bringing together a single portal for accessing library resources and using mobile, wearable and mobile devices for student induction as well as for delivery of learning materials and online assessments. Examples of this include: the Handsprings to Learning project at East Carolina University and the ActiveCampus project at the University of California at San Diego.

Handsprings to Learning and OWLS (Online Wireless Learning Solutions, East Carolina University (ECU)

At the East Carolina University courses have been delivered to handhelds since 2000, providing course content for students on-campus and from their distant locations. Handsprings to Learning (HtL) was combined with another research initiative called OWLS (Online Wireless Learning Solutions). The success of the initiatives led to the creation of the ECU Centre for Wireless and Mobile Computing.

The philosophy behind HtL and OWLS enables study at any time, and anyplace, beyond the gates of the physical campus, allowing for greater flexibility for the learner and providing added functionality at a significantly lower cost than the price of laptop, tablet or desktop computer. The Handsprings to Learning project is based upon OWLS (Online Wireless Learning Solutions), a three-year project for developing "integrated collaborative eTools" to support distance learning at the East Carolina University [Shields 2002, p. 2]. The project is now providing solutions to 20 universities and colleges and has global sponsors. Applications of handhelds

include access to email, web pages, electronic resources and examinations enabling students to hot sync from their desktops. This approach to "snatch and go learning" enables mobile professionals to learn from updated content [Du Vall, pers. comm., 28th May 2003].

Figure 7: Convergence device consisting of Sprint PCS 3G Smart Phone, Toshiba 2032 PDA, with SD card slot and access to 802.11b WiFi. Photo courtesy of Matthew R. Powell

Aimed at face-to-face as well as distance learners, the project allows individual tutors to develop course content, using their own pedagogical models and approaches according to specific content and context of learning. These projects demonstrate how different methods of delivery of learning materials can transform how learning is developed and supported. The OWLS project offers new solutions to distance education as well as supporting collaborative learning.

One of the most recent research projects in the Centre for Wireless and Mobile Computing involves the use of QUATRA Intelligent Mobile Communicator [Figure 7], with the freshman class of 60 Teacher Fellows. What is being used here is a four-featured convergence device including 3G smart phone, PDA, 802.11bWiFi Connectivity and secure digital smart card with large storage memory [DuVall, pers. comm., 8th May 2003]. In this way both on-campus and distance learners can continue to communicate when they are in range of a WLAN network, as well as using interactive flash modules and sound when they are travelling. Another advantage of this type of convergence device is that it can be used to establish learning communities located virtually anywhere. This approach could also have added value for tutors allowing them to share resources, form tutor support groups and discuss pedagogies.

ActiveCampus, University of Califormia, San Diego (UCSD)

The ActiveCampus project is based at the University of California, San Diego and aims to "sustain… educational communities through mobile computing" [Griswold et al. 2002, p. 1].

The ActiveCampus project provides a useful model for interaction between the physical and non-physical campus. The project makes use of E-Graffitti and GeoNotes software where learners can post notes at given physical locations within the campus, so that other learners can pick up these notes when navigating in the proximity of the location at which the note was posted [Griswold et al. 2002]. This allows the learner to see past the buildings and

pick out their learning groups and mentors, and more easily navigate the physical campus [Figure 8].

This project provided HP Jornada PDAs to 700 undergraduates in the Computer Science and Engineering department in order to investigate research questions relating to the sustainability of educational communities. The technical specification for this system used PDAs, wireless communications and dedicated E-Graffitti and GeoNotes software.

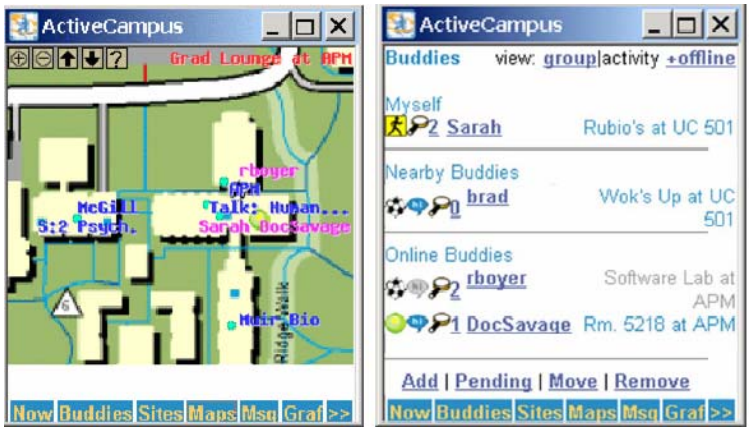

Figure 8: The Map and Buddies services of ActiveCampus. Image used courtesy of the ActiveCampus project.

The ActiveCampus project is informed by a mediated approach to learning developed by Michael Cole [1996] from activity theory giving an emphasis to the cultural dimensions of learning:

> Learning activities, spontaneous and otherwise, are heavily mediated (assisted) by a university campus through its structural configuration and its institutions. First, the campus organization itself brings people with complementary interests into close proximity, easing communication and increasing the chances of serendipitous interactions. The campus not only brings learners and teachers together, but also concentrates area specialists by organizing the campus into schools and departments of expertise… Because these institutions operate through proximity, they function less well when people are not there. Moreover it can take considerable time for someone to internalise the workings - the culture - of an institution. [Griswold et al. 2002, pp. 2-3].

This 'campus without walls' provides one possible model for how the virtual campus of the future may work. Not only can the learner orientate more quickly to their physical environment, they can also augment the mediation of learning through the use of a mobile device. The device can store electronic messages tagged to physical objects saving graffiti for students to collect. It can facilitate introductions between like-minded students through messaging, it can alert the learner that a mentor or friend is close by or that there is an interesting lecture or talk going on.

ActiveCampus does not replace the physical environment of the campus but does suggest a way of using technology to facilitate and mediate learning by shortening the time needed for orientation and induction, as well as facilitating serendipitous meeting and supporting communities of learning.

Scenario 3: Field trips

Field trips currently rely upon travel in groups to a remote location where study is undertaken and field notes collected and compiled; the synthesis of that experience then takes place back in the class or seminar room. The use of wearable and mobile devices for recording data therefore can be regarded as a facilitator of field trip study and may provide new models for how study is moving away from desk-based research towards more proactive and experiential learning or action research.

Two examples of how mobile and handheld devices can be used to facilitate field study are included here.

A tool for capturing museum visits

(www.exploratorium.edu/guidebook/)

The *Rememberer*, a tool for recording museum visits, is part of the Electronic Guidebook project at the San Francisco Exploratorium, which is investigating the use of handheld devices to enrich learning experience for museum visitors. An important goal of the project is to allow both individuals and groups of visitors a continuum of activities before, during and after the visit, to create an extended interaction between the museum and its visitors beyond the actual visits to the museum. The Exploratorium provides an ideal testing ground for such technology, as it is very much an open space supporting hands-on science exhibits. The Rememberer is simpler than an electronic guide as its main functionality is to create a record of the users' visit rather than assist them during the visit itself [Figure 9]. It allows a user to select objects during their visit creating an ordered list of exhibit names that the user interacted with. The user is left with an URL to a website documenting the visit record, which is augmented with additional links to related content. The implementation of the system is achieved through PDA technology coupled with wireless technology. Preliminary evidence shows that the Rememberer tool was much less distracting to users than a guidebook tool. Ongoing research [Levene and Peterson 2002] is investigating the use of such "experience recording" in a learning model which supports both teachers and learners in maintaining a record of their activities that can be shared, refined and enhanced.

Figure 9: Electronic Guidebook. Image reproduced with kind permission of the Exploratorium.

CyberTracker field computer

(www.cybertracker.org)

CyberTracker is a software system developed for a PDA supporting the Palm Operating System, which enables trackers to record all the significant observations they make in the field. The user interface is icon-based enabling trackers to record sighting of animals, track observations, species and other animal activities [Figure 10]. It is also linked to a GPS that records the location of each sighting. The tracker can also add field notes to record information not covered by standard menu. When the tracker returns to base the data can be transferred to a PC. The device is currently being used in a range of wildlife projects in over 30 countries and it has applications in other areas such as market research and social research.

Figure 10: CyberTracker: being used in a South African Park. Copyright: Cybertracker Software.

Potential usage of wearable and mobile devices in tertiary education

Potential uses of wearable and mobile devices for tertiary education include a range of supplementary learning services facilitating: collaborative learning in groups, learning on the move, delivery of assignments, field trips and the delivery of synchronous and asynchronous lectures and materials. Benefits may also include improved communications for and between lifelong learners [Sharples 2000], distance learners, part-time learners and work-based learners. While the use of PDAs as learning tools are currently being piloted in the UK in tertiary education for field trips and assignment delivery, this mode of learning may be expected to become more commonplace due to scalability and the ease of data dissemination as well as due to the relatively low cost of handheld and mobile devices [Smith 2003].

For learners with disabilities this mode of delivery of e-content may provide additional benefits, for example: voice-activated interfaces for the blind learners'; visual interfaces for those with literacy and numeracy problems and cognition assistance for the elderly [Goodman et al. 2002]. There are clearly potential benefits to those with disabilities that may include location finding, induction aids, cognitive assistance and orientation for learners with disabilities on campus. These mobile devices also have the added functionality of allowing for built-in location sensing devices [Roussos 2002] that may help

freshman learners and those with disabilities to find their way more easily around campus.

In addition to localised orientation, wearable and mobile devices may be used to allow learners to ask questions and discover more about the physical campus and it can also allow learners to orientate themselves to tutors, support staff, learner groups and other students, thereby facilitating collaboration within and between different communities of practice [Wenger 1998]. The devices can also augment the learning experience, allowing learners to access supplementary data from the Internet, access assignments and complete evaluations and assessment. Additionally the use of mobiles can facilitate better access to digital resources as well as providing for authentication and security to educational resources.

The introduction of mobile learning also has implications upon how course materials are developed and how pedagogies are applied. In this way, the use of wearable and mobile devices for learning may also facilitate different teaching and learning methods and approaches thereby supporting, supplementing and innovating current teaching and learning practices, for example supporting conversational learning [Sharples 2003]. The wearable and mobile devices will potentially allow for a more seamless and transparent interface between the learner and datasets - subject to connectivity both on and off campus. Greater interactivity will be based upon the usability and adaptability of the devices.

Part Three: Consideration of the uses and purposes for wearable and mobile devices in tertiary education.

The social and technological implications upon the tertiary learning communities need consideration if the use of wearable, mobile and handheld devices in tertiary education is to be supported and promoted on an institutional basis.

The social and educational benefits of wearable and mobile devices include the greater mobility and flexibility for the learner by potentially increasing the capacity of the learner to learn "anytime, anywhere" according to subject specificity and selected pedagogical models and approaches. This has particular benefits for lifelong learners, distance and part-time learners, as well as campus-based learners, providing greater flexibility by facilitating collaborative learning within 'communities of practice' [Wenger 1998] - both in disparately located groups as well as in locally based groups.

A sensible institutional approach would be to pilot the use of mobile computing devices in specific contexts such as those highlighted in part two, and to progress incrementally. Educational researchers will pilot specific wearable devices to ascertain their wider application and the best context for use.

Perhaps a more central concern for the use of mobile devices in educational contexts is the need to provide stable pedagogies that can migrate for the benefit of the learner according to the device, location and learning outcomes and objectives. While mobile communications offer certain advantages to the learning communities, issues such as privacy, security and authentication are primary concerns [Satyanarayanan 2003]. Another issue that needs to be addressed is the public health issue associated with wireless connectivity, while some new evidence points to the health risks attached to mobile phones [Salford et al. 2003] clearly more informed research and debate are needed.

Hardware manufacturers and software developers are engaged in a continuous technological race to satisfy new and increasing requirements from users of handheld, mobile and wearable devices. For example, the issue of extending battery life through new battery technologies and lower energy consumption hardware will continue to affect the range of possible wearable applications. The fierce competition between mobile phone companies is evident where new features are continuously being added, many of them pointing towards the convergence of computing devices in terms of features such as web connectivity, advanced software tools and graphic and video displays. Especially in the wearable computing sector there will probably be differentiation of products for a while to come, since, as we have shown, their uses and context are varied.

At this moment in time the innovations seem to be progressing at such a rapid pace that often suppliers of these devices are trying to create new demand for products at a relatively early stage of their development. It is not hard to predict that the technological issues addressed in part one of this report will continue to be addressed and improved. Regarding standards we expect current ones to evolve in parallel with new developments, but due to the experimental nature of some of these devices, there will be periods where non-standard appliances will be piloted.

A major challenge for developers, in order for handhelds and wearable devices to be adopted on a large scale within the educational sector, is to provide intelligent and specialised software that is useful within a learning context. A first step is recognising the different types of learning scenarios such as

lifelong learning, learning in the workplace and distance learning, with special attention given to individual learners and the community they belong to.

Developing novel user interfaces to overcome limitations of handheld and mobile devices is particularly important. Some examples are: (i) peephole displays [Yee 2003], which combine pen input with spatially aware displays, enabling navigation through objects that are larger than the screen, (ii) Halo [Baudish and Rosenholtz 2003], which is a technique that supports spatial cognition by showing users the location of off-screen objects, surrounding these objects with rings at the border of the display, and (iii) map-based access to educational resources [Brusilovsky and Rizzo 2002], which uses a self-organising neural network to automatically build a concept-map of learning objects.

Personalisation of the user interaction is also an important issue, where adaptation to the user behaviour is critical, easing the customisation of the interface to suit users' specific needs within the context of the device being used [Weld et al. 2003]. Advances in machine learning and artificial intelligence on the one hand, and information overload on the other, have led to a new challenge of building *enduring personalised cognitive assista*nts, which adapt to their users by sensing the users interaction with the environment, can respond intelligently to a range of scenarios which may have not been encountered previously and can also anticipate what is the next action to be taken [see Brachman 2002].

Finally, it is also important to investigate the social potential and impact of wearable and mobile devices [Kortuem 2003] so that collaborative systems can be developed to facilitate and encourage interaction between members of the community. One possible educational application of such a collaborative system may be an interactive learning environment, which supports a range of mobile and wearable devices in addition to integrating a range of learning services.

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