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Ubiquitous Computing

David Ley, Becta

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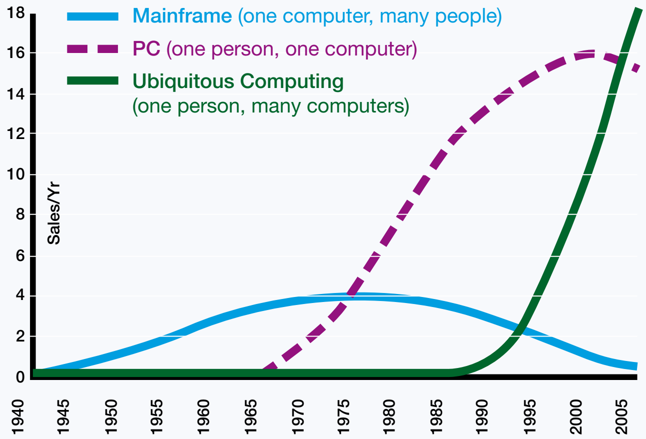
The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it.

Mark Weiser[1]

Ubiquitous computing is a vision of computing power 'invisibly' embedded in the world around us and accessed through intelligent interfaces: 'Its highest ideal is to make a computer so embedded, so fitting, so natural, that we use it without even thinking about it.'[ii] This is about a shift to human-centred computing, where technology is no longer a barrier, but works for us, adapting to our needs and preferences and remaining in the background until required. This implies a change in our relationship with ICT to a much more natural way of interacting and using the power of networked computing systems which will be connected not just to the internet or other computers, but to places, people, everyday objects and things in the world around us.

If achieved, such a vision would be transformational and have profound implications for how we live, work, interact and learn. When Mark Weiser wrote about ubiquitous computing in 1991, his vision of computing power deeply embedded in objects, places and devices seemed some way off. Today, various elements of ubiquitous computing are beginning to appear and be useful in their own right, as increasing numbers of devices and objects become addressable (have a unique ID) and connected (usually wirelessly).

Just as with the rapid development of the internet and web technologies, many applications of ubiquitous computing cannot be predicted today and rely on these technologies reaching a critical mass. Weiser saw three waves of computing: the mainframe age when many people shared a computer; the personal computer wave when one person has one computer (the focus of many initiatives); moving to the ubiquitous computing wave when each person shares many computers. The current internet age is seen as a transitional phase between the PC and ubiquitous waves.



The three waves of computing [Source: http://sandbox.xerox.com/ubicomp/]

Implications

The increasing maturity, performance and miniaturisation of processors, networking technologies, memory, displays and sensors is enabling a move towards pervasive computing, ubiquitous connectivity and more adaptable interfaces that are sensitive and responsive.

Many objects and devices already have embedded processors and sensors. Some cars, for example, use sensors to monitor wheel slippage and apply the brakes to stop us skidding. Radar-controlled cruise control will automatically keep the distance with the car in front. However, these systems tend to be stand-alone and do not necessarily interact with other connected objects and devices. Washing machines have sophisticated electronic programmes, but we need to explicitly control them. In the ubiquitous computing world, the washing machine would automatically interrogate tags embedded in our clothes and adjust the wash cycle accordingly.

Increasingly then, connections are not just people–people or people–computers, but between people–things and most strikingly, things–things.[3]

1 Weiser, M. (1991): *The Computer for the 21st Century.* In: Scientific American 265, Nr. 3, S. 94-101.

2 Weiser, M **http://sandbox.xerox.com/ubicomp/**

3 'Things' here means objects and devices that are not computers

This is what the International Telecommunication Union (ITU) calls the ‘internet of things’[4]. These new connections create the possibility of new interactions and access to enormous amounts of information. This changes the web from being a purely virtual, online space to a system that can provide appropriate information, help and services in the real world. If properly harnessed this information will make us better informed and enable smarter decisions by both people and machines.

These technologies have modes of use that can be implicit or explicit. Explicit interactions are those where a conscious action by a user enables an interaction. Implicit interactions are automatic and can happen without any direct user intervention. Our opportunities for explicit interactions with the real world are increasing, but it is the implicit, unseen interactions that will provide a real shift in how we use and gain benefit from computer systems.

Ubiquitous computing encompasses most areas of IT and achieving the vision will rely on several factors coming together:

- Miniaturisation (smaller, lower power processors, sensors and wireless technologies.)
- Ubiquitous connectivity
- Interoperability (standards for networks and devices; identification; network and device discovery; self-configuring, seamless networks etc.)
- Improved intelligent interfaces (natural interfaces; intelligent agents; display technologies etc)
- Intelligent systems (including sensor networks; context awareness; location; semantic networks; data handling; and search etc.)
- Security and reliability (reliable, secure systems; and privacy features)

Many parts of ubiquitous computing are still in development and many of the possible uses and implications of the technologies are still unknown. However, there are already clear possibilities for improving learning both through individual technologies and increasingly through using these technologies in unison. As will be explored, ubiquitous computing technologies can lower the barriers to using the power of ICT, enable much more personalised, context-aware interactions and help with a move to more experiential learning: learning by doing, interacting and sharing.

Key elements of ubiquitous computing

The key elements that devices/objects/nodes in a ubiquitous computing environment need are: identification, location, sensing and connectivity

Identification

In order for objects and devices to usefully become part of a wider intelligent, information sharing network, it is vital that each one has a unique identity. This not only enables more things to be interconnected, it also means that objects that surround us can become resources and act as interfaces to other resources. Two important technologies used to provide identity are Radio Frequency Identification (RFID) tags and visual barcodes.

RFID

Radio Frequency Identification (RFID) is a type of auto identification system and refers to technologies that use radio waves to identify objects, locations or people. RFID is a generic term and does not refer to a particular technology. However, more recently, the term

4 ITU Internet Reports 2005: *The Internet of things* (ITU 2005 7th edition)

has become associated with a form of the technology called RFID tags. These are tiny microchips attached to antennae (transponders). The data on these chips can be read by a wireless reader (transceiver) and the data passed back to computer systems. There are two main types of RFID tags: passive (energy harvested from the reader) and active (with their own power supply). The more sophisticated tags offer read/write capabilities. RFID chips can be as small as 0.05 mm^2 and can be embedded in paper. More recently, printable tags have been developed. RFID systems do not require line of sight and work over various distances from a few centimetres to 100 metres depending on the frequency used and type of system. Standards for tags and electronic product codes (EPC) are being overseen by EPC Global **[http://www.epcglobalinc.org]**.

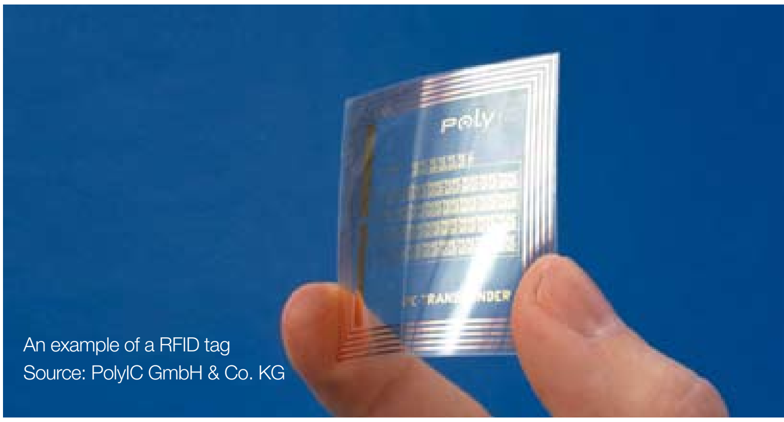
The ability to identify, locate and track RFID tags is seen as a transformational technology, potentially allowing any object to be interrogated by computer systems. However, high costs, technical issues and concerns about privacy will need to be overcome before RFID tags become widespread. Currently, the main area of use is in the retail supply chain, but analysts predict that 50 per cent of the uses for RFID in 2012 have not even been thought of yet.

The retail/supply sector is only one area of use for the technology. Some examples of other uses are: security, authentication of goods/banknotes **[http://networks.silicon.com/lans/0,39024663,39122553,00.htm]**, asset tagging, document tagging, library book tagging, road tolls, safety systems, and payment systems. RFID is already in use in contactless card systems for door entry and on public transport such as the London Underground **[http://www.rfida.com/nb/oyster.htm]**.

ABI Research[5] believes that by 2009 50 per cent of mobile phones will have embedded RFID chips to access services and pay for goods. This technology is already being used in Japan **[http://www.nttdocomo.com/presscenter/pressreleases/press/pressrelease.html?param[no]=474]**.

In education the main use of RFID tags so far has been in library management systems, for asset tagging and ID/tracking purposes. However, a number of more innovative education projects have shown the value of learners being able to interact with tagged objects in the real world. For example, an object's ID could trigger information or sounds to be sent to a learner's device. Such systems are increasingly being used in museums **[http://www.rfid-weblog.com/50226711/rfid_in_museums_another_growing_market.php].**
RFID tags can also play a part in creating intelligent classrooms (see below).

RFID readers can now also be included in mobile phones, potentially making the readers as ubiquitous as the tags are expected to become. However, RFID tags can operate without user intervention, automating many applications and providing huge amounts of data, which creates a need for more sophisticated systems to support them (see data handling).



An example of a RFID tag
Source: PolyIC GmbH & Co. KG

5 ABI Research **http://www.abiresearch.com**

Visual bar codes - hyperlinking the world

A simpler way of giving an object an identity and allowing a user to interact with it is through a visual or 2D 'bar code'. These are printed 'pictures' containing data, which when photographed by a cameraphone will provide information about the object or, more often, act as a 'smart URL' taking the user to a particular web page. Examples include Semacode, Bango spots and Shot codes. Software for creating these 2D barcodes can be downloaded from the relevant websites. Newer versions such as those from Fujitsu (Fine Picture code) allow the 'barcode' to be invisibly embedded into photographs or pictures. NTT DoCoMo has also developed a system that allows URLs to be embedded in sounds or music, which can be interpreted by some mobile phones.

In Japan, a type of 2D barcode, called QR (quick response) codes, is widely used to save having to enter information such as addresses into mobile phones or even to purchase goods. They are found in advertising, in the print media, on business cards, products, websites and vending machines. Some teachers in Japan are using QR codes to distribute resources to learners

[http://delivery.acm.org/10.1145/1190000/1181244/p123-fujimura.pdf?key1=1181244&key2=6214984611&coll=ACM&dl=ACM&CFID=15151515&CFTOKEN=6184618]

or in more innovative projects to allow interaction with real world objects (as with RFID) – see for example, *Future Experience Workshop,* Takeyama Laboratory, Keio University **[http://www.childresearch.net/RESOURCE/RESEARCH/2005/TAKEYAMA.HTM].**

An example of a QR code. This QR code is a link to the Becta website (Source: http://qrcode.kaywa.com/)

The BBC/Open University used a similar system for their Coast project. Data Matrix 2D barcodes were placed on signs around the coast allowing walkers with cameraphones to connect to related text, directions, images and audio **[http://www.gavitec.com/fileadmin/template/main/downloads/CaseStudy_EN_BBC_CoastMobile_F0608.pdf]**

The drawback of visual bar codes is that they are not wirelessly linked, so rely on explicit user interaction rather than the automatic, implicit use that is the real vision of ubiquitous computing.

IPv6

An alternative technology that could be used for identification is Internet Protocol version 6. IPv6 is the next generation protocol designed by the IETF[6]. Currently the internet and most networks rely on IPv4 addresses which have a limit of 2^{32} addresses. IPv6 provides 2^{128} potentially allowing billions of unique IP address. IPv6 also offers other advantages over IPv4 such as support for auto-configuration of devices, Quality of Service (QoS), mobility and security. However, adoption of IPv6 is expected to happen relatively slowly, with most interest currently coming from government/military and research organisations.

6 IETF: Internet engineering task force

Location

The ability of objects and devices to have location information adds another important level of intelligence, allows the discovery of people, objects and resources and enables location based tools and services. Indeed, location services are expected to be increasingly important over the next few years. It is predicted that there will be 70 million GPS enabled phones in Europe by 2010 (IMS Research[7]). Tim O'Reilly, who coined the term Web 2.0, has now started a new annual conference called Where 2.0[8], underlining the potential for innovation in this area.

Devices and objects can establish their location in a variety of ways and to varying levels of accuracy. At a basic level an RFID tag can be recognised as it passes a fixed wireless reader. Devices with accelerometers can detect motion and know their orientation. Wi-Fi enabled devices can be tracked to a reasonable degree of accuracy (for example Ekahau[9] systems). Mobile phones can also be pinpointed, but the accuracy can vary considerably. It is with the advent of inexpensive satellite positioning technologies that location can be determined to within a few metres and absolute geographic locations can be accurately established. Global Positioning System (GPS) chips now provide better coverage and can be found in many consumer devices such as PDAs, mobile phones and even school bags **[http://ubiks.net/local/blog/jmt/archives3/2004/10/index.php]**. GPS can be coupled with navigation and personal locator services (likely to appear in UK in 2007 according to ABI Research**[http://www.abiresearch.com/abiprdisplay.jsp?pressid=766]**). An alternative European satellite positioning system, Galileo[10], is also in development and should provide greater reliability and accuracy

Proximity devices like RFID chips rely on a user or device coming near to them before an event is triggered. This 'event' could be relevant learning materials downloaded to a users' device, or automatic connection to a large display, for example. Other location services are about knowing your relationship to other people or devices. MIT's iFind service allows students and staff to let other people know their location on campus **[http://ifind.mit.edu/]**. Mobile location based services are increasingly combining presence (information about the status of a user) with location information **[http://www.mologogo.com/]**. Some countries are using these technologies to track students for safety and control reasons, but these raise concerns over privacy (see issues). For example the Japanese government is piloting a system using RFID, GPS and mobile phones to track students and keep parents informed of their whereabouts **[http://ubiks.net/local/blog/jmt/archives3/005856.html and http://www.sankei.co.jp/seiji/seisaku/070103/ssk070103000.htm]**

Real world search

More recently, location systems allow the user to point cameraphones at an object or location and receive back relevant information from a database. Nokia researchers have developed a Mobile Augmented Reality Application (MARA) that is able to overlay digital information onto cameraphone feeds of the real world. It uses GPS, an accelerometer, digital compass and database of locations **[http://research.nokia.com/research/projects/mara/index.html]**.

Japanese mobile phone networks offer a similar system developed by GeoVector Corporation. It enables users to point their devices at buildings or other locations in order to retrieve information and services related to that place. A variety of innovative uses from mapping, tourist information, local search, mobile commerce, entertainment/shopping guides and advertising are envisaged **[http://www.geovector.com/appdemos/]**.

7 IMS Research **http://www.imsresearch.com/**

8 O'Reilly Where 2.0 Conference, **http://conferences.oreillynet.com/where2007/**

9 Ekahau **http://www.ekahau.com/**

10 Galileo European satellite navigation system **http://ec.europa.eu/dgs/energy_transport/galileo/index_en.htm**

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Tagging the world

Location based and visual recognition systems have also been used in educational projects to allow learners to access context related content (text, sounds, photos, video and websites) about objects and places in museums or in especially created learning environments (see for example EQUATOR projects such as Ambient Wood **[http://www.mrl.nott.ac.uk/]**). For more information on innovative projects in these areas see Bill Sharpe's article in *Emerging technologies for learning* (Becta, 2006).

These 'mediascapes' or learning trails are relatively straightforward for teachers to create, for example **[http://createascape.org.uk/]** or CAERUS **[http://portal.cetadl.bham.ac.uk/caerus/default.aspx]**. Students then navigate and interact with these learning environments using mobile devices. Often a record of the learner's route and interactions can be recorded. It is also possible for learners to tag their own content to particular locations so that others can access it when they are at that location, or it can be explored in more detail in the classroom. This 'digital graffiti' (such as photos, text, video or audio files) is 'geotagged' data that can be uploaded to the web and shared. Mappr **[http://www.mappr.com]** is one website that combines tagged photos from Flickr with Google Earth maps. This is part of Web 2.0, using the power of communities to add value to data. Indeed, combining location-based information with digital maps can be a powerful learning tool. For example pollution levels could be tracked and overlaid on maps. By adding sensors to the environment, this could be done in real-time.

Sensing

Having an identity and location information enables a variety of applications and uses, but adding a sensing capability can give systems 'eyes and ears' creating intelligent networks that can collect a range of data and even respond to events.

Sensor networks

Attaching sensors to RFID tags or other wireless nodes enables much more information to be gathered and analysed as well as adding more 'awareness' to ubiquitous networks. This awareness means that the network can detect and respond to the environment, often without any human interaction. Typically sensors can measure things like pressure, temperature, speed, air/water quality, stress, humidity, or acceleration. Wireless sensors consist of sensor(s) connected to micro-controllers, memory, batteries and radios. Each wireless sensor node usually forms part of peer to peer, mesh network (routing data through other nodes) that is self-configuring and has inbuilt redundancy. These autonomous networks are very scaleable and flexible, allowing self-discovery of new nodes and can cover large areas without the need for extensive fixed infrastructure (for example a sensor mesh network monitoring island weather conditions off Korea covers 80 square miles). Sensor networks can now be deployed very quickly and can use web services to integrate with other IT systems. Many sensor networks require little power and could potentially be deployed for a number of years.

MEMS

Micro Electro-mechanical Systems (MEMS) are moving parts on chips that are used to sense the environment and potentially to initiate an action, allowing systems to respond to the real world around them. For example these are already used in cars to detect collisions and deploy airbags. Inertia sensors have been embedded in some mobile phones and games controllers (such as the Nintendo Wii) to allow users to interact with the device through movement.

Research from InStat suggests that MEMS in mobile handsets will be worth $1 billion by 2010 **[http://www.instat.com/newmk.asp?ID=1671&SourceID=00000366000000000000]**.

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Motes/smart dust

A development of sensor networks variously known as motes, smart dust, and speckles, involves extremely small sensor nodes, potentially the size of a grain of rice. These 'smart dust' networks are very robust and can be scattered or sprayed into an environment or on an object. These systems are still very much in development, but are being researched by various organisations around the world **[http://www.specknet.org/publications/Steven4_ICSE04.pdf]**.

Connectivity

Wireless connectivity is key to enabling ubiquitous computing, but the increasing range of technologies is beyond the scope of this article. You can keep up with developments in wireless technologies through Becta's TechNews **www.becta.org.uk/technews**.

Potential for learning

In education the ability to receive and manipulate real-time data and interact with objects and devices in the real world has a range of benefits. Science, for example, involves measuring the world, analysing data and testing hypotheses. By accessing sensors embedded in the environment, learners have the opportunity to conduct their own investigations, develop analytical/critical thinking skills and model concepts. The Coastal Ocean Observation Laboratory based at Rutgers University (USA) can be accessed online by schools enabling learners to use and manipulate real time data collected from sensors in the ocean **[www.coolclassroom.org/home.html]**. In this experiential learning learners have the opportunity to use exactly the same data as professional researchers. This is part of what Bruner calls 'learning to be'[11] rather than 'learning about'.

Context awareness

One of the main goals of ubiquitous computing is to provide relevant information, in the right form, at the time and place it is needed. If objects and devices can recognise you and know about their location and environment and automatically discover other devices and resources (multi-sensorality), then the potential for delivering the appropriate, 'just in time' information increases. Learning systems would be able to adapt their output based on a range of unique characteristics. This is key to customised and personalised information systems that remain invisible until needed.

Already, our attention is being taken up by streams of often unmediated information. Context- aware systems should help filter information and make IT work for us without us having to actively interrogate systems. This allows learners to concentrate on the task rather then the technology.

Intelligent agents

Intelligent agents are proactive, autonomous, software tools and systems that can determine appropriate actions based on a range of data from multiple sources. Often they can 'learn' from experience. They enable systems to become 'aware' and respond intelligently to events. Sometimes this will mean informing or alerting a human user, but in other cases the system will make decisions. These systems may respond to environmental data (much as the thermostat in your home controls the central heating), but for learning it means systems that know who you are, what your preferences and learning styles are, where you are, what device you are using and what you are doing. This allows systems to become much more human/learner centred. **[http://agents.umbc.edu/]**.

11 Bruner, J. (1969) *The Process of Education*, Harvard University Press, US

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Service discovery and follow me services

Increasingly, devices and systems will be able to discover tools and services automatically. At a simple level this could mean being able to locate and use nearby printers, or large-screen displays, but increasingly this will allow content to recognise and follow the user (rather then the device), seamlessly moving from device to device or display to display as a user moves from home, to a car to a classroom or office. Some of this is already beginning to happen: automatic connection to Wi-Fi hotspots; the ability to access remote content/devices through any device with a browser; follow me phone services; presence capabilities in instant messaging applications. However, it is not yet seamless or personal enough and usually relies on some user action.

Emotional/social awareness

Initial applications are likely to make interfaces behave more socially by knowing where you are or what you are doing. This could mean, for example, that your phone won't ring during an exam or while you are in the cinema, and devices will switch on when you pick them up and off when you put them down.

Research is also looking at 'affective computing', through detecting the emotional state and attention of the learner. Voice analysis (already used in call centres), gaze tracking, skin conductivity, facial expression analysis (machine vision) **[http://web.media.mit.edu/%7Ejackylee/publication/p1007-lee.pdf]**, location and the way a user interacts with a system can all give clues as to the state and receptiveness of the learner. Research such as the EU-funded Learning in Process[12] project has already looked at delivering context-sensitive resources to the learner **[http://www.andreas-p-schmidt.de/publications/abis05_aschmidt.pdf]** Over time developments are likely to allow educational applications to tailor outputs more appropriately to how receptive to learning the user is at any given time and not just to a more fixed profile of preferences and learning styles.

The acknowledgment of the user's affective state might play an important role in improving the effectiveness of e-learning. The emotional unawareness has been considered one of the main limits of the traditional e-learning tools (especially the ones where learning takes place mostly individually). In fact, while skilled teachers can modify the learning path and their teaching style according to the feedback signals provided by the learners (which include cognitive, emotional and motivational aspects), e-learning platforms cannot generally take account of these feedbacks resulting often too rigid and weakened.

The Potential of Affective Computing in E-Learning: MYSELF project experience (Centre for Research in Communication Science, University of Milan paper for INTERACT 2005 Conference) **[http://images.1-to-x.com/acse/artMySelf02.pdf]**.

Human Computer Interaction (HCI)

We have seen how location- and context-aware technologies can help provide the right information in the right place and at the right time, but for this to be truly transformational it also requires a shift in the way that we interact with computer systems themselves.

Despite major advances in computer technology, human computer interaction is still largely based on mice, keyboards and the monitor. Interacting with computers and the skills needed to do this effectively can present a barrier to using the potential of connected information systems and the real world web of connected objects and locations.

There have been developments in voice recognition, gesture recognition, haptics, eye-tracking, handwriting recognition, display devices and a range of other technologies (see Paul Anderson's piece on HCI in ETL 2006 for an exploration of how these technologies may develop and be used in education). However, these have

12 Learning in Process (EU Framework 5) **http://www.learninginprocess.com/**

largely remained niche technologies, prevented from becoming more widely used due to usability issues or the fact that they don't necessarily improve productivity.

In ubiquitous computing the traditional computer and display no longer provide the only window on the virtual world; the computer will have become embedded all around us in a variety of devices, objects and locations. These non-PC end points (smart objects) often benefit from non-PC interfaces involving touch and movement (tangible interfaces). This is not to say that in a few years we will no longer be staring at computer monitors, but that there will be increasingly more intuitive and natural ways of receiving information from computer systems and interacting with them. This has been likened to the role of electricity and writing in our environment, both of which are fairly ubiquitous, but which largely go unnoticed until needed.

Ambient Information

Information is increasingly available in ways that do not require our permanent attention. Already, RSS feeds push relevant news and other web content to us, saving the need to actively visit the websites to see if anything has been added. That idea is now being taken further with the relevant information been presented 'ambiently' through everyday objects and devices in our environment, without the need for explicit user action or continuous attention. This lowers the barriers to accessing digital information and makes the increasing amount of data vying for our attention more manageable. Ambient display devices can use audio/sound, light, vibration, colour or movement. This is part of a move to more natural, multi-modal interfaces.

Some ambient display devices with glanceable interfaces are already available in the consumer market. For example the Nabaztag (Armenian for rabbit) connects to the internet via Wi-Fi and through sound, light and movement can provide its owner with emails/messages, information from RSS feeds (such as news or weather updates), inform the owner when friends are online and even teach TaiChi.

[http://new.nabaztag.com/en/index.html]

Nabaztag/tag by Violet

http://new.nabaztag.com/en/index.html

The Ambient Orb changes colour to present information relevant to the user such as share prices and the weather. **[http://www.ambientdevices.com/cat/orb/orborder.html]**.

Source: Ambient Devices

Ultimately, HCI may not be about how we interact with particular devices. As the environment around us becomes the 'computer', HCI could become a separate layer for interacting with multiple computers, nodes and systems.

Smart classrooms

Commercial products can already automatically capture audio, video and digital resources from lessons and publish them to the web; several research projects have looked at how classrooms could benefit from the use of embedded technologies (see examples below). These intelligent classrooms are able to track and respond to the needs of learners and teachers and allow the use of technology to become much more seamless. This not only reduces the burden of managing and operating technology in the classroom, but ultimately allows the classroom to add to the learning process. Intelligent environments make use of sensors, cameras, microphones/speakers and actuators and are controlled by intelligent agents (see above). At a simple level these technologies allow automatic environmental control (such as appropriate lighting for a particular task and automatic switching on of devices), but as the room can recognise the learner or teacher more sophisticated interaction is possible, enabling user/context sensitive actions and a seamless link between school and home.

> At the front-end of an AmI [ambient intelligece] system are a variety of tiny devices that can hear, see, or feel an end-user's presence. At the back-end, wireless-based networked systems make sense of these data, identifying the end-user and understanding his/her needs.
>
> *Ambient Intelligence: Changing forms of Human-Computer Interaction and their social implications*[13].

Some examples of intelligent classroom projects include the MIT Project Oxygen (E21 Intelligent Spaces) **[http://www.oxygen.lcs.mit.edu/E21.html]** and Intrinsically Motivated Intelligent Rooms

[www.arch.usyd.edu.au/~mary/Pubs/2005pdf/Ubiq_Comptg_Macindoe.pdf]

(Owen Macindoe and Mary Lou Maher, December 2005). This paper describes classrooms that respond and adapt to human occupants and the technologies that can be used to create them.

Tangible interfaces and learning

The use of smart objects and ambient/tangible interfaces in education can have many benefits, including helping kinaesthetic learners. They allow students to learn by doing and remove the barrier of the standard computer interface so that learners can concentrate on the task rather than how to do it. However, although the more physical learning which is possible through smart objects/tangible interfaces can improve performance, there is a risk that if not used well, they will prevent more theoretical understanding of concepts

> *…research has shown that it is important to build in activities that support children in reflecting upon the representational mappings themselves. DeLoache's work suggests that focusing children's attention on symbols as objects may make it harder for them to reason with symbols as representations.*
>
> *Literature Review in Learning with Tangible Technologies,* O'Malley, C, Fraser, D, Futurelab, 2006

Telepresence/robots

Telepresence refers to technologies that allow a user/learner to act remotely as if they were actually at another location. Telepresence technologies are developing in two ways. Firstly, high-definition, life-size video conferencing facilities are now available from a variety of companies (see for example HP's Halo system: **http://www.hp.com/halo/index.html**).

Secondly, a range of technologies allow users to control cameras, robots and other devices equipped with sensors at remote locations. Here, intuitive, immersive interfaces using video, haptics, and/or virtual reality are being developed (see **http://www.chattenassociates.com/** (a head-aimed remote viewer) and **http://telepresence.dmem.strath.ac.uk/technology.htm**).

13 Mahesh S. Raisinghani*, Ally Benoit, Jianchun Ding, Maria Gomez, Kanak Gupta, Victor Gusila, Daniel Power and Oliver Schmedding, *Ambient Intelligence: Changing Forms of Human-Computer Interaction and their Social Implications* Journal of Digital Information, Volume 5 Issue 4 Article No. 271, 2004-08-24 **http://jodi.ecs.soton.ac.uk/Articles/v05/i04/Raisinghani/**

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Source: http://www.hp.com/halo

> …I can envision a future in which robotic devices will become a nearly ubiquitous part of our day-to-day lives. I believe that technologies such as distributed computing, voice and visual recognition, and wireless broadband connectivity will open the door to a new generation of autonomous devices that enable computers to perform tasks in the physical world on our behalf. We may be on the verge of a new era, when the PC will get up off the desktop and allow us to see, hear, touch and manipulate objects in places where we are not physically present.
>
> Bill Gates, *A Robot in Every Home*, Scientific American, January 2007

These sorts of technologies are already being used in scientific and military work and for consultations or surgery carried out remotely.

For education the potential of these technologies is huge. They can allow learners to experience, explore and interact with remote locations, foreign countries and inhospitable/inaccessible or environmentally sensitive places. Some simple, educational projects already exist. For example, the MIT iLab[14] allows students to conduct experiments remotely over the internet. The Bradford robotic telescope allows learners to request images from a professional space telescope located in Tenerife **[http://www.telescope.org/]**. An evaluation of the project found that it was:

> *…a new type of learning website supported by a real world facility which provides real time access to operational data to support learning programmes. The learner has a degree of freedom to define which data they wish to obtain from the facility and to generate information in support of their learning programme. This could be extended to many other areas of the curriculum, by looking at the real world science used across a range of industries.*

An evaluation of the Bradford Robotic Telescope, Smith, P., Hoshin, 2006 **[http://www.telescope.org/articles/YFRobotics.pdf]**.

Information/data handling

The power of the network increases exponentially by the number of computers connected to it. Therefore, every computer added to the network both uses it as a resource while adding resources in a spiral of increasing value and choice.

Bob Metcalfe[15]

The real world network of data will allow humans to be better informed and make better decisions, but it will also mean that machines can make better decisions too. However, the vast amounts of data about people, things and the environment that a ubiquitous computing world would generate will require new ways of handling, searching and presenting information.

Firstly, we will need new applications to take advantage of the range of real-time data being collected. Something similar to this can be seen in business intelligence applications that provide constantly updated sales figures, trends and performance measurements to managers' desktops. In education learners will be able

14 MIT/Microsoft iLabs **http://icampus.mit.edu/ilabs/**

15 Metcalfe's law. Attributed to Robert Metcalfe

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to receive and manipulate real-time data from sensor networks and other distributed devices around the world.

Systems will increasingly be able to respond to data coming from the real world and take appropriate action without human intervention. Increasingly computers will be making decisions on our behalf, only presenting data and information once it has been analysed and filtered to be appropriate to our needs. This is part of a shift towards using computer intelligence ‘on demand’ and being presented with useful information rather than just data.

Secondly, we would need new architectures and data structures (scaleable and adaptable) to cope with the enormous processing and storage requirements of the ubiquitous world. This is likely to involve large scale networks using commodity technology to create massive, resilient information networks with in built redundancy. Currently, the closest example of this is the server farms employed by search companies such as Google. Here commodity servers are used to carry out massive parallel processing of data. However, this is a highly centralised model; increasingly with ubiquitous computing the intelligence is more distributed and moves to the edge of the network. Conceivably, connected devices and objects with embedded processors could become part of a massive distributed computer.

More intelligent ways of managing (data warehousing), searching (data mining), retrieving (knowledge discovery) and presenting data are developing to cope with the vast quantities of digital information stored and available in real time. Displaying information so that it can be interpreted intuitively will be important to making use of the data. New knowledge presentation techniques such as visual representations (and 3D) rather than text and figures are likely to be increasingly important. There is already a shift towards larger and multiple displays to improve productivity.

Machine to machine communication

The ability for machines and systems to interrogate other machines and systems and share information will be key to enabling the ubiquitous computing vision. The development of a semantic web is one suggested solution. The semantic web uses ontologies and schemas to separate data from how it is presented (unlike HTML) and give it a structure that enables information on the web to be retrieved, interpreted and shared by machines/ intelligent agents rather than just humans. **[http://www.w3.org/2001/sw/]**

For an exploration of potential uses of the semantic web in education see **http://www-jime.open.ac.uk/2004/1/**.

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Issues

Some commentators believe that ubiquitous computing is too complex to be achievable and that even if the technology worked, we would not be able to cope with the amount of data produced. There are also many technical issues to overcome such as the reliability and dependability of systems. Other areas needing development include hardware, interfaces, system architectures, standards for interoperability and battery life.

There are also genuine concerns about invasion of privacy, trust and the security of systems. Already, some RFID schemes have been halted in schools **[http://networks.silicon.com/lans/0,39024663,39127946,00.htm]** and the commercial sector because of public concerns **[http://www.theregister.co.uk/2004/03/01/german_revolt_against_rfid/]**. RFID enabled passports have been shown to be insecure **[http://www.fidis.net/press-events/press-releases/budapest-declaration/]**.

Ubiquitous computing is more invasive and persistent than for example, the internet. It would often work without any explicit user action and generate a great deal of information about a user's location and actions. It has been suggested that we may need to move to a new idea of 'privacy'. This would involve acceptance that a great deal of information is collected about us, but concentrate on maintaining control of who has access to that information and for what purposes it can be used.

Even now, people can be tracked through their mobile phones, credit/loyalty cards, and CCTV, but the convenience and benefits of these technologies are often seen as outweighing the concerns. This may not always be the case and policies and protections need to be put in place, especially when dealing with information about learners.

The problem, while often couched in terms of privacy, is really one of control. If the computational system is invisible as well as extensive, it becomes hard to know what is controlling what, what is connected to what, where information is flowing, how it is being used, what is broken (vs what is working correctly, but not helpfully), and what are the consequences of any given action (including simply walking into a room).

> Weiser, M., Gold, R., Brown, J.S., *The origins of ubiquitous computing research at PARC in the late 1980s* **[http://www.research.ibm.com/journal/sj/384/weiser.html]**.

Finally, there are questions over the social impact and desirability of such pervasive technologies. Potentially ubiquitous computing technologies could, among other benefits, help tackle the digital divide, address issues of an ageing population and encourage life-long learning. However, many benefits may be more trivial or marginal and need to be set against the financial and privacy costs of developing such an infrastructure. We need to separate the desirable from the possible.

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Conclusion

The original vision of ubiquitous computing, with an extensive real world web of networked objects and devices may take at least 10-15 years to come close to being realised. Indeed, it is unclear whether we will ever reach a situation where widespread intelligent, embedded technologies operate seamlessly in the environment around us. However, even if this vision is never achieved, processing, identity, connectivity and sensing are already being added to an increasing number of objects, locations and devices. These are beginning to allow new interactions and ways of interfacing with computer systems, as well as adding new intelligence to systems. These technologies are likely to develop rapidly over the next five years and will see a number of elements of ubiquitous computing being actively and usefully adopted. Moreover, many of the possible uses of these technologies cannot be imagined today. Over time these developments will increasingly enable more immediate, personalised, experiential and context-based learning where natural interactions take place between people, systems, places and objects.

Mobile learning[16] takes computers out of the classroom into the world; with ubiquitous computing the world becomes the classroom and the computer.

Mobile phone as interface to the world

Connected mobile devices could provide a gateway between us and the virtual and physical worlds.

Today, handheld devices (and in particular the increasingly smart mobile phone) offer us a pervasive, trusted and reliable interface that is always with us. A recent report from the ITU [ITU Internet report 2006:Digital Life, **http://www.itu.int/osg/spu/publications/digitalife/**] found that one in three of the world's population (much more in developed countries) now have mobile phones and within two years that is expected to increase to over 50 per cent. Mobile phones are adding more powerful processors and applications, content creation tools, a range of wireless technologies, GPS, cameras, sensors and RFID chips and readers that enable always-on connectivity, internet access, social networking and the possibility of interacting with objects and devices in the real world. The social aspects of the mobile phone already make it a natural and personal part of our lives, arguably unlike the PC. This is especially true for students. The permanent 'info-cloud' formed by wireless, mobile devices and the internet and the fact that these technologies are unobtrusively becoming part of our lives, helps create what Wade Roush calls 'continuous computing' [**http://www.continuousblog.net/2005/05/what_is_continu.html**]. This can only be achieved with always-on connections and unlimited data tariffs to encourage widespread use.

16 for an exploration of the benefits of mobile learning see Geoff Stead's article in *Emerging technologies for learning* (Becta, 2006)

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British Educational Communications and Technology Agency (Becta)

Millburn Hill Road, Science Park,
Coventry CV4 7JJ

Tel: 024 7641 6994
Fax: 024 7641 1418

Research email: research@becta.org.uk
Main email: becta@becta.org.uk
URL: www.becta.org.uk

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