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Pervasive Technologies and Support for Independent Living

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Abstract

A broad range of pervasive technologies are used in many domains, including healthcare: however, there appears to be little work examining the role of such technologies in the home, or the different wants and needs of elderly users. Additionally, there exist ethical issues surrounding the use of highly personal healthcare-related data, and interface issues centred on the novelty of the technologies and the disabilities experienced by the users.

This report examines these areas, before considering the ways in which they might come together to help support independent-living users with disabilities which may be age-related.

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1 Motivation

This following scenario shows the use of some of the devices and systems described in this report.

The Scenario

Gerald is an elderly gentleman, who since his wife passed away has lived alone in their house. He's approaching his late seventies, and his health is good for a man of his age. Nonetheless, he is on various medications, and his short-term memory is not what it used to be. He is increasingly frail, and his daughter worries that he may have a fall.

Since his wife's death, Gerald's daughter has guided him through the process of selecting various computer systems to be installed about the house. A significant one of these, which is very broad in nature, concerns organisational matters. Gerald is able to set up all manner of reminders to himself, from watering plants and paying bills to calling his daughter daily. He never forgets this last item, but knowing that he will be reminded each night puts his mind at ease.

He sets up these reminders through an interface on his television, which lets him select from pre-made categories or 'type' in personalised reminders using an on-screen keyboard. He can also place reminders through the home telephone system, in which case the keypad allows him to specify the time, date and frequency of the reminder, and he speaks the words to be played back to him at a later date. Gerald, like many users of this system, prefers to use the TV, but other users favour the phone.

Gerald can choose what form the reminders take. The system can phone his telephone, display text on his television screen, or print a slip of paper for him. The latter two options can be accompanied by the sound of a bell ringing. Again, Gerald prefers to be reminded via his television.

For some of the reminders, the system notices if Gerald doesn't take action: although it can't detect him going to the Post Office to collect his pension, it can sense whether he does or does not pick up the phone and dial his daughter's phone number. It is possible for the system to be set up to contact external people if an action doesn't occur ("Your father has not called his cousin to wish him a happy birthday, although he was reminded half an hour ago. He usually responds to reminders within ten minutes, and he is not in bed or the bath. Perhaps you should get in touch."): Gerald has chosen to opt out of this choice.

Another system helps Gerald handle his groceries. As well as informing him when his foodstuffs are approaching their use by dates, it detects the removal of food items from the cupboards and fridges, and each week – on Gerald's chosen day for weekly shopping, a Tuesday – it provides an editable lists of these used items, as a provisional shopping list. This appears on the television. Gerald can remove items, or edit the number desired, and add new items. Once he is happy with the list, he can choose to have the groceries delivered, or have a copy printed for him to take to the shop himself. Again, this interaction takes place using the television.

The systems in place in Gerald's home are not just associated with day-to-day life. His bed is fitted with discrete weight monitors, which report any major changes to his doctor. Similarly, Gerald's watch incorporates a blood pressure monitor, which communicates information to his doctor when his blood pressure moves beyond a particular range: Gerald doesn't always wear his watch, but tends to put it on when he leaves the house. This is sufficient to grant a regular reading, potentially allowing doctors to act before a serious decline in Gerald's health. Gerald's medicines are delivered weekly, with the packaging communicating with his household system to remind him when it should be taken. If he does not take the medicine within a certain timeframe, the system re-reminds him, and eventually contacts his daughter. Gerald was unsure about this set-up at first, but has decided it is for the best.

The systems in Gerald's house aren't all mundane and health-related or organisational: Gerald takes pleasure in a colourful orb whose shade represents his house's current energy usage, and a picture frame which rotates, half-hourly, the most recent pictures of his loved ones. He can read emails on his television (and view picture attachments), or have his phone dictate them to him. He can dictate replies via the same system.

The interfaces in all of the above systems account for Gerald's age, using large text or clearly spoken words to communicate. Gerald has the power to switch these systems off at any time, although it has been agreed that they will notify his daughter if he does so.

2 Introduction

This literature review concerns the confluence of various technological areas of research, in addition to several broader topics. In total, six areas are touched upon, which are represented in the following figure:

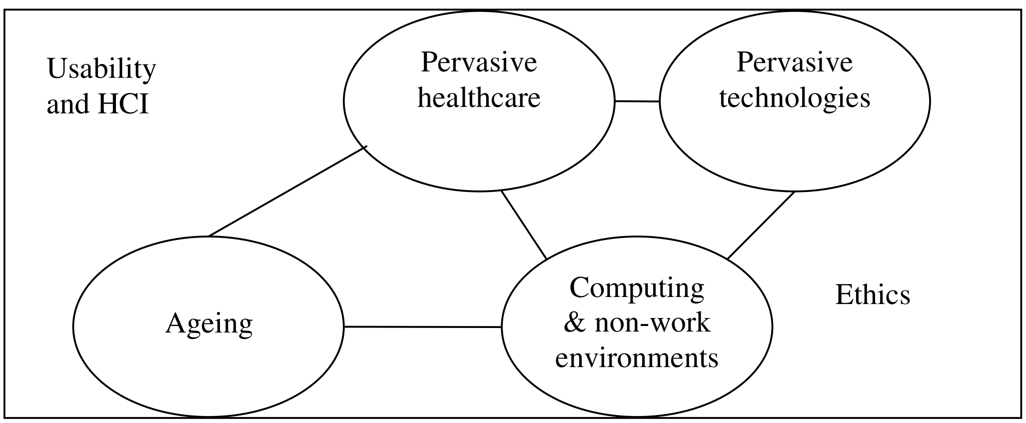

Figure 1: The six research areas considered

Of the circled four areas, the focus is upon the trio on the right, with close links between pervasive technologies, pervasive technologies in the healthcare domain, and computing in non-work (domestic and care) environments. Research on ageing provides input into work on pervasive healthcare and computing in non-work environments. Underlying all of the above are the research areas of usability and HCI, and ethics.

This document proceeds by describing each of the six areas noted above, beginning with pervasive technologies and moving into pervasive healthcare, followed by a look at the medical aspects of ageing, and computing and non-work environments.

Interaction and usability are considered next, followed by the ethical and moral aspects of all of this work. Next, this document summarises the above areas, describes relevant researchers and projects, and considers support for independent living, including challenges in this area. Finally, conclusions and thoughts on future work are presented.

3 Research areas

This section outlines the six research areas relevant to this literature review.

3.1 Pervasive technologies

The term 'pervasive computing' appears to have connotations with actual computing systems (e.g. Varshney (2003), Lorincz (2004) and Stanford (2002)), while 'ubiquitous computing' seems to have been associated with Weiser's vision of 'calm computing' (Weiser, 1989) (Brown, 1999). That said, the current literature (and therefore this document) largely uses the terms 'pervasive' and 'ubiquitous' interchangeably. For example, Ark and Selker (1999), in their introduction to the 1999 IBM Systems Journal, explicitly state "The terms *pervasive computing* and *ubiquitous computing* are used interchangeably throughout this issue." Similarly, Korhonen and Bardram (2004), in their introduction to the section on pervasive healthcare in the IEEE Transactions on Information Technology in Biomedicine, refer to "pervasive computing—or ubiquitous computing, proactive computing, ambient intelligence."

Pervasive or ubiquitous computing involves the availability of many effectively invisible computers throughout the physical environment (Weiser, 1989): that is, the technologies are so transparent to use that we do not notice them. Weiser suggests this invisibility as analogous to text: we do not explicitly notice or struggle with text in newspapers, books, adverts and on food wrappings, but simply read it if we so desire. Weiser describes pervasive technologies as being the opposite of Virtual Reality technologies, which work to simulate an alternative world: in comparison, pervasive technologies invisibly enhance the existing environment.

Weiser (1993) suggests traditional computers are in the way of work to be done, not due to their interfaces, but because they demand the focus of those using them.

Weiser suggests that pervasive systems can be used by those in shared situations, regardless of their technological skills: people can simply pick up a notebook-sized computer, which is not associated with one specific person but is analogous to (and as easy to use as) scrap paper, and use it, whether in a shared context or not.

The aim of this is to produce 'calm' computing, where the technology is not the focus of people's attention, and where the people using it control the technology, rather than being driven by it (Brown, 1999).

There are, of course, ethical issues associated with this kind of wirelessly-networked, ubiquitous technology (Stone, 2003), not least surrounding privacy. This is discussed in section 3.6.

Some researchers have investigated methods to support small screens. For example, Brewster (2002) suggests the use of sonically-enhanced buttons to augment the information provided visually, increasing their usability and allowing their size to be reduced. Tests in the usability laboratory found that this worked very well, although testing in more realistic situations (whilst walking outside) found the improvements were not quite so strong. Nonetheless, the addition of sound decreased the workload for users, and participants found it less annoying than having no sound. The effect on bystanders was not looked into.

Ark and Selker (1999) in their introduction to an IBM Systems Journal focused on pervasive computing, note that there are a hugely broad range of areas for pervasive computing research. These include, but are not limited to education, communications, infrastructures, input devices and healthcare.

3.2 Pervasive healthcare

Pervasive healthcare has been defined as 'the application of pervasive computing technologies for healthcare, health and wellness management' and 'as making healthcare available everywhere, anytime, pervasively' (Korhonen, 2004). Pervasive healthcare technologies integrate healthcare into everyday life, at home and elsewhere. Pervasive tools can help manage illness or wellness through underlying infrastructures, communications systems and tools such as RFID and wearable devices. Widespread usage of the latter requires, as well as good interfaces (suitable for use by young children, the able-bodied and the elderly) user acceptance and affordability.

Wheelchairs, walking sticks and remote controls can all be augmented, as can monitoring equipment and patient records systems. Challenges include the need for real world testing, because patients and care-providers are not, as a rule, early adopters (Korhonen, 2004). Not all challenges are technical: for example, Korhonen and Bardram (2004) note a political issue, which is the need for de facto communications standards. Another issue is dependability, which becomes very important in some circumstances, for example when a system is dispensing or regulating medicine (Cheverst, 2003).

The Royal Society (2006) noted the potential of technology to transform healthcare delivery, and also the necessity of accounting for user needs. Its report suggests that patient-led approaches are the way forward, but that the NHS – with its unfortunate track record adapting to new technologies such as PCs and mobile phones – may face organisational difficulties in bringing about change, due to resistance and scepticism. The report notes the advantages in a preventative approach to illness, and of providing patient-focused healthcare and treatment as close to patients' homes as possible. The management of chronic diseases, such as diabetes, could be a good place to begin with this work.

Pervasive computing can be used for tracking patients or materials (such as medicines) and monitoring and testing at home. The report also notes that we should be wary of unanticipated results: for example, home-based monitoring could cause an upsurge in queries for reassurance, rather than reducing such demands.

3.2.1. Existing devices and systems

There already exist many applications in this domain. For example, Geer (2006) describes the technology involved in robotically-enhanced surgery, and various wearable devices. Motes are described: these are very small devices, usually composed of a processor, memory, low-power radio, antenna and power supply. A project, CodeBlue, is currently looking at use of motes for medical applications such as real-time triage and large-population studies.

Other applications described by Geer include the Pluto mote, which is similar to a wristwatch. This device measures heart rate and respiration, and can help study limb movement in cases of stroke. Such information helps clinicians predict tremor episodes and adjust medication dosages as needed.

There is also the 'Vital Dust' mote, which measures heart rate and blood oxygen saturation. Other research, looking at kidney failure in children, uses Bluetooth-enabled scales and blood pressure cuffs. These allow nurses to manage fluid levels and monitor many more children at once. Finally, diabetic monitoring has been examined, using IBM's Personal Care Connect technology. This technology uses Johnson and Johnson's Lifescan glucose meter, and sends graphs of the device's readings to doctors.

Other applications include a system to ask unobtrusive questions of its users at random times, to predict declines in health (Intille, 2002); packaged medicine which alerts relevant people when it is not taken at an expected time (Floerkemeier, 2003); a medicine cabinet which can monitor conditions, provide medication reminders, interact with healthcare staff, and access health information (Wan, 1999); and systems to pass relevant information to paramedics at an emergency scene (Varshney, 2003). On a similar note, Lorincz et al (2004) propose a protocol and framework for integrating devices into disaster-response scenarios.

Such technologies have been put into active use in the assisted living complex run by Elite Care (Stanford, 2002): here, residents reportedly have 'as much autonomy and responsibility for themselves and their environment as possible'. Sensors help staff identify residents who may need immediate care – for example, when a resident wanders off disoriented, or is wakeful in the night – helping to concentrate efforts where they are needed. This is achieved via the use of locator badges: dual-channel infrared RF tags, which act as apartment keys and can be detected when within 90 feet of an IR sensor. Embedded weight sensors in the beds help detect tossing and turning, and frequent bathroom trips. In-apartment touchscreen computers allow communications with family and friends. Personalised databases allow monitoring of long-term trends, avoidance of extensive manual record keeping, and communication with families and physicians about any changes in their elderly relations.

3.3 Ageing

The UK population in 2004 was 59.9 million, with a median age of 38.6 years (Royal Society, 2006). It has been broadly predicted that the population will reach 65 million by 2021, with a median age of around 41 or 42 years. The proportion of the population aged over 65 years is expected to have risen from 16% to around 18%, leading to increased demands on the healthcare system. Of course, not all elderly people require medical care, but the proportion of the elderly population requiring such attention is higher than that in the working-age UK population.

A widely acknowledged psychological change that comes with age is the decline in cognitive processes, especially memory (Mather, 2005). However, not all types of cognitive process decline with age: for example semantic memory (memory of meanings and understandings) typically increases or remains steady. As such, recall of words studied a few minutes previously has been shown to decline over a four-year period, but implicit memory of recently studied words does not show a decline with age.

Shock (1951) carried out a great deal of work looking at ageing. He notes that hearing, vision and motor responses are all affected by ageing: loss of hearing is greater in males, and the loss tends to affect the higher tones more. Presbyopia (farsightedness) tends to occur with ageing, and the elderly require a greater minimum level of light. Motor responses are slower, due to changes at various levels of the nervous system; a very gradual decline begins between 40 and 50 years of age. That said, there is a large range within this: the performance of the fastest third of the eldest group in a study equalled the average performance of the young group. Reaction times also slow, with a positive correlation between the length of reaction time and age of participant, which was significant even between the ages of 17 and 36.

Shock also noted that average scores on intelligence tests diminish with increasing age: vocabulary type scores are good, but those involving numerical computation, series completion, picture arrangement and so forth all featured a significant decline. The most difficult areas were those where subjects had to break away from old mental habits and adapt to unfamiliar situations. Shock notes, however, that the elderly have slower responses and more knowledge and experience, all of which biases the results of such tests.

Shock also notes that there are wide differences in the decrement of performance with age. The relationship between performance level and age decrement is greatest in those with lower performance ability; in the upper 5% of the population he found the decrement to be minimal or absent.

The elderly cannot be simply classified as one group: they are hugely diverse, particularly given the extensive and varied life histories and experiences which define them. Nonetheless, certain physiological changes, described above, tend to be found in us all as we age. These must be considered when designing computer systems for the elderly.

3.3.1. Uptake of technology by the elderly

An issue in this arena is the uptake of technologies by the elderly. Namazi et al (2003) noted a range of obstacles to this uptake, which vary widely. Categories of obstacle are:

- physical and cognitive
- personal
- technological
- organisational
- environmental

An issue to be resolved is that of identifying and mitigating such obstacles. It is important to ensure that the elderly are not pressured to take on new systems in which they have no interest.

There exist several theories used in Information Systems research that could be relevant. The first is the Technology Acceptance Model (Davis, 1989), in which perceived usefulness and ease of use determine an individual's intention to use a system. The second is the Unified Theory of Acceptance and Use of Technology (Venkatesh, 2003), in which usage intention and behaviour is influenced by user expectations of performance and effort, as well as social influence and facilitating conditions. This model is the unification of eight prior models, including the Technology Acceptance Model. Such models may be useful during the course of this research, especially as the technology in question is not being used in standard, workplace environments.

3.4 Computing and non-work environments

It has been noted that both domestic and care environments are very different settings to the workplace (Cheverst, 2003). Care must be taken when working in these new areas to avoid blindly following the assumptions and methodologies associated with workplace-based research: personal routines and environments are involved, and research looking at such matters can be seen as inappropriate and intrusive. That said, in some respects carrying out research can be easier in these environments. For example, buy-in is generally gained from all participants, not just the owners of a particular facility, who require their employees to cooperate.

Other aspects of domestic and care environments are emotional. Work environments are generally regarded as just that: professional places where work gets done. However, these other environments have very different uses, some of which are ‘worklike’ (the administration of balancing household accounts, for example, and paying bills and cleaning), others of which are completely different (such as family meals, parties, television watching, game playing, and so on). In these environments, the primary aim is living, not productivity (Cheverst, 2001).

One piece of research looking at ‘living’ and not ‘productivity’ is by Howard et al (2004), who investigated the support of intimacy between family members. They note the ambiguity of intimate communications, which convey emotions and feelings, and are very private. Electronic ‘gifting’ is described: this is the giving and receiving of messages of love and appreciation. Ideas which emerge from their work include codes shared between couples and shared living diaries.

Care must be taken, when working in non-work environments, to work out exactly what is being investigated, and how. Cheverst et al (2003) carried out research under the EPSRC IRC Network project Equator, in a hostel for former psychiatric patients. Their approach combined several techniques, including ethnographic study, user-centred design and evaluation, and cultural probes (Gaver, 1999). These methods helped Cheverst et al to build two systems at this particular hostel: one helped provide medication reminders, whilst the second allowed patients to send an alert when in danger or distress (Cheverst, 2001). The cultural probes, described in section 3.5, help overcome some of the 'professional distance' between researchers and users. Whilst designing a system to support inhabitants taking responsibility for their daily medication, various ethical aspects arose, which are discussed in section 3.6.

The majority of existing work on integrating technology with everyday life focuses on the office environment (Rodden, 2004). The home is a very different environment to that of the office, with a focus away from 'tasks' and 'procedures' and more towards 'routines'.

3.4.1. Computing and the domestic environment

Smart Homes

Various 'smart home' projects have been pursued in recent years. One such project is the Aware Home (Kidd, 1999), which consisted of two identical living spaces. Aims included investigation of context awareness and ubiquitous sensing, and individual interactions with the house.

Another project is the Millennium Home (Dowdall, 2001), aimed at elderly users who are not cognitively or physically impaired, but are at risk of becoming ill or injured through the course of home life. Perry et al (2004) note that only 10% of older people live in supported accommodation and that characteristics of the elderly population tend to include a fear of crime, forgetfulness, and hearing and motor limitations.

Dowdall and Perry (2001) note that the elderly are frail and very prone to accidents in the home; they often lie injured and undiscovered should one happen. The Millennium Home project involves use of unobtrusive sensors, which attempt to detect a situation where a resident's well-being is threatened – if this arises, the system will communicate with the resident to resolve the situation, or contact an external party for assistance.

Interaction with the Millennium Home system is mostly speech-based. The system has various alarm states with different priorities (for example, detection of a possible burglar or a fall is more urgent than a wrong temperature or failed sensor). The system accounts for the time of day, resident activity and location and urgency of the situation, then selects a mode of communication. The time allowed between attempts to establish communications, and the number of attempts made before contacting external assistance is defined on an individual basis.

Perry et al (2004) discuss the design process of the Millennium Home. The system notes appliance and environmental activity, as well as visual and speech-audio data. Systems such as these must have a fast, low effort way to cancel false alarms, but also to elicit a fast response in a real emergency. The system needs to select the correct mode of communication – for example, the mode may differ if the resident is in the bathroom, as opposed to if they are in bed or cooking.

Consistency is important in this kind of a system, as different interaction methods can be confusing. User preferences are likely to be broad, due to differing backgrounds. The resident can interact with the system by acting on their environment, speaking, or using a particular input device. Devices include infrared movement sensors, pressure sensors under chairs and beds, windows and door sensors, medication alerts and temperature sensors.

Communication can take place through a telephone, loudspeakers, or a TV or monitor system. The resident can input information through a telephone (an audio menu or key-press menu), screen (TV or monitor, using a remote control), their environment (open or close a door or window, stand up) or voice recognition.

Factors considered during design included: what default medium to use for initiation; how to indicate dialogue completion; timing of dialogue; priorities for dialogues; and urgency management. Contextual issues included ensuring interaction is appropriate to the location and activity, and coping with multiple users.

Factors to consider in such systems are:

1. appropriate modality
2. location
3. user control
4. multiple interactions and dependencies between them
5. consistency
6. modal switching

Other work has considered technical, social and pragmatic challenges involved in providing such technologies in the domestic environment (Edwards, 2001). Edwards and Grinter list seven such challenges:

1. 'Accidentally' smart homes: issues may arise when technology is brought piecemeal into homes which were not built smart. For example, neighbours may install speakers which inadvertently take the noise from your stereo, or someone may unexpectedly use your wireless connection and see your files.
2. Impromptu interoperability: the difficulty of having different technologies simply work, without planning or implementation. This concerns the need for standard protocols (e.g. currently, installation of a printer onto a PDA requires that the PDA knows specifics about that printer).
3. No sysadmin: smart homes do not come with support staff. Residents must be able to cope with technical difficulties.
4. Designing for domestic use: users adopt technology in unpredictable ways.
5. Social implications: these can be unpredictable. For example, social implications of mobile phones include teaching children about money, and increasing safety.
6. Reliability.
7. Inference in the presence of ambiguity. For example, the home needs to differentiate between a person standing in a certain place, and that person leaving their smart badge there.

Home Routines and Design

Technology today is often intertwined with routines – for example, Crabtree and Rodden (2004) often encountered situations where a household member would watch a specific program on the television (or listen on the radio) before leaving for work, or carrying out some other daily activity.

Crabtree and Rodden examined 22 family homes, and comment that the process of carrying out research in the home is little different than carrying out such studies in the workplace: the logistics involved and issues such as the Hawthorne effect (Mayo, 1933) are similar. They found that there are many information resources in the home involved with producing and consuming communications. One example which they study in depth is the handling of mail: for example, who picks it up, where it is placed, who opens it, and so on. They define three types of location with regard to this: the 'ecological habitat' (where communications media are stored); 'activity centres' (where media are produced and consumed); and 'coordinate displays' (where media are displayed).

A similar piece of work by Hughes et al (1998) considers a series of studies of domestic environments, and the design challenges they raise. The information was gathered over the course of six-month long ethnographic studies at various homes in the UK. It was noted that the placement of technology within the home reflected the daily routines of inhabitants. For example, the majority of households had mobile or portable TVs and stereos, allowing the distribution of their functionality at will. Participants were often wary of new technologies, citing high running costs, a lack of time to use them, or envisioning their children over-using them: disruption was also seen as a dissuading factor.

Spaces are designed to support particular activities, usually multiple activities. A room may perform as a study, playroom, guest room or games room, depending on its configuration. It was noted that aesthetics are important in all of this. Hughes et al conclude that binding a technology to a space can limit what use can be made of the space; a commitment which should not be undertaken lightly.

Rodden and Benford (2003) have considered the form of buildings, and the implications of this for pervasive technologies. They note that one can understand the domestic setting through ethnographic studies, longitudinal studies and design based methods. Devices can take the form of information appliances (stand-alone interactive devices with specific functionality), interactive household objects (where interaction is incorporated into the object's form – for example, picture frames as displays), or augmented furniture. The first of these three forms is the most intrusive.

Rodden and Benford draw upon Stewart Brand's (1994) model of buildings, which views them as being composed of six areas:

- Site: geographical setting and legally-defined boundaries
- Structure: the foundations and buildings
- Skin: exterior surfaces
- Services: utilities built into the building – wiring and plumbing
- Space plan: the interior layout – positioning of walls, ceilings and doors
- Stuff: furniture and possessions

(Note that Brand's model is American. The equivalent UK model counts site, structure and skin as one item, 'shell', because UK legislation tends to view these three things as one.)

It is noted that research so far has not focused on the site, structure and skin of buildings, instead focusing very much in the areas of stuff, space plan and services. That said, the former three dominate the latter three, influencing their placement and operation.

Existing work involving digital artefacts in the home operates in the stuff and space plan areas, and that involving environments and infrastructure operates in the services area.

People are constantly altering their home environments, and the different 'layers' of a building interact. For example, the placement of a TV makes demands on services (where power and aerial points are). Issues arising include cueing the presence of pervasive systems (which lack physical wires), supporting services, and predicting how inhabitants will engage with the services and their maintainers.

3.4.2. Computing and the care environment

Many of the pervasive healthcare technologies described in section 3.2.1 apply here: for example, 'smart medicines' (Floerkemeier, 2003) could be appropriate and useful in a care environment. However, this section is not about specific devices or systems, but about overall approaches to technologies in the care environment, where ill, disabled and infirm people reside. The term 'care environment' is used to refer to residential buildings where the support provided goes beyond that of warden-run retirement homes: for example, care homes and hospices.

Newell and Gregor (2004) discuss specialist and mainstream design for older and disabled people. They note some differences found in older users – for example, an elderly user is more likely to have one or more disabilities, as well as different wants and needs to an able-bodied user. Those with disabilities are only a fraction of the population of people with reduced functionality: everyone has times when they are temporarily disabled by accidents, alcohol, stress, fatigue or their environment.

There is a difference between traditional user-centred design for able-bodied users, and that for a user group including those with disabilities. Traditional methods are not always appropriate. Newell and Gregor have proposed 'user-sensitive inclusive design', where older and disabled users are included as informants on research and development teams. They also note that narrative methods – that is, story-telling metaphors – could help, as could attention to the aesthetics of design.

Gaining understanding of user requirements in care settings can pose methodological challenges (Cheverst, 2003). It is necessary that designers know not only what they are designing and what it should do, but also who will use it. Designing for people just like the designers themselves may exclude a host of people, including the disabled and those in care.

Dewsbury (2001) has considered the social and psychological aspects of smart home technology specifically within the care sector. Technology influences how people act in their environment, and people are often wary of technology in the home: Dewsbury notes the importance of looking beyond technology in the care setting. Assistive technology does not replace personal care, and those with disabilities need more than just technology to meet their needs. He also notes the use of technology as an aid for disabilities – glasses to improve sight, cars to improve mobility, and so on. Dewsbury recommends that, in this area, one takes a long-term view of the inhabitant's condition; consider emotional aspects; and consider all stakeholders.

The cost of smart home technology in the care sector is difficult to estimate: several years of usage are needed to establish the real cost. Similarly, the acceptability of such technology requires investigation: the needs and desires of patients and carers must be met.

3.5 Usability and Human-Computer Interaction

The suitability of a computer system's interface is always important: even the most useful and efficient system is worthless if people cannot use it correctly. Having an appropriate interface becomes still more important when dealing with a pervasive system, due to the novel nature of that interface: for example, is there a standard, textbook interface for a medical temperature-monitoring system? It has been noted that interaction with smart homes can be difficult (Dowdall, 2001). Similarly, the appropriateness of a system's interface is particularly important when the people who will use it are not able-bodied – for example, the elderly, small children, or those with health problems (Newell, 2004).

Gould and Lewis (1985) describe three principles of system design which allow production of a useful and easy to use computer system. These are:

1) early and continual focus on users.
2) empirical measurement of usage.
3) iterative design whereby the system (simulated, prototype, and real) is modified, tested, modified again, tested again, etc.

Although these principles are straightforward, Gould and Lewis' evidence suggests that they are not always intuitive to designers: 447 designers were asked to list five major steps in developing and evaluating a new system. Only 16% mentioned all three items, and 26% mentioned none.

Awareness of the end-users of a system is essential. A method to help build this awareness, cultural probes, have already been mentioned in this document. These were designed by Gaver et al (1999): they are packages sent out to research participants containing maps, postcards, cameras and booklets. Postcards would have very open-ended questions, such as 'what is your favourite device?' or 'what place does art have in your life?' Cameras had similarly open requests for photographs. The packs were designed to be informal and friendly, and to elicit the participants' attitudes to life, cultural environments and technology.

The researchers found that the probes reduced the distance caused by their professional status (as well-funded experts), as well as reducing geographic, cultural and linguistic distances. They gained invaluable knowledge about the elders of the communities to whom they sent the packs, comparable in volume to that gained from other methods.

Hughes et al (2000) consider design patterns as a means of presenting ethnographic materials and sharing knowledge about application domains and design solutions. They suggest a template, which describes, amongst other aspects, the motivation for the pattern and problems solved; context; examples; and positive and negative consequences of the pattern's use. Example patterns include "multiple users need multiple access" (dealing with ownership and sharing of technology), and "design for temporary beauty", involving the aesthetics of domestic technologies. Such patterns may help researchers in this field.

3.6 Ethical and moral aspects

Ethical

Relating to morals or moral questions. Science of morals, moral principles or code.

Moral

Concerned with goodness or badness of character or disposition or with the distinction between right and wrong; virtuous in general conduct; (of rights etc) founded on moral law; capable of moral action.

The Popular Oxford Dictionary

It is important to be aware of the ethical implications of any research. These aspects are particularly relevant when dealing with elderly or vulnerable users, using technology of a potentially invisible nature, and accessing highly sensitive information relating to health or security around the home.

The ethical implications of pervasive technologies, especially, attract attention, due to fears over issues such as the stealing or unscrupulous use of data. Stone (2003) discusses some issues. One example used is the EZ Pass, which tracks cars and allows the users to automatically pay highway tolls, speeding up traffic: yet use of such a pass allows the tracking of cars as they pass through toll gates. Wearable tracking devices for children are discussed: if a child is kidnapped or lost, these devices would be extremely useful. As Stone points out, however, it is unlikely that a teenager about to go out on a date would hold such a viewpoint. Others are yet more concerned at these technologies, with a Professor of applied ethics saying "We are building an infrastructure for totalitarian control."

Another Professor suggests a future where we could embed devices which could, for example, increase our elasticity, letting us jump higher: he says this will threaten our sense of what it means to be human. He is not asked his opinion on existing augmentations, such as glasses, pacemakers and false teeth.

Stone also wonders whose responsibility it is to consider the ethical implications of pervasive systems – the engineers who build them, or the people who commission them.

3.6.1. Ethics in the healthcare domain

A major issue when providing assistance via technology is correctly empowering users and supporting independent living, rather than simply creating a dependence on the technology (Cheverst, 2001) (Cheverst, 2003). Awareness of the individual care needs and social implications of the technology is deeply important, as is awareness that technology cannot simply perform tasks for patients – at least, not without creating that dependence. Facilitating the daily living routine and skills of ex psychiatric patients in a hostel (Cheverst, 2001) is a prime example of this issue: it was necessary to build a system which would reassure patients (who worried about forgetting medication), but leave the task of managing medication in their own hands, rather than doing it for them. The intrusiveness of the technology is another issue to consider in this context (Dowdall, 2001), especially in situations where the users have a lack of computer experience.

Another question concerns the increased efficiency which can be brought about by these technologies. For example, the 'Vital Dust' mote described in section 3.2 (Geer, 2006) allows nurses to monitor many more children at once than otherwise – yet perhaps the children in question benefit from time spent in the presence of these nurses. The broader context of such situations should be considered.

Gostin (1997) notes uses of medical data: primary use is when the data is used to help the patient. Secondary uses include education (conferences, teaching), regulation (litigation, accreditation), commerce (biotechnologies, marketing), social services/child protection (tracking records of abuse), and public health services (report on disease mortality). The detail on US medical records is sufficient to compile a detailed profile of each individual: records hold demographic and financial information, details on disabilities, diagnoses, treatments, histories, social aspects (e.g. sexual orientation, family status), and so on. As such, this data is highly important.

Ting (1999) notes that the issue of confidentiality is growing in prominence as use of computing and communication technologies spread. (These concerns are not new; Weiser (1989) noted nearly two decades ago that one rogue device could record everything in a room.) Various legislation, such as privacy and freedom of information acts, has been introduced, although it has been said that US legal safeguards on privacy are inadequate, fragmented and inconsistent (Gostin, 1997). Ting also notes that the trust between a patient and physician is an important part of the medical profession, and that similarly, the confidentiality of medical records is highly important. There are fears associated with the security of computerised medical record systems.

Gostin (1997) claims that there exist good reasons for collecting and using health care data (for example, assessing quality and cost-effectiveness of services; detecting fraud and abuse; medical research), but at a cost of lost personal privacy.

Introna and Pouloudi (1999) note the need to disclose information for the benefit of some people, and to safeguard the privacy of other people by not doing so. They describe this tension as being between privacy and transparency. They note that privacy is hard to define, with no universally accepted definition existing. Definitions range from 'the right to be left alone' (Brandeis, 1890) to 'control over knowledge about oneself' (Fried, 1968).

Rindfleisch (1997) discusses Electronic Patient Records (EPRs). These allow timely access to information, simultaneous access by medical staff, and help keep information current and accurate. Yet these records can contain some of the most sensitive information about us – for example, information concerning fertility, abortions, emotional problems, psychiatric care, STDs and substance abuse. This information can affect jobs, insurance and bring people face to face with prejudices.

Rindfleisch suggests that the biggest threats to the confidentiality of EPRs are:

- Accidental disclosures (innocent mistakes, overheard conversations, etc.)
- Curiosity by staff (who may look up friends, family and celebrities)
- Subordination by staff (who may release information for revenge or profit)
- Uncontrolled secondary usage (usages which do not support primary care: for example, data mining by pharmaceuticals)
- Unauthorised access (ex-employees, angry patients, malicious hackers)

Protection against this can include deterrents (alerts, reminders and education regarding ethical behaviour), obstacles (controlling the ability of users to access information) and system management precautions (ensuring known vulnerabilities in systems are eliminated). Audit trails are also effective, and the use of pseudonyms may help maintain patient anonymity.

Database records in the healthcare domain have been discussed (Introna, 1999). Such records can be reinterpreted in different contexts in inappropriate ways: for example, the HIV positive status of an individual is relevant to a potential sexual partner, but not to the owner of a taxi company to whom the individual is applying for work. Another issue associated with these data is that of ownership: is the owner of the data the doctors who typed it in, the NHS, the database administrator, or the patients from whom it originated? Who is liable if the system fails and the data is lost or stolen?

Rindfleisch (1997) describes security and privacy of health care information as a "people problem". Technology can help ensure that the right people access the right information, but it cannot ensure that those people handle the information appropriately: that is the area for ethics, supervision and sanctions.

4 The intersection of these areas

The relationships between each of these six areas may now be considered. These research areas together provide a solid starting point for research towards support for independent living. This phrase, support for independent living, refers to the provision of support to people who live in domestic (not care) environments, but are perhaps frail or suffering from various illnesses or disabilities. As such, they are in a somewhat vulnerable state, where a relatively probable event (such as a fall, or consistently forgetting to take medicines) may require the provision of external help or a move to a care environment. Support for these people helps them to continue with their current arrangements, by helping them to avoid accidents which may exacerbate their condition and to live more healthily – both in terms of keeping to medication regimes and handling day-to-day events such as shopping and socialising. It is possible that such support may also be relevant to those in care environments, helping residents to take on some simpler responsibilities from their caregivers.

This section outlines the research areas at a glance, before going on to examine people and projects in these areas, and discuss support for independent living.

4.1 The research areas, at a glance

Pervasive technologies represent the application of pervasive technologies in the healthcare domain. Pervasive technologies may also be implemented in non-work environments. Ethical issues focus around privacy and security, whilst the novelty of these interfaces mean that usability issues should be focused upon.

Pervasive healthcare technologies are relevant in the care and domestic environments (healthcare, monitoring, reminders). As ageing has health implications, these technologies should consider elderly users. Ethical issues become especially important, as sensitive information is held about vulnerable people. Interfaces should account for the potential frailty and disabilities of users.

When considering **computing and non-work environments**, the different needs and desires of any elderly or disabled users should be considered. Designs must account for all users, not just an able-bodied majority.

Ageing: again, vulnerability should be accounted for, and should the different (and very broad) profiles of elderly users. **Ethics** and **usability and HCI** are covered in the above comments.

There exist commonly-found research aspects through the material presented. One such theme is the need to consider privacy and security, especially of vulnerable users; another is the need for a user focus in interface design.

Some of the literature discusses supporting independent living in the elderly and frail, and bringing this about ethically, with suitable interfaces and user-focused design. The work covered suggests that a holistic approach which accounts for non-technology aspects (such as the comfort and social interaction of users) is important.

4.2 People and projects

This section outlines the researchers and research projects which may be worth investigating in the future.

One project which has provided a useful background against which to continue this work is the Equator IRC. Now completed, the project brought about a great deal of work which looked at the meshing of physical with digital interaction; highly relevant when considering pervasive technologies integrated into the home and care environments. Work related to Equator includes that of Cheverst et al (2001) (2003) and Rodden (2004).

Tom Rodden, now based at the University of Nottingham, was the Director of the Equator project. His research interests include the development of technologies to support user groups: he has worked in HCI, ubiquitous computing and CSCW (Computer Supported Collaborative Work).

Meanwhile, a group of people at the University of Dundee (including Alan Newell and Peter Gregor (2004)) explored design of home environments for the elderly, taking a participatory approach with real older people.

Another group of interest are the Interact Lab, of the University of Sussex. Their research themes include ubiquitous domestic environments, and growing old (e.g. assisted living environments and supporting care)[1].

One other group which may prove relevant is MIT Media Lab's Things That Think group. They look into "bridging digital, physical and human needs for creative expression and design", the design of enjoyable interactions, facilitating creativity, and taking control of individual health[2]. Their research includes a project on wearable computing.

4.3 Support for independent living: summary

The systems and devices described in this document can be summarised as:

- wearable devices and motes which convey biometric information elsewhere (Geer, 2006)
- a wearable device which asks regular questions to help determine the health of its wearer (Intille, 2002)

[1] http://www.informatics.sussex.ac.uk/research/groups/interact/research.htm
[2] http://ttt.media.mit.edu/vision/vision.html

- packaged medicine which knows when it should be used (Floerkemeier, 2003)
- a medicine cabinet which monitors biometric information, issues reminders about medication, communicates with care givers and allows access to healthcare information (Wan, 1999)
- A system to pass information to paramedics at an emergency scene (Varshney, 2003)
- A care system which uses sensors, locator badges, communications systems and databases (Stanford, 2002)
- A smart home which uses sensors to detect untoward events (Dowdall, 2001)
- A system to remind users of when to take medication (Cheverst, 2001)
- A system to allow users to indicate distress (Cheverst, 2001)

This functionality can be summarised as:

- eliciting and conveying contextual (e.g. location-based) information to appropriate places
- eliciting and conveying biometric information to appropriate places
- detecting or allowing the signalling of untoward events and distress
- reminders
- communications
- provision of healthcare information

This functionality appears in different (domestic and care) environments, and as such may be used differently according to its location. The environments include the family home, the flat, the warden-controlled flat, and the care home.

It is possible to map the functionality type against the usage environment, thus:

	Family home	*Flat*	*Warden-controlled flat*	*Care home*	*Hospital*	*Out and about*
Elicit and convey contextual information	Questions	Millennium Home Questions	Questions	Elite Care Questions		
Elicit and convey biometric information	Medicine cabinet	Medicine cabinet Millennium Home	Medicine cabinet	Elite Care	Motes Surgery	Emergencies
Detect or allow signalling of distress		Millennium Home		Elite Care		Signal
Reminder	Medicine cabinet Smart medicine	Medicine cabinet Smart medicine	Medication support Medicine cabinet Smart medicine			
Communication				Elite Care		
Provision of healthcare information	Medicine cabinet	Medicine cabinet	Medicine cabinet			

Table 1: The occurrence of pervasive healthcare functionality in various contexts

See over for a key.

Each phrase in Table 1 refers to a previously described piece of research:

Elite Care: this care home uses sensors to help monitor resident wellbeing (Stanford, 2002). Biometric information can trigger distress signals, and the technologies used facilitate communications.
Emergencies: A system to convey vital information to paramedics at emergency scenes (Varshney, 2003).
Medication support: a system designed to support ex psychiatric patients in taking their medication (Cheverst, 2003).
Medicine cabinet: a cabinet to monitor conditions, provide medication reminders, interact with healthcare staff and allow users to access healthcare information (Wan, 1999).
Millennium Home: smart home where sensors monitor for untoward events (Dowdall, 2001). It contacts an external person when required, and thus is relevant to signalling distress and communications.
Motes: these help monitoring biometrics systems (Geer, 2006).
Questions: System asking questions to predict health declines (Intille, 2002).
Signal: A system to allow users to signal distress and coordinates using a GPS receiver and SMS (Cheverst, 2001).
Smart medicine: medication which reminds patients when to take it (Floerkemeier, 2003).
Surgery: surgeons may pre-define safe boundaries for surgery (Geer, 2006).

As can be seen in the table, there exist many gaps. There exists very little technology for:

- use outside of residential environments.
- the explicit signalling of distress (the Millennium Home and Elite Care can detect distress, but only the Signal system allows users themselves to indicate this). Traditional pendants used to signal distress are often rejected by elderly users, perhaps being the reason for the lack of further technologies here.
- communications: only the Elite Care system provides communications functionality, whereby the systems facilitate communications between staff

and adult children of residents. These communications are not directly relevant to the residents themselves.

- provision of healthcare information.

By contrast, a high proportion of work supports the eliciting of information (be that biometric or contextual) and also reminders. Presumably this is due to the high rewards from gaining such information, and perhaps the simplicity of reminder systems.

There also exist requirements which drive the design of pervasive healthcare systems, both in terms of technology and approach. They include:

- good interfaces (for the young, the able-bodied and the elderly)
- real world testing
- de facto standards
- dependability (especially in the region of healthcare)
- accounting for user needs
- preventative approach to illness
- healthcare and treatment as close to patients' homes as possible

4.4 Support for independent living: challenges

Making it possible to help the elderly and ill to live at home is a worthwhile cause: the home environment is far more comfortable than a hospital environment. However, various problems have come to light.

Resistance to change and wariness of technology

The elderly are generally more resistant to change than younger members of society, and as such are more cautious about adopting new technologies (Gill, 1985). The elderly can often by intimidated by computer systems (Namazi, 2003): Namazi et al note that computers are not designed for operation by frail individuals and elderly persons with physical or mild cognitive impairments. As such, will the elderly want to use systems to aid independent living on their part? How tolerant will they be of problems in such systems? After all, it is not uncommon for the elderly to be uninterested in wearing pendants which can be used to signal an emergency (perhaps because they are frightened of breaking them during a fall, or because they will forget to wear them, or simply because they do not like the idea (Perry, 2004)), so why would we expect them to accept other technologies to support them?

Use of existing technologies which with the elderly are familiar (for example, televisions and phones) can provide a possible way forwards. It is also important that systems are unintimidating, with a minimal learning curve: Weiser (1989) wrote about being able to pick up a computer and use it, as you would a piece of paper. Additionally, use of technology acceptance models such as those described in section 3.3.1 could help predict the outcomes when new users are presented with technologies.

Emotional impact and perceptions

It is also important to consider the emotional impact of any technologies introduced in the care (or home) settings. Technologies which increase the independence of an elderly home-owner, for example, may also increase their isolation – because suddenly, their niece (or son, or any relative who has assumed responsibility for checking they are well) no longer needs to keep close tabs on them. As such, a long-term, holistic view (which accounts for all stakeholders, including patients and carers) can help anticipate such scenarios. Another area requiring a careful approach is that of empowering patients: avoiding an increase in their dependence on technology can be difficult when tackling this task.

Additionally, the existing literature appears not to examine people's perceptions of the systems with which they interact. Systems and devices have been tested for functionality and usability, but not acceptability or impact. How will the father of a family using a blood pressure monitor each morning change in his interactions within that family? What if he uses it four times a day? How is the family dinner affected when a system is monitoring the location of the youngest child? How does the sister of this child feel about what is happening, and how does the mother perceive or understand the system as working?

Studies outside the workplace

There seem to be very few studies looking into people's interactions and use of technology outside the workplace. In general, they appear to be avoided, and seen as inappropriate and intrusive, despite Cheverst et al's (2003) successful use of ethnographic study, user-centred design, and cultural probes to elicit useful information in these environments. It would appear that such studies need not be inappropriate or intrusive: indeed, in some respects they can be easier than workplace-based studies (for example, as a rule the entire household agrees to take part, in contrast to a workplace study where individual employees are not generally consulted beforehand). The environments are certainly very different, with a non-work focus on living, not productivity. Given that this is an area where technology can be used to bring about fulfilment and joy in the elders of our community (and not just drag out a waning life as hospital machinery might), perhaps it is worth considering what further investigations might be of use.

Intrusiveness of monitoring technology

The question of intrusiveness is highly relevant: for example, measuring someone's weight via their bed can be a highly sensitive thing to do. Who chooses for this to be done? Can it be done in a tasteful manner? Gerald, from the opening scenario, must agree to the systems in his house tracking him and potentially contacting his daughter. Would he want to? What would his feelings be? What support (technological, administrative and emotional) exists for the carers and family of these people?

Data management

Other issues involve the storage, ownership and security of data produced by such sensors: how should it be stored, for how long, and who owns it? The management of this very intimate data is highly important.

Smart home technologies

Overall, it is necessary to find out what sort of smart home and wearable technologies people will accept. There exist various issues surrounding smart homes, which are outlined in section 3.4.1.

5 Conclusions and Future Work

In the next twelve months, my intent is to look into the use of pervasive technologies to improve the quality of life of people living alone, with various disabilities which may be age-related. There exist many possible research directions within this area. One path involves the use of biometric information to improve health: however, as demonstrated in the earlier sections of this report, particularly section 4.3, a great deal of research has been done in this area. Of greater interest to the author is the use of communications technologies, not in the sense of alerts, reminders and alarms (which, again, are well-supported), but in terms of managing relationships between people. As noted in section 4.3, there exists very little work in this area. One challenge is reducing the isolation often felt by elderly members of the community; another is the use of technologies to improve a sense of community, especially amongst older, more isolated people.

Elderly people in blocks of flats may feel isolated, especially if they have no families, or families who live far away. Technology to link these people, allow them to safely get to know one another, and facilitate their meeting up in person has the potential to be very useful. The work carried out by Stanford (2002) has shown that pervasive technologies can facilitate the use of communications on a small scale (e.g. between staff members and adult children of elderly residents in a care home), but there appear to be no works looking at communications of this nature at the scale of the community. Similarly, the use of contextual and healthcare information in this social fashion (that is, neighbours sharing knowledge and opinions) could yield great gains.

Pursuing such a goal will necessitate overcoming some of the challenges discussed in section 4.4. Primary among these is the resistance to change and wariness of technology often experienced by older members of the community; additionally, the emotional impact and perceptions associated with these systems will be paramount, as the systems themselves concern people's relationships and emotions. It is possible that the research will require the undertaking of one or more studies, in which case the difficulties associated with carrying out studies outside the workplace may apply. Issues around intrusiveness, data management and perhaps practicalities concerning smart home technologies may also arise.

The goals can also be examined with respect to the functionality found in the existing devices and systems: the use of communications technologies will be central to any such research. Contextual information is highly likely to be relevant to future work, as is detecting or signalling untoward events and distress. It is difficult to foresee the way in which healthcare aspects will be involved in the future work: however, it is common for community members to look after one another, and so it seems likely that the use of biometric and healthcare information will come into play.

An important part of any research carried out will be ensuring that the technologies developed will foster independence and empowerment, not dependence and isolation: as has been noted, this can be difficult as, for example, increased independence can lead to increased isolation.

There exist yet more decisions to be made on the next stages of work. These include whether to:

- focus on interfaces and usability, or the technology and infrastructures under the covers
- examine the role of technology in these areas
- evaluate current technologies and people's experiences with them
- talk to real people
- use existing information, or create fresh information
- build a solution which is specific to a certain domain, or which is more general, with technological commonality allowing many end uses

This report has examined a broad set of research areas – pervasive technologies, pervasive healthcare, ageing, computing and non-work environments, usability and HCI, and ethical and moral aspects – and the links between them. Some of these areas are very closely linked indeed, although there exist gaps such as the dearth of studies into people's acceptance of pervasive and healthcare technologies, and the overall impact of these technologies on interactions in the home and care environments.

As described, there remain many decisions about where to take this research. One final thought to bear in mind over the course of this research is noted by Cheverst et al (2003), who state that successful interactive domestic technologies aren't radical revolutions, but just routinely get used at home. The user is as important, if not more so, than the technology.

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Appendix A: Taught Courses and Other Activities

A requirement of the Engineering Doctorate is that 120 credits of modules are taken over the course of the first two years. These consist of technical, MBA and generic modules. In this case, it was decided to front-load the modules, and complete the majority of these during the first year. The following table lists the modules taken, and results. At the time of writing, 17.5 credits remain to be taken.

Course code	*Course Title*	*Grade*	*Credits*	*Type*
EDUC6286	Inclusive Learning Environments	55	20	Technical
INFO3004	eLearning and Learning Technologies	73	10	Technical
ENTR6005	Creating Entrepreneurial Ventures	70	15	MBA
MANG6049	Problem Structuring	72	7.5	MBA
MANG6091	Business Ethics	83	7.5	MBA
MANG6126	Change Management	60	7.5	MBA
	Generic Skills Course	Pass	10	Generic
	EngD Conference	Pass	5	Generic
	British Sign Language Level 1	Pass	20	Generic + Technical
Total credits:			102.5	

The above courses reflect the broad approach taken in the first year. There was an early interest in learning (EDUC6286 and INFO3004: these provided valuable insight into inclusiveness and educational technologies respectively). The sign language course was most helpful in gaining an insight into Deaf culture, as well as the language. The MBA modules provided an interesting set of information in this area, whilst the generic courses helped broaden the author's transferable skills.

In addition to taking the above courses and carrying out the work leading up to and including this report, the writer spent a little over one quarter of the first year of her degree working at IBM Hursley. This was spread over the twelve months, usually taking up one to two days each week. Finally, the author carried out demonstrator work, attended the SET for Britain 2007 event at the House of Commons and was a finalist for the Anita Borg Scholarship, 2007.