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The design of personal mobile technologies for lifelong learning

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Abstract

This paper sets out a framework for the design of a new genre of educational technology — personal (handheld or wearable) computer systems that support learning from any location throughout a lifetime. We set out a theory of lifelong learning mediated by technology and indicate how it can provide requirements for the software, hardware, communications and interface design of a handheld learning resource, or HandLeR. The paper concludes with a description and formative evaluation of a demonstrator system for children aged 7–11. © 2000 Elsevier Science Ltd. All rights reserved.

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1. Lifelong Learning

Since 1970, an approach to education has been articulated that neither embraces nor challenges institutional education, but is complementary to it. The approach, of lifelong learning, has gained currency through attempts to harness it as a means of providing people with the knowledge and skills they need to succeed in a rapidly-changing world. Thus, the UK Government's Green Paper on lifelong learning, *The Learning Age* (Secretary of State for Education and Employment, 1998) states:

In future, learners need not be tied to particular locations. They will be able to study at

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home, at work, or in a local library or shopping centre, as well as in colleges and universities. People will be able to study at a distance using broadcast media and on-line access. Our aim should be to help people to learn wherever they choose and support them in assessing how they are doing and where they want to go next.

The basic premise of lifelong learning is that it is not feasible to equip learners at school, college or university with all the knowledge and skills they need to prosper throughout their lifetimes. Therefore, people will need continually to enhance their knowledge and skills, in order to address immediate problems and to participate in a process of continuous vocational and professional development. The new educational imperative is to empower people to manage their own learning in a variety of contexts throughout their lifetimes (Bentley, 1998).

There is no accepted definition of lifelong learning and the term has been interpreted in *The Learning Age* as the training of a workforce capable of adapting to a rapidly-changing world. This paper takes a broader and more humanistic view of lifelong learning, as an extended and holistic process of developing skills and understanding. The abilities, approaches and tools for learning that a person gains from childhood onwards provide a context and resource for learning and performing in later life.

The learning addressed in this paper is fundamentally situated. It occurs whenever there is a break in the flow of routine daily performance and the learner reflects on the current situation, resolves to address a problem, to share an idea, or to gain an understanding. It happens serendipitously in the workplace (for example, when a problem cannot be solved in some routine way), at home (such as when a conversation leads to a train of reflection or discussion), and at play (in learning a new game or sport).

Lifelong learning is primarily collaborative rather than competitive (though it may involve short-term competition and rivalry). Individuals belong to multiple communities that encourage learning and provide resources, including sports clubs, religious and ethnic groups, workplaces, trade and professional organisations, and nations. A survey by Tough in 1979 showed that the typical person undertakes eight personal learning projects (lasting seven days or more) in a year, with only 0.7% of these projects being for formal credit (Tough, 1979).

There has been widespread discussion on the need to widen access to learning resources, particularly the Worldwide Web, from public places such as libraries. Far less consideration has been given to providing learners with technology to help them learn when and wherever they choose and to support their personal learning throughout their lifetime.

2. Tools for lifelong learning

The aim of the project described in this paper is to equip people with personal tools, such as memory aids, concept and topic maps, case archives and communication devices that are:

- *highly portable*, so that they can be available wherever the user needs to learn;
- *individual*, adapting to the learner's abilities, knowledge and learning styles and designed to support personal learning, rather than general office work;
- *unobtrusive*, so that the learner can capture situations and retrieve knowledge without the technology obtruding on the situation;

- *available* anywhere, to enable communication with teachers, experts and peers;
- *adaptable* to the learner's evolving skills and knowledge;
- *persistent*, to manage learning throughout their lifetime, so that the learner's personal accumulation of resources and knowledge will be immediately accessible despite changes in technology;
- *useful*, suited to everyday needs for communication, reference, work and learning;
- *intuitive* to use by people with no previous experience of the technology.

Some of these requirements can be satisfied by traditional tools and methods of organising learning, such as notebooks, pencils, textbooks, course notes, study guides, timetables, and diaries. New technologies can supplement these by offering learners the opportunity to manage their learning over long periods of time, to engage in worldwide collaboration, and to relate near-unlimited information to situated problems.

3. The convergence of lifelong learning and personal technology

The development of a personal computer for learners began in the early 1970s with the Dynabook project from the Learning Research Group at the Xerox Palo Alto Research Center (Kay & Goldberg, 1977). The technology needed to realise the Dynabook vision (such as large LCD screens) was foreseen but not available in the 1970s, nor was there an obvious educational imperative to build such devices. Recently, however, educational thinking and technological development have converged, so that they now form the preconditions needed for producing a new type of handheld learning environment (see Table 1).

As learning has become more individualised and learner-centred, so too have the new digital technologies become increasingly personalised. Just as learning is now regarded as a situated and collaborative activity, occurring wherever people have problems to solve or knowledge to share, so the major advance of the 1990s has been in mobile networked technology, enabling people to communicate regardless of their location.

Computer technology, like learning, is ubiquitous. Computers are embedded in devices such as fax machines and televisions that perform human-oriented functions (including basic instruction and user guidance) rather than acting as general-purpose computing devices. They

Table 1
The match of new communications and information technology to lifelong learning

Lifelong learning	New technology
Individualised	Personal
Learner centred	User centred
Situated	Mobile
Collaborative	Networked
Ubiquitous	Ubiquitous
Lifelong	Durable

are also becoming more durable, in that although the hardware may last only for two or three years, the basic software packages evolve through successive versions, with a large measure of backward compatibility. There is now the opportunity for people to preserve and organise their personal information in digital form over a lifetime[1].

One consequence of the recent convergence of new theories of education with new personal technologies is that it offers the possibility of constructing personal mobile technology for lifelong learning. This paper sets out a framework for the design of such technologies. It proposes some generic design guidelines, suggests an agenda of work to design a range of personal technologies to support lifelong learning and concludes with a description of a project involving the University of Birmingham, Kodak and BT to develop a HandLeR, a handheld learning resource.

4. A theory of technology-mediated lifelong learning

This section sets out a general theory of personal learning mediated by technology, based partly on social constructivist theories of learning with technology (see for example, Brown & Campione, 1996) and on Conversation Theory (Pask, 1976). It should be supplemented by a more detailed analysis of the cognitive, social and cultural aspects of learning (see Jarvis, Holford & Griffin, 1998 for an overview).

Personal learning starts with a learner in a social, cultural and technological environment. The act of learning involves the artful deployment of the environment, including its tools and resources, to solve problems and acquire new knowledge. Learning is a constructive process of acting within an environment and reflecting upon it. Action includes solving problems, engaging in dialogues of enquiry, and acquiring new knowledge. Reflection involves the learner in abstracting from a situated activity, to integrate the current experience with previous knowledge and to construct new interpretations (see Fig. 1).

Pedagogy requires a teacher to assist in the learning. Successful teaching generally involves a two-way conversation. The teacher adjusts to the learner's needs and ability and engages the learner in a conversation, to diagnose problems and misunderstandings. There is also an implicit communication through mutual interaction with the tools that mediate learning such as workbooks, reference materials, and lab equipment.

As they perform a learning task, both learner and teacher reflect on their activities. Reflective learning includes dialogue at the levels of action and reflection. Conversation between learner and teacher alternates between particular examples and activities and general principles. The reflective dialogues are also mediated by the environment, in this case, the tools and resources that support reflective learning such as textbooks, dictionaries, logbooks, diaries and concept maps.

[1] There is no guarantee that these standards will last a lifetime. However, it is likely that software will be available to transfer the data to new standards, without loss of information or format and at increasingly higher levels of organisation. Thus, ASCII has provided a standard for interchange of characters from the early 1960s, PostScript provided a page description standard in the early 1980s, and Portable Document Format (PDF) has enabled hypermedia documents to be interchanged since the early 1990s. Each of these standards has embraced the former.

There is a further level of reflection and synthesis that is mostly unvoiced, but is coming to be recognised, in higher education and continuing professional education at least, as promoting active and skilful learning. This is the level of 'learning to learn', reflecting on one's activities as a learner, questioning previously-held knowledge and beliefs and developing a more strategic approach to study (Brockbank & McGill, 1998). The resources that mediate this level of learning are techniques, such as brainstorming, and meta-languages with which to talk with oneself or a teacher about styles and strategies of learning, creativity, problem solving, and the organising of knowledge. They provide a mutual 'conceptual framework', a combination of notation and conceptual structure that enables the sharing of generalised knowledge and experience.

Normally, a learner is not alone with a teacher, but is working along with other learners, all carrying out a multiplicity of conversations with themselves, with the teacher and with other learners (Fig. 1). These conversations are more than exchanges of information; they create a continuing process of conceptual development (as the learner re-interprets situated activities as general principles (Karmiloff-Smith, 1992)), mutual adjustment, and social change (through communities of co-learners). As well as calling on resources to solve immediate problems, a learner needs the means to manage this conceptual and social change: to organise the accumulation of knowledge and experience; to remember, and sometimes to forget past events and understandings; to argue and debate; and to engage in dialogues with the past, interpreting previous events in the light of new experience and creating a coherent personal history.

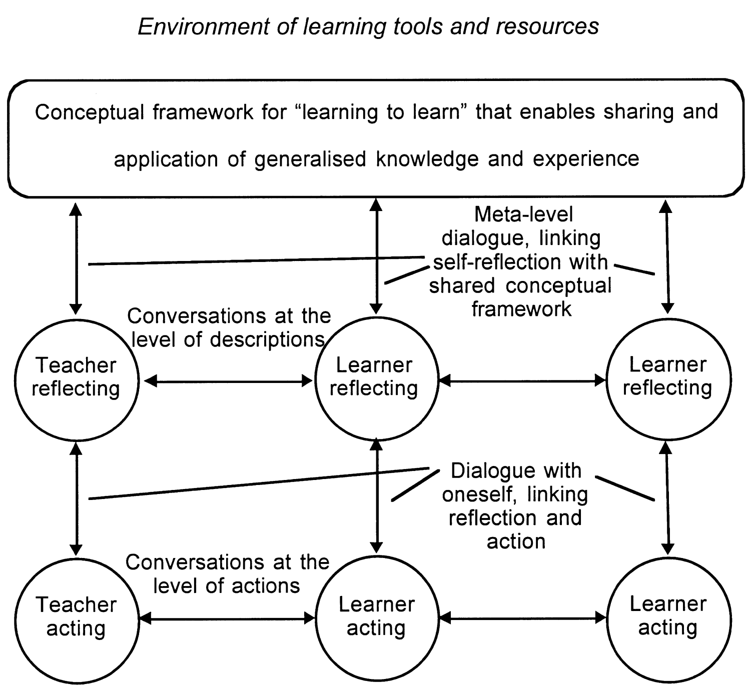

Fig. 1. A conversational framework for personal learning.

5. Personal technologies for lifelong learning

How does computer technology fit into this conversational framework? We can explore this by substituting computer systems for the actors in the dialogues (see Fig. 2).

5.1. Computer-based teacher and tutor

One role for computer is to be a substitute for the teacher. This is the goal of computer-aided instruction. However, to be a successful replacement, it must be able to carry out the kinds of teacher dialogue shown in Fig. 2, conversing with the learner about the task, relating it to general principles, conducting a meta-level dialogue with the learner about general conceptions and misunderstandings, and relating these to a shared framework of terms and concepts. A few Intelligent Tutoring Systems, such as SOPHIE (Brown, Burton & Bell, 1975), have been able to carry out such responsive teaching, but they have been designed for very limited domains and are the products of many years of research and development.

5.2. Computer-based assistant and mentor

If the computer acts as a learner's assistant rather than a teacher, then the problem is more tractable. Such enabling technologies include simulations and modelling tools as well as more interventionist guides and mentors. The development of pedagogical software agents is a

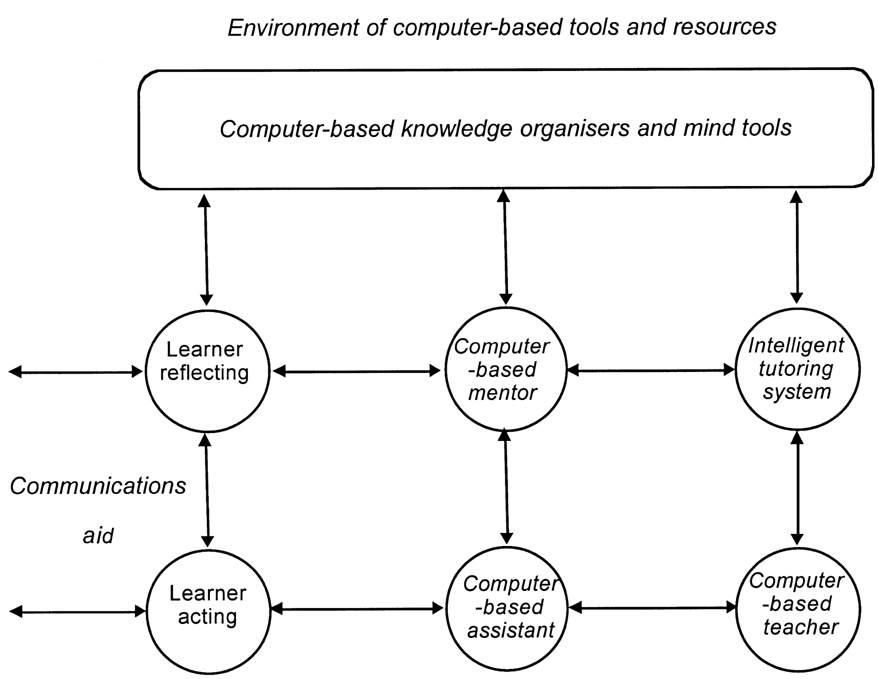

Fig. 2. Possible interactions between learners and learning technologies.

promising area of research and commercial development. Examples range from the Microsoft 'Wizards' to prototype 'mentor agents' such as Steve (Rickel & Johnson, 1997).

Pedagogical agents for lifelong learning might be embedded in everyday devices such as cameras, offering advice not just on how to operate the equipment, but also guidance on how to use it effectively or creatively (an agent embedded in a digital camera might suggest how a photograph could be improved, either by using a particular photograph as an example, or by referring to theories of composition or technical principles such as depth of field). The camera or other device acts as a tool to perform a task and also as a medium of instruction. Another type of lifelong learning agent is one that assists with managing, learning, for example helping a learner to generate and organise ideas, to study effectively, or to carry out more efficient Web searches.

5.3. Computer-based tools and resources

A third place for technology within the framework of Fig. 2 is to provide tools for learning to learn and organise knowledge within a coherent and sharable conceptual framework. These include dictionaries and bibliographies, topic and concept maps, learning organisers, timelines and schedulers, planners and project management systems. For lifelong learning, the aim is to develop software that can organise information accumulated over many years. Methods such as information filters and graphic visualisations (Sharples, du Boulay, Jeffery, Teather & Teather, 1996) could be used to display the detail of individual ideas and events within the context of broader schemas and episodes.

5.4. Communications aid

Technology can also mediate communication. Instead of viewing conversation between learners as a transmission of messages through a passive medium, it can be reconceptualised as the sharing of knowledge and language within an environment that actively supports and participates in the dialogue (Pask, 1975). For example, a Web site can present material differently depending on the abilities or previous activities of the user. An internet link can alter its bandwidth to match the user's demands, allocating a video channel for establishing a relationship between a learner and a distant teacher and a narrower bandwidth for more task specific communication. An active communications system can offer predictive communication based on patterns of learning. For example, it could automatically download homework material from a school database to the learner's personal system at the end of a school day, or search for other users who are performing similar tasks and who might engage the learner in conversation.

5.5. Computer-based learning environment

Lastly, technology can form part of the environment that mediates learning, for example, by providing simulated labs, virtual worlds that mirror real locations, and online classrooms and colleges. These not only place the learning resources in a familiar context but also provide social environments for engaging with teachers and other learners.

6. The design of a HandLeR

The learning theory presented above identifies a central purpose for personal technology — to support mathemagenic (conducive to learning) conversations between learners and teachers at the levels of action, reflection and learning to learn. Many possible designs for technologies could fit within this broad framework. This section describes the approach that we have taken to the design of a handheld learning resource.

The different roles for technology to support lifelong learning are not mutually exclusive. A personal learning system could act simultaneously as tutor, guide, assistant, communication aid and learning environment. A key issue is to combine these functions in a way that supports rather than hinders learning, and that presents a consistent and helpful system image. A device that oscillates between being a teacher, a guide, a colleague, a communicator and a virtual classroom would overwhelm the learner. Even when the functions are separated into different applications they can still confuse, as, for example, with the plethora of active tools and assistants in commercial office software.

We have given our HandLeR the role of a 'mentor'. A mentor system can act as a companion to a young learner (a partner in games, for example); it can suggest ways of studying and set up systems for organising resources and remembering ideas and events; it can provide long-term guidance on developing skills, particularly where the mentor could have direct access to the technology needed for performing the skill (such as the Worldwide Web, or a digital camera); it can act as a learning assistant in performing tasks or solving problems, by suggesting new strategies and solutions; for professional development it can store and abstract information from cases (such as medical images) and support experiential learning. A computer-based mentor need not reside in a single piece of hardware; it might migrate across different physical devices, but retaining its persona and knowledge of the learner.

7. Software organisation

To support the lifelong conversational learning outlined above, a personal mobile learning system requires the means to store, organise and retrieve cases, events, knowledge structures

Table 2
Possible organisation of software for a HandLeR

Software for	Interfaces and interactions	Mentors to assist with
Meta-learning	Tools for thinking, e.g. concept maps, timelines, notes networks.	Learning to learn. Organising learning.
Reflection	Collaborative learning and knowledge organising tools, e.g. synchronous and asynchronous communication, search engines, tools for knowledge sharing.	Idea generation and creativity. Communication and knowledge sharing.
Teaching and problem solving	Virtual learning environments. Problem solving tools. Simulated equipment. Informal capture and organisation of sounds, images and sketches.	Using tools, solving problems, teaching, information storage, organisation and retrieval.

and processes worldwide over long periods of time. Table 2 shows the general organisation of the software. It is structured at three levels, to support active learning, reflection and meta-learning. Associated with each level are a collection of learning tools, a generic interface, and a set of activities for the mentor to perform. The software for active learning may alter depending on the task and context, the software for reflection will remain fixed across tasks but will need to adapt to the needs and abilities of the learner, and the software for meta-learning is designed to provide a consistent set of tools to manage learning over long periods of time.

8. Hardware

Rather than adapting hardware designed for the mobile office, we are considering how new hardware designs might afford different learning activities. The prime consideration is whether an individual's HandLeR should be a software system, capable of running on a variety of physical devices, or a fixed combination of software and hardware. We have taken the approach that, if it is to last a lifetime, then a HandLeR should be a software environment that can run on different hardware platforms to suit the user's needs and context (in the same way that personal organiser software can run on a desktop machine or a palmtop device).

One advantage of disassociating the learning environment from the hardware is that schools and companies could reduce the problems of unequal access to learning resources by providing each learner with a standard hardware device of a guaranteed specification to support the learning task. For learning outside the classroom or workplace, a user would own one or more personal devices, which they can customise to their needs. Thus, a child might have a smart card that provides that child's personal learning resources and profile, along with (access to) individual or custom software. At home, this card could be used in a family personal computer or games machine. In school, the child would insert the card into a school-owned HandLeR, which would display the child's own learning environment and context of use (for example, inside a classroom it might disable games programs). Some children may also own their personal HandLeRs, to store personal information, capture and share images and sounds, use as a communicator, collaborate with other HandLeR users in creating pictures, animations and music, and play multi-user games.

The design of the hardware for a HandLeR is determined by the general requirements given at the start of this paper. The requirement of high portability indicates that the device will either need to be handheld or wearable, or both. The main difficulty in achieving high portability comes from the battery technology. The battery should be light and capable of quick and easy recharging.

There will need to be a method of interacting directly with high resolution images, which suggests a display that can be laid horizontally on a flat surface, and pen or direct touch input. The system will need to support other basic means of input and interaction, including camera and voice. The requirement for unobtrusiveness need not extend to the entire hardware, but it should be possible to make notes and capture images or video in an informal way without the hardware intruding on the event.

In order to adapt to the needs of an individual learner, it should be possible to add additional modes of interaction and communication, such as the ability to control lab equipment. This suggests a modular and extensible hardware architecture.

To enable it to communicate seamlessly with online resources and other learners, it must be able to match the method of communication to the location, switching from an office or home network, to mobile communications outdoors, and eventually to satellite communication when out of range of cellular transmission.

Fig. 3 shows hardware models for two HandLeRs, a generic device based on an 'electronic book' metaphor and one that is intended as a personal device for children aged 6–12. Both devices provide similar functions but their constructions afford different styles of learning and interaction.

9. Interfaces and interactions

The software organisation shown in Table 2 does not (unlike the 'desktop metaphor') prescribe a particular interface design or mode of interaction. A learner might interact with a mentor by voice, by text, or by cooperating in some mutual activity such as creating a topic map or exploring a virtual environment. Some of the tools and activities indicate a need for direct manipulation of interface objects (such as simulations of equipment), support for drawing and sketching, and easy operation of connected devices such as a camera.

The overriding requirement is for the system to support learning in a variety of contexts over long periods of time. This suggests an interface design that represents or adapts to its context of use, for example, by offering virtual 'learning areas' such as laboratories and classrooms, and simulations of real environments such as art galleries, geological and historical sites. It will also need to provide the means for learners to describe and preserve their reflections on these environments, by means of log books, diaries, planners, and timelines. The interface also needs to enable learning to learn, through ways of organising ideas, memories and personal resources to support long-term learning.

From Table 2, the mentor is the only part of the software that has a permanent presence on

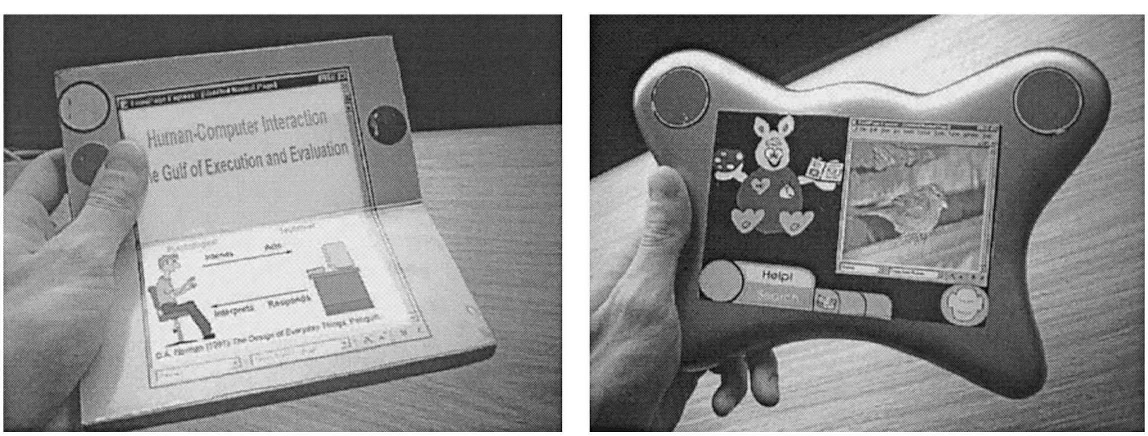

Fig. 3. Hardware mockups of a generic and a children's HandLeR (designed as part of an MEng student project).

the interface and so its design requires particular care. Should the mentor be represented as an animate entity (person, animal, alien) or as a collection of software tools, such as a search engine or study organiser? Should it be presented as the learner's *alter ego*, a co-learner, a simulated teacher, or an avatar of another human teacher or learner? If it changes roles will this lead to confusion? How can the mentor adapt to the learner's cognitive and social development (will it grow with the learner, or should the learner control its appearance and style of interaction)? Should it have multiple instantiations (perhaps depending on the tool in which it is embedded) or a single embodiment and personality?

Other design issues that will need to be addressed include how to:

- develop a 'personal area network' that supports communication between the central processor and capture and display devices such as a buttonhole camera without the need for cumbersome wiring;
- integrate pen, keyboard and speech input in a way allows easy viewing and interaction with the system;
- combine a handheld unit (for viewing and direct manipulation of visual images and text) with wearable peripherals such as a miniature camera, microphone and earpiece (to capture everyday events and for voice communication);
- allow an appropriate mixture of direct manipulation and voice communication, for example, by supporting combined voice and gesture recognition;
- provide secure, efficient and assured storage of multimedia data over long periods of time.

The latter will involve developing methods for secure and unobtrusive backup of information over multiple networks and for compression of data appropriate to the learning task (a stored image may need to be compressed differently depending on whether it is to be kept as a work or art, a personal memento, or a record of an event). Companies may offer services for guaranteed storage and management of personal and learning data (for example, tagging images with metadata to describe their context, or providing topic maps with links to provide information on a given subject).

10. Concept HandLeR

An MEng student group design project has produced an operational proof of concept HandLeR for children aged 7–11. The system was developed using the OVID object-oriented development methodology (Roberts, Berry, Isensee & Mullaly, 1998), with requirements based on a study of the literature on situated and lifelong learning, informant design sessions (Scaife, Rogers, Aldrich & Davies, 1997) with children and their teachers, and a questionnaire administered to children aged 11–12 (112 returns) and 7–12 (107 returns). Among the findings from the questionnaires were that the children would like a 'computer of the future' to (in order of frequency of response) speak, be intelligent and have a personality. A 'man in the machine' was a recurring theme in drawings that the children made of an imagined future computer (Fig. 4).

The concept HandLeR developed by the student group employs an animate mentor as the main interface metaphor and method of interaction. Fig. 5 shows two screen displays from the implemented system. The mentor, shown as a cartoon rabbit, acts as an *alter ego* that could offer assistance with capturing events, solving problems and managing learning (these functions were not implemented in the demonstrator). The mentor also provides icons for the main tools of HandLeR, based on the mentor's body functions and displayed objects. Thus, clicking the mentor's eyes shows an image from the HandLeR's video camera, the palette brings up a set of drawing tools, the book opens the user's topic book, and the heart opens a profile of the user.

The profile might include private details, information that could be shared with other HandLeRs and, possibly, details of learning activities and attainments. Some teachers saw HandLeR as a means of creating attainment profiles, raising issues of ownership of HandLeR and its data, children's investment of trust in the system (particularly given the child's relationship with an animate mentor) and consent for information to be shared. We have taken

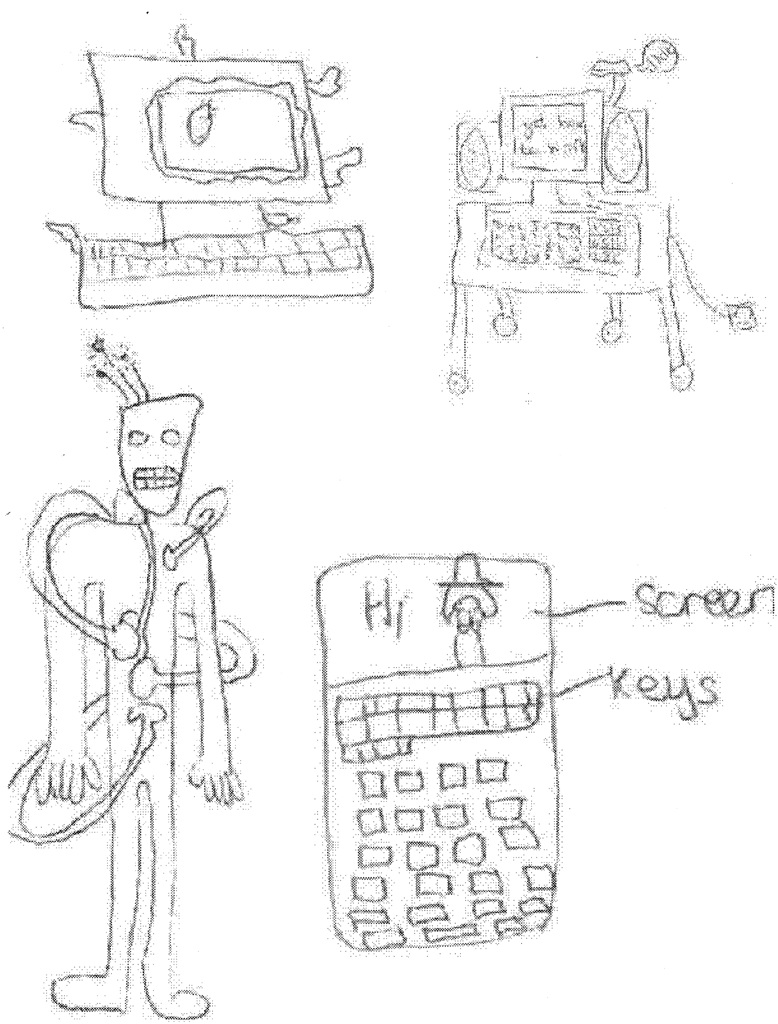

Fig. 4. Drawings by children aged 7–12 of a 'computer of the future'.

the approach that learners should own their personal information and that the profile is a means by which a learner can configure the software and create a sense of ownership of the system.

Basic functions provided by the system include still and video image capture, drawing, and text input through a screen keyboard or handwriting recognition. Data from each of these sources can be tagged by time and location (demonstrated using a GPS position location card). The user can copy and organise the images, drawings and text in the topic book.

Clicking on the mentor's 'brain' opens up a map (shown at the right of Fig. 5) showing linked concept words, named topics created by the user (from the topic book), and items of external information including Web pages and documents. If the topic item is not available on the HandLeR then it automatically initiates a cellular phone connection to a Web server and downloads the Web page identified for that topic. For example, clicking on the 'hurricane' topic item opens the Web page http:\\www.hurricanehunters.com. The aim for future versions of HandLeR is to enable the user to create new nodes in the topic map for drawings, notes or camera images, linked together by title, keywords and time and place of origin.

The user can navigate through the topic map either by clicking on one of the outer ovals, which brings it to the centre and displays the topics related to it, or by clicking 'search' and writing a keyword or phrase that identifies the topic. Much further work is needed to enhance the navigation and search facilities and to provide other views such as a timeline that orders events by time of creation.

The main interface to the demonstrator system also provides a means to connect to other HandLeRs. Clicking on the face at the lower right of the screen opens a list of known contacts and selecting one brings up an image of that other person's mentor. The user can then click on the other mentor's body parts, such as the heart (to show the person's sharable profile). A click on the mouth or ears initiates a direct cellular phone connection with that person's HandLeR.

All the functions described above have been demonstrated on a handheld device consisting of a Fujitsu Stylistic pen-based tablet computer running Windows 95, a Nokia GSM card phone, a PCMCIA card GPS receiver, and a Kodak DVC 323 miniature digital video camera. Fig. 6 shows the system in use (without the camera attached).

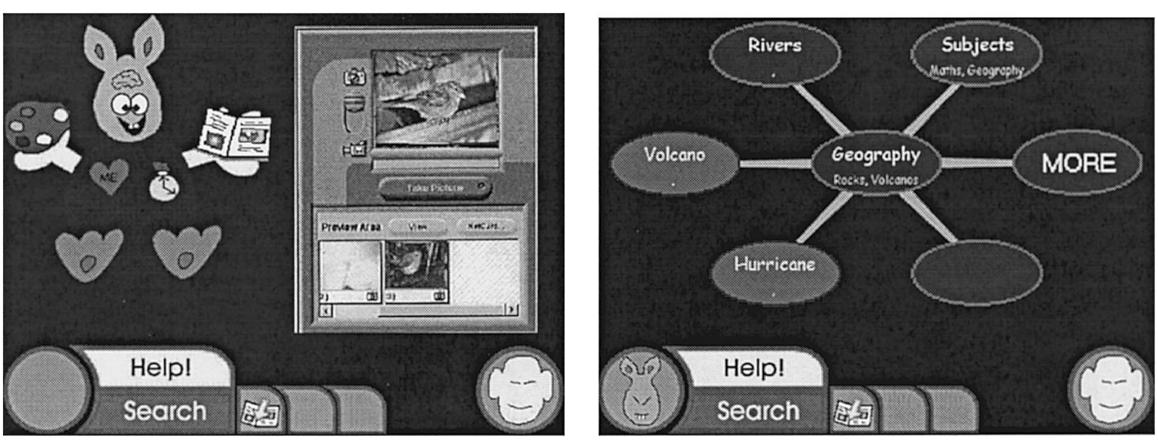

Fig. 5. Two screen displays of a HandLeR for children aged 9–11 (from the undergraduate group design project).

A small formative evaluation of the demonstrator system (using an earlier hardware configuration based on an Acer Travelmate sub-notebook computer) was carried out, consisting of a questionnaire to 29 children aged 10, and scenario-based observations of three children aged 11. These children were also shown a picture of the rabbit mentor and asked to deduce the function of each body part.

In outline, the results of the questionnaire showed that the function of each body part was correctly deduced by over 50% of the respondents, except for the watch (intended to activate a diary) and the feet (to connect to the Web). The three children in the observational study successfully completed an online tutorial on the use of HandLeR, created a topic book with a drawing and camera image, and set up a phone call from the HandLeR to a mobile phone. The children were able to perform all the activities without difficulty.

Issues raised by the evaluation included the need to adapt the interface (including colours

Fig. 6. The concept HandLeR running on a Fujitsu Stylistic tablet computer with a Nokia GSM card phone.

and mentor) to suit the age and taste of each user. The children liked the idea of a mentor but suggested a range of other personalities including animals, robots and aliens. The three children were keen to use the device to take pictures easily and informally, and they indicated the importance of getting hard copies of the topic work and images.

11. Research issues and further work

The concept HandLeR has demonstrated the viability of one configuration of hardware, software and mobile communications. It has also shown how this complex combination of technologies can be managed through an intuitive interface that supports active and reflective learning.

The project has raised many questions and issues for further research, including:

- altering the role and appearance of the mentor for learners of different ages, contexts and abilities;
- how to match the system and interface to the learner's cognitive and social abilities;
- management of a lifetime of learning resources, and the role of companies and institutions in providing services to support personal mobile learning;
- design and standardisation of the interaction between learners, teachers and experts, mediated by a range of personal technologies;
- adaptive communications, to make optimal use of available bandwidth given the location and needs of the learner;
- distribution of learning resources across personal technologies and the integration of personal learning resources with Web-based learning environments;
- design of new hardware to support easy and unobtrusive capture of everyday events;
- support for collaboration between mobile learners (for example, to allow capture and sharing of knowledge about a distributed or long-lasting event).

We are addressing some of these issues through a series of related projects. MEDIATE is a longstanding collaborative project between Birmingham, Sussex and De Montfort Universities and the Institute of Neurology, London, to develop a personal learning and decision support environment for neuroradiologists (Sharples, Jeffery, Teather, Teather & du Boulay, 1997). It has provided insight into the similarities between a HandLeR for basic learning and for professional development (such as the need for tools to support knowledge visualisation and a 'lightweight' approach to tutoring) and the differences (such as the role and appearance of the mentor). We are developing a wearable computing system for paramedics to enable them to retrieve and apply knowledge while dealing with an emergency and to communicate with medical experts. Undergraduate and postgraduate projects are underway to:

- investigate the design of external representations for recall and management of personal learning materials;
- develop personal technology to support children with learning difficulties;
- develop contextually aware mobile devices;

- provide seamless integration between mobile communication systems such as wireless LAN and GSM;
- provide multimedia on demand to mobile learners.

12. Conclusion

Learning is changing. This is true in both senses. Learning is a process of mental and social change over an entire lifetime. Moreover, the organisation of learning is changing, in schools, in the workplace and at home. New technology offers the opportunity for children and adults to communicate with teachers and fellow learners around the world, to interact with rich learning resources and simulated environments, to call on information and knowledge when needed to solve problems and satisfy curiosity, and to create 'personal learning narratives' through an extended process of capturing and organising situated activity. The component technologies for this new learning environment will soon all be in place. This paper has indicated how these components can be combined into powerful devices to support mobile lifelong learning.

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