

Interface design and evaluation of a personal information space for mobile learners

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Abstract: In response to the market penetration of mobile phones, educational institutions will soon focus on delivering information to mobile phones. This paper presents the design and evaluation of a prototype mobile application for lifelong learning. The application is a personal information space for mobile learners to access, compose and manage their learning in a variety of settings. As a result of the evaluation, a revised set of design guidelines is produced that can potentially feed into other attempts to develop a framework for designing applications for mobile learners.

Keywords: mobile learning; lifelong learning; interface design.

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1 Introduction

Educational institutions have focused on delivering class-related information, such as lecture notes and exercises, only to personal computers (desktops and laptops). This will change soon with the market penetration of mobile phones growing rapidly, in some countries being near or even more than 100% (Business Wire, 2005; Jaques, 2006; Taylor, 2007; Wallace, 2006). Alongside the number of learners owning a mobile device reaching saturation levels (Lindquist et al., 2007) and getting comfortable with its use, the capabilities of today's mobile phones make their use for learning apparent. New technologies, such as cameras, media players, global positioning system, Bluetooth, etc. are appearing into mass market mobile phones, with many of these features existing even in entry-level phones (Froehlich et al., 2008). Also, the expansion of the 3G network coverage gives the opportunity to all the users of 3G-capable phones to have broadband access, anywhere and anytime.

In this context, managing the complexity of the learning experience has been at the top of the educational institutions' agenda. In the area of lifelong learning in particular, which is one of the most important motors driving education in the 21st century, learning becomes self-directed and a collaborative and community-supported experience. This perspective to learning calls for tools and services that would support independent lifelong learners and communities throughout life and would ensure that learners are experiencing an appropriately increased learning challenge and autonomy as well as independence. Making this happen in practice requires that learners become more aware of their own studying and thinking processes, and demands that tools and guidance are provided to support this process of learning through various courses, levels and stages of an educational system and beyond the desktop into new physical and social contexts.

Traditional e-learning systems can address some of these challenges when the lifelong learner has access to a PC with an internet connection. This is not always possible, especially when the learner is on the move, and needs information specific to the problem at hand, or has to reflect on the current situation. As Wagner (2005) points out, just-in-time access to information, even if the information is not well-formed, is far more preferable than not having the information at all.

This paper presents the design of a personal information space for lifelong learners on the move and empirical results of the use of the prototype we created. In general, an information space is a metaphor used to represent the information available on a specific subject and/or information related to the activities of a specific user. It is a fluid entity characterised by the content, organisation and constant user interaction with it (Krishnan and Jones, 2005).

This paper exploits the concept of the personal information space and extends it further into the domain of lifelong learning for representing a collection of information related to the activities of a lifelong learner and the relevant information around them while on the move. A personal information space aims to help mobile learners to become more effective and productive to support their rapid development and learning of new skills and knowledge. This paper builds on previous work (Dimakopoulos and Magoulas, 2006), and expands it further, presenting the design challenges and our choices for the front end and the features of the personal information space in Section 2, and the components of the prototype mobile application for lifelong learners in Section 3. A small-scale study with users of the system is presented in Section 4 to evaluate the usability of the application. The results of the study are discussed, and then the findings are used in Section 5 to revisit our design choices and propose a list of design guidelines for personal information spaces for mobile lifelong learners. This paper ends in Section 6 with conclusions.

2 Designing a personal information space for mobile learners

In the evolving educational landscape, mobile phones appear as an ideal solution to support lifelong learning education since by definition they are highly portable, personal, available anywhere and unobtrusive. Mobile learning appears to be a promising approach to enable learning in context and analysis of real-world problems. On a daily basis, a lifelong learner needs to resolve problems, share ideas or understand situations. In order to accomplish these goals, there is a need for accessing information or a way of communication with other members of the community in order to share ideas, plan lifelong learning and meet learning goals (Baajour et al., 2007). Furthermore, a need might exist to enhance his/her knowledge by attending courses, which follow specific schedules that have to match with a busy lifestyle, learn at different times and places and participate in professional development activities (Sharples, 2000). This generates new requirements for delivering learning content, accessing information, learning on demand, and for support at the workplace, in the classroom or in the current situation. However, not all kinds of activities and content are appropriate for mobile devices (Keegan, 2001). Thus, mobile learning should not be considered as a replacement of traditional forms of education but rather as an extension to traditional learning (Kukulska-Hulme, 2002; Waycott et al., 2002). In the context of mobile learning, Berri et al. (2006) explain that it is not feasible to simply port existing learning resources from desktop-based learning to mobiles. Also, Parsons et al (2006) point out that we should not simply apply known design requirements from e-learning into the mobile learning context because of the special limitations and benefits of the mobile phones.

There are quite a few challenges in designing a mobile learning application that have to be addressed for m-learning to become a beneficial and enjoyable experience to learners. Below we present an analysis of the user interface (UI) design challenges, based on relevant literature and previous work (Dimakopoulos and Magoulas, 2006), and explain the way these have been addressed in our prototype application. These challenges relate to the size of the screen of the mobile phones, users' navigation, tools for communication and information sharing between learners and ways that the mobility offered by the use of mobile phones can be advantageous in the learning process.

2.1 *The screen size*

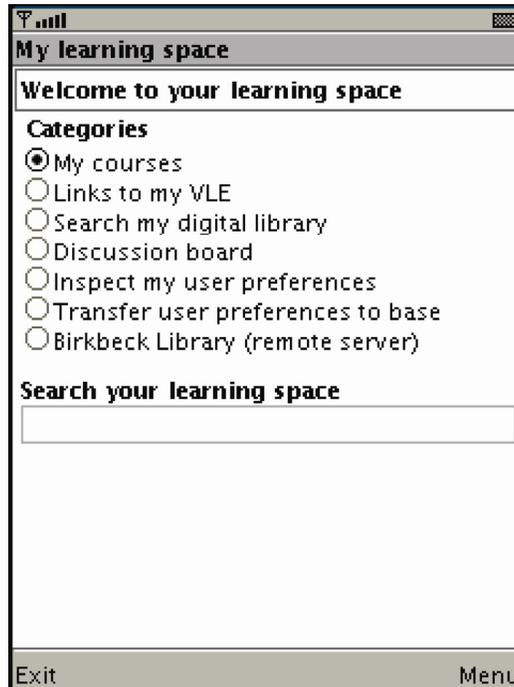
The small screen size is typically considered restrictive for the creation of a usable interface. As Ziefle et al. (2007) mention, the way of fitting the information in the small screen of mobile phones is a big challenge. Beyond handling and visibility problems, the restricted screen space allows only little information to be displayed at a time. This increases memory load (Ziefle et al., 2007), particularly for older users whose cognitive abilities (verbal memory and spatial ability) are less pronounced.

A variety of approaches have already been proposed for browsing websites using mobiles (Baluja, 2006; Blekas et al., 2006), but there are no guidelines for designing a UI that presents all the information in one screen. Instead, application-specific approaches have been proposed so far when it comes to screen space real estate (Holtzblatt, 2005; Newcomb et al., 2003).

Parsons et al (2006) have looked at the design of mobile learning applications from four perspectives: the mobile environment, the learning context, the learning experiences and the learning objectives. Regarding mobile environment issues, they argue that features of the mobile phones like mobility and limitations like small screen, poor input methods and limited battery life dictate the creation of a UI that should meet users' needs without overloading them or operating too slowly. They propose the use of rich media objects that do not distract the attention of the learners from their main activities. In order not to distract the learners, the objects have to be in short pieces and in several media types.

Lifelong learners need just-in-time access to information, especially when they are away from their personal computers, in order to accomplish several activities, such as information about the courses that they are currently taking, information about other learning opportunities offered and access to digital resources in order to find information relevant to the task they perform and communicating with peers and tutors. Our approach to design the UI of the personal information space was to decompose the activities lifelong learners need to accomplish when using the mobile application. These activities are modelled as the parent (root) categories of a taxonomy, which includes all the information that is relevant to their courses and status as lifelong learners. In our implementation, the application relies on a main taxonomy that includes all the information and is common for all learners, and the parent categories are activities such as viewing learner's current courses, searching a digital library, participate in a discussion board, etc. In order to facilitate the use of the taxonomy, the learner is initially registered to be able to see specific parts of the category, a step done by her institution when she enrolls.

Our application uses menu hierarchies to represent the activities available. The idea of using menu hierarchies to let a user navigate through the different menu items that represent the functionalities of a mobile phone has been investigated a lot in the literature (Buchanan et al., 2001; Ziefle et al., 2007). Users with higher verbal memory capacity might have a better orientation within technical menus. Nevertheless, orientation in menus might still be complicated for some users, particularly those who cannot experience how the menu can be spatially structured (Ziefle et al., 2007).

Figure 1 The home screen of the prototype

Since the users are already familiar with the use of hierarchies (Ziefle et al., 2007), the UI design of our application follows the same standard, but in our case, each menu item is a task or activity that the user needs to have access when is mobile (Figure 1). By selecting the menu item, a list of items and subcategories contained in that category are shown. This approach provides a feasible way to guide the user in navigation (Brusilovsky and Rizzo, 2002). Ziefle et al. (2007) also report that older users, who are an important group in lifelong learning programmes of study, become more disoriented when using hypertext structures interconnected by links than using hierarchical menus. In addition, our proposed visualisation of each category/task follows the design guideline proposed by Luchini et al. (2004), which suggests task-based workspaces. Moreover, our application is reordering the items of the menu according to the user preferences and depending on the usage of each item by the user, as Smyth and Cotter (2002) suggest.

The items in our prototype personal learning space can represent text or multimedia (e.g. podcasts, instructional videos, a mixture of rich media objects in short pieces), as Parsons et al (2006) suggest. Such an approach appears to be particularly beneficial in a lifelong learning application, where a lecturer posts online slides that should be viewable by almost any computing device, in any order and at anytime (Lindquist et al., 2007), that a user needs to be able to review specific slides in short amounts of time.

Offering multimedia content also shows potential for overcoming limitations due to the lack of output screens. This can be done by converting some parts of the content into audio format, minimising the use of the screen for reading that is tiring due to the continuous scrolling needed for long texts (Lee and Benbasat, 2003). Alternatively, with the new generation of mobile phones that all feature an MP3 player, the use of podcasting

to deliver information to learners on the move has been proposed (Ractham and Zhang, 2006), giving them the ability to download and listen to the lectures, or other information uploaded by the tutors. Similarly, Liu and Choudary (2004) created a system that broadcasts lecture videos to mobile devices by using a modified encoding of the video, optimised for mobile devices.

To alleviate problems with production costs and slow downloading time, multimedia files should be small in size and contain only the information that is needed. This means that large files, like a whole lecture, should be sliced into small parts that are meaningful and tags could be used to make the information available for searching (Chang et al., 2001), and the learner should be able to download, and listen or watch, only the part that would be relevant to what he/she is searching.

2.2 Navigation considerations

Different learners would use a structured information space in different ways, visiting only the parts they are interested in. For example, users typically create a 'personally ordered, edited version' of a taxonomy (Lave, 1988) that matches their personal preferences (Nardi, 1996). So in our approach, it is important to allow learners to navigate a personalised subset of the space: providing them with the whole taxonomy would be a waste of time and bandwidth for them, as they would always need to navigate only to particular parts of the information.

In our approach, the personal space is initially set up to match the profile of the learner (a term synonymous with the user profile used in software applications to store user-related information, preferences, user attributes), e.g. depending on the courses he/she enrolled, as defined in the initial user profile created by the institution for each learner. Gradually, the user is able to customise the content and enrich the information that is linked to his/her personal information space (Figure 2). In order to help the user navigating in the information space, automatic categorisation of the search results into categories of the personal learning space is used (Figure 3), as proposed by Kules et al. (2006). This kind of categorisation creates a directed situated navigation, which helps the users understand the context of the results they obtain (Tabard et al., 2007).

The personalisation of the system requires the creation of a user profile, which is a collection of attributes depicting the preferences of the user regarding various aspects of the application and also the usage of it (Figure 4). Bealle and Lonsdale (2004) have noted that context should not be considered as static but as a dynamic process, which changes through users' interactions with the learning materials and the surrounding world over time. The context features should be used either as excluders or as filters. Therefore, the system needs a mechanism, such as a personalisation engine, to fine tune the user profile according to the interaction of the user with the mobile phone, in order to have an up-to-date view of the user stored in the user profile. Also, the system has a screen that the user is able to review and change the user profile, so that it matches his/her way of working and thinking. The user is also able to let the system modify the user profile automatically according to the observed use of the mobile application, and, if needed, to tweak the values to correctly depict his/her choices.

Figure 2 Courses the learner is enrolled

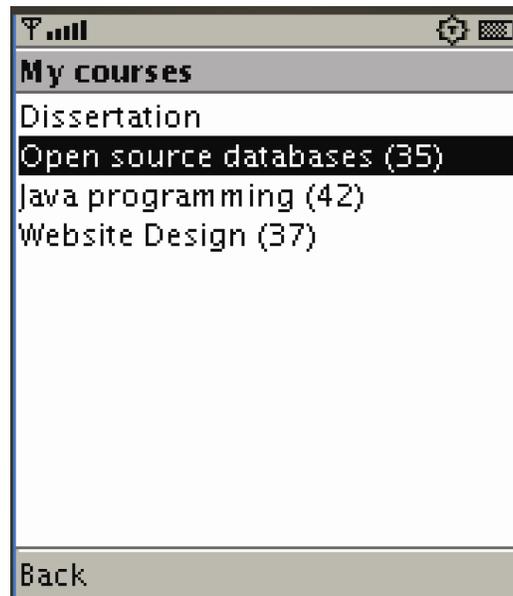


Figure 3 Categorisation of the search results

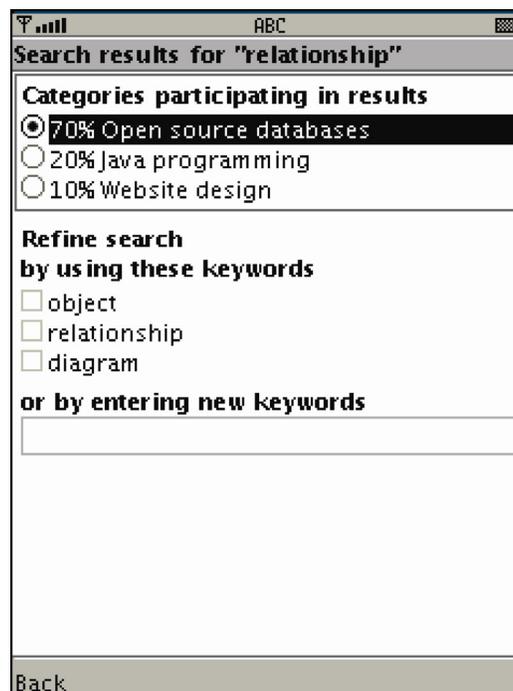
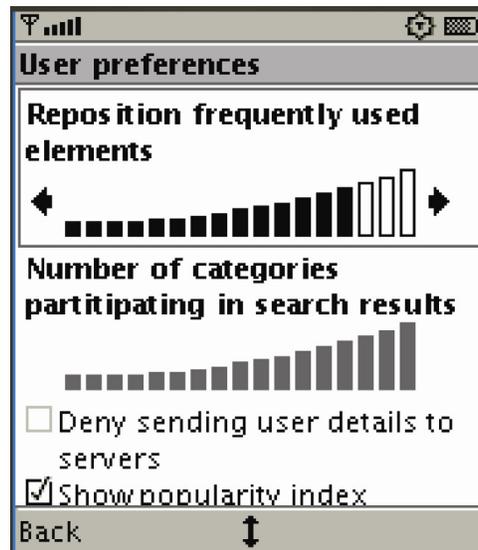


Figure 4 User preferences screen



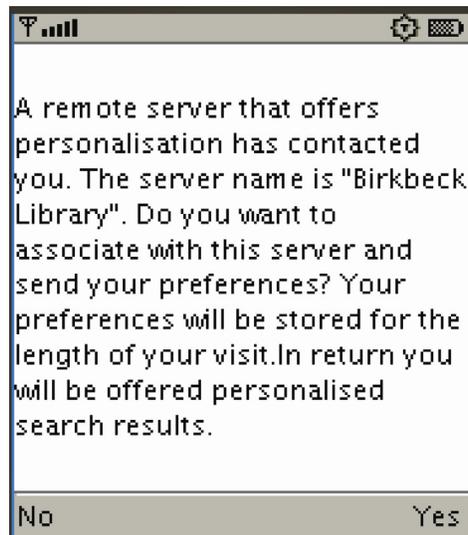
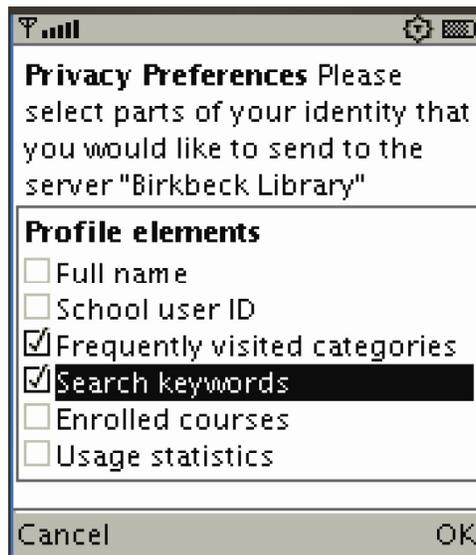
2.3 Tools for communicating and sharing information with others

A discussion board is used in our application to enable users, mobile or otherwise, to communicate and share their experiences and questions, in accordance with Davis (2002) findings, which show that communication for sharing practices and reflections on course concepts could provide additional motivation and engagement with mobile learning.

Our system annotates a category/item with the number of times other members of the community accessed it (Figure 2). This indicates what parts of the overall taxonomy other people found interesting, in line with previous work by Brusilovsky et al (2004), who proposed a web-based system that indicates the times other members of a group have used a specific resource by the saturation of the colour of the cell.

2.4 Supporting mobility, location awareness and discovery

Tools need to facilitate information discovery based on location, unifying and managing information beyond the users' desktop, and support mobility into new physical and social contexts. This is of paramount importance to successfully engage learners with the lifelong learning process, as they struggle to find a balance between limited personal resources, such as time, money and energy, and their workplace efficiency and productivity.

Figure 5 Alerting the user about available personalised services**Figure 6** P3P privacy preferences screen

Bluetooth, which is common nowadays on mobiles, is used in our system to get information about users' location and to receive offerings for personalisation from other systems (Aalto et al., 2004). The user profile is saved on the user's mobile device and could be released in exchange for personalised services, in line with the results of Brar and Kay (2005). The system informs the user when inside the range of a Bluetooth network that offers personalised content, as Ackerman and Cranor (1999) recommend. The system informs about the services the remote system provides (Figure 5), the way the

user's details will be used and for how long they will be stored, as described by the P3P policy. The user has the option to either send some of his/her personal data to the system or decline the offer, and use the system without personalisation (Figure 6). In order for the systems, the mobile device and the service provider, to exchange information, they should be able to communicate using a standard way of exchanging information, such as using P3P (W3C, 2006b) and APPEL (W3C, 2006a), or another XML-based defined protocol.

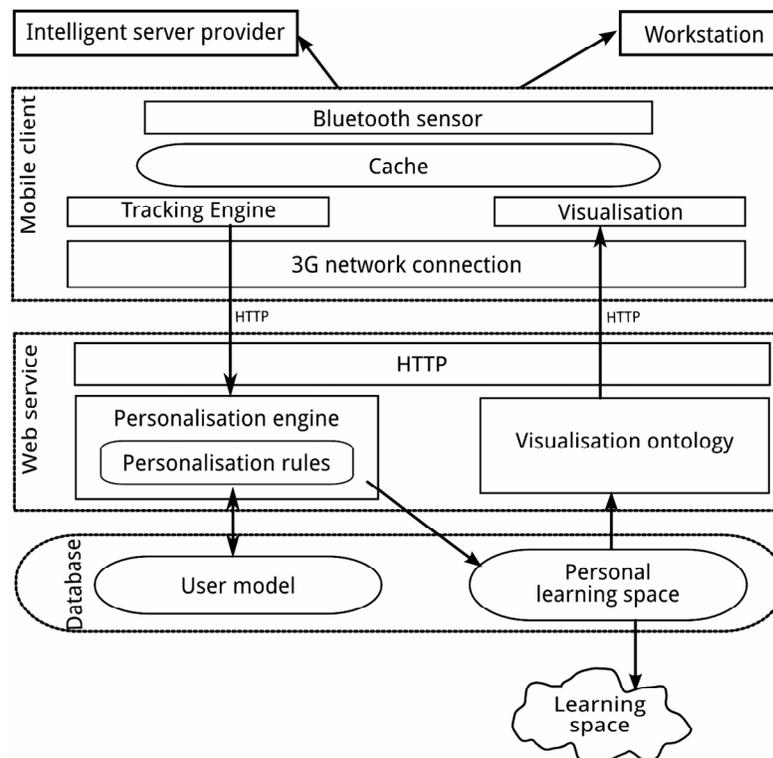
We described above our choices for designing the front end of our prototype. The next section describes how the different parts of the mobile application make use of the capabilities of the mobile phone and the way they connect to different components that comprise the system.

3 The architecture of the mobile system

The system architecture that appears in Figure 7 shows the connections between the main components of the system:

- the mobile client
- the web service that acts as middleware between the mobile client and the database
- the database.

Figure 7 High-level architectural description of the system



The connection between the mobile client and the web service is done using the internet and specifically the HTTP protocol. This approach was followed in order to make the mobile application lightweight, taking into consideration the limitations of the mobile phones. All the logic and expensive calculations are taking place on the server, and the results are being served as web services and are presented by the mobile application on the device.

The mobile client is having two main functionalities.

- Act as the interface between the user and the information space.
 - tracking the user actions, passing them to the web service
 - reading the visualisation result from the web service and show the corresponding screen to the user
 - caching the tracked actions and the resultant screen in the mobile client database, so that it remains usable in the event of loss of connectivity.
- Act as a sensor that is discovered by remote systems available, where personalised services are offered.

The web service part is collecting the data from the mobile client and is deciding on what the user asks to see next. It is using a user profile to track the user preferences.

The personal information space incorporates a hierarchical taxonomy similar to web directories like Open Directory Project (www.dmoz.org). The space is available to all lifelong learners and holds the information from all the courses that are available, and also links to other resources like a digital library or a discussion board. Its contents can be text, audio or video. The initial personal space for each learner is formed by the categories that are relevant to the courses he/she enrolled, so the personal space is a subset of the learning space provided, but the students have the ability to explore the whole taxonomy and expand their personal space. Furthermore, the personal space can be expanded by creating new categories that do not exist initially and by importing into them new or existing categories and items from the learning space. This gives flexibility to lifelong learners to expand and order their personal information space in a way meaningful to them. Learners can also create connections between existing categories that do not currently exist but are relevant according to their view.

The user can select between saving the user profile on a base system or on a mobile device and only release specific types of personal information for each interaction with the server. If the user profile is saved securely on a base computer, then the mobile phone could download the user profile using Bluetooth to build a direct connection, if it is a personal computer or if it is stored on the university server, then it can be downloaded using HTTP.

The system tracks the interactions of the user with the mobile client and feeds them into the tracking engine of the server. These events are passed to the user profile, either directly, if the user has selected to have a static user profile, or after being processed intelligently to decide whether the user profile should be changed or not. The user profile on the server is containing either all the information or only the information that the user accepted to provide. The event captured is then passed to the personalisation engine where a set of rules will run to personalise the data the user asked to see from the personal learning space. A visualisation ontology can use these data to decide on particular ways to present the information to the learner at the level of the mobile client.

Beyond the communication with the server component, the mobile device is able to communicate with remote servers available in a public library or a museum. The communication with these servers is done using Bluetooth technology. First, the phone is discovered by a remote server, and an offering is sent regarding the services that are provided, together with the parts of the user profile that are needed and the URL where the web services of the server can be located. If the user accepts the offering, a connection is created with the remote server to send the portion of the user profile needed, and to use the services provided. The services provided by remote servers appear in the personal learning space as new categories at the top level. The full contents of the services are available while the system is in range of the mobile client, but a cached version of documents that were retrieved can be held on the mobile device as proposed by Cohen et al. (2002).

4 Evaluation

We conducted a small-scale evaluation study in order to get feedback from mobile phone users, current or prospective lifelong learners, on the usability of the prototype mobile application. Among the various usability engineering methods, we have used heuristic evaluation, which involves the interface of an application being scrutinised against a set of recognised usability principles, or 'heuristics' (Nielsen, 1994a; Nielsen and Molich, 1990). This was done by checking the UI of our prototype for compliance against a set of heuristics. Heuristics are guidelines, or rules of thumb, that are used in order to guide design decisions for new UIs or critique decisions that have already been taken on prototypes. The advantages of heuristic evaluation are reflected by its commercial and industrial applications: it is easy to conduct, is inexpensive, finds many major and minor interface problems and can be used effectively by both novices and experts and there is no need to give formal usability training to the participants (Chen and Macredie, 2005; Levi and Conrad, 1996; Nielsen and Molich, 1990). Also, heuristic evaluation, being a discount usability engineering method, needs only a small number of participants in order to identify most of the interface problems (Nielsen, 1994b). Finally, it is having a faster turnaround time than other ways of testing (Kantner and Rosenbaum, 1997). The useful features of heuristic evaluation have been confirmed in practice by a number of studies that have shown that problems overlooked in user testing can be in fact identified through heuristic evaluation (Fu et al., 2002; Jeffries et al., 1991). In particular, the study by Jeffries et al. (1991) compared heuristic evaluation, software guidelines, cognitive walkthroughs and user testing to identify usability problems for a software product prior to its release. Jeffries et al. confirmed the practical value of heuristic evaluation as it managed to reveal more usability problems than the other methods requiring fewer resources.

4.1 Participants

A total of 24 persons participated in this evaluation. All participants had the basic computing, internet and mobile usage skills necessary to understand and use the prototype; 66% were males and 34% females. All participants were educated at university level, or being enrolled in a lifelong learning university course. They all had

experience using a virtual learning environment. The participants varied in age from 23 to 38 years, with a mean of 30 years. They were recruited from mailing lists and word of mouth.

4.2 Evaluation instruments

The instruments used for this evaluation included the prototype, running on a series of mobile phones, all capable of running midlets (JME enabled), and an exit questionnaire to identify users' views and attitudes towards the design choices and the usability of the prototype with an emphasis on the fit of the system to users and their work needs as lifelong learners.

4.2.1 Prototype and mobile phones used

The prototype was created using JME MIDP 2.0 and compiled using the J2ME Wireless Toolkit 2.3. It was installed and tested on a variety of java-enabled mobile phones. These included Nokia Series 40 platform phones (6233, 6280 and 6500) and Symbian phones (Nokia E65, Nokia 6120 and Sony Ericsson P910).

The handsets used are a balance of low-end mobile phones, which are usually given free or almost free with a contract, and middle- to high-end smart phones. The phones were all Bluetooth and 3G capable. They were connected using 3G networks, on a pay monthly package, with correctly set up GPRS and mobile web settings. During the evaluation, the Nokia 6120 handset was able to connect using the HSDPA protocol, which is known to offer improved data rates, reduced latency and round trip time.

4.2.2 Exit questionnaire

A paper-based questionnaire was chosen because it has the potential to collect perceptive and affective data quickly and easily (Kinshuk, 1996). Another advantage of questionnaires is that the data may be both qualitative and quantitative, allowing them to play a part in both quantitative and qualitative studies (Su, 1991). The questionnaire used in this evaluation was based on the ten usability heuristics as they are described by Nielsen (1994a). These are: visibility of the system status; match between system and the real world; user control and freedom; consistency and standards; error prevention; recognition rather than recall; flexibility and efficiency of use; aesthetic and minimalist design; help users recognise, diagnose and recover from errors and help and documentation.

The questionnaire covered a wide range of design and usability issues and was constructed by taking into account the design features proposed by Dimakopoulos and Magoulas (2009), with an emphasis on the activities of lifelong learners. The exit questionnaire was designed using a semistructured format. In all, 61 questions were applied to identify the participants' perceptions towards the choices of interface design and the usability of the prototype, including:

- 1 content presentation
- 2 screen layout
- 3 difficulties and problems.

The participants were asked to answer the questions using a pre-existing set of answers, but they were also able to comment openly on any question. The provided answers for the questions were using the Likert ranking scale, with the options being

- 1 to denote a usability disaster
- 2 a major problem
- 3 a minor problem
- 4 a superficial problem
- 5 not a problem at all.

It took approximately 30 min to respond to all questions of the questionnaire.

4.3 Design of tasks

In order to identify the users' perceptions regarding the usability of the mobile prototype, participants were asked to perform a series of activities that are representative of the activities that a lifelong learner would be expected to perform. These tasks were designed so that the participants would have a personal experience on the use of the tools provided by the prototype. They followed the procedure outlined in the scenarios describing the prototype by Dimakopoulos and Magoulas (2009). Three tasks were carried out:

- 1 Log on to the discussion board and send a personal message to your tutor requesting his/her opinion about the subject you picked for your dissertation. Read the reply of your tutor. Your tutor will reply that the topic you proposed is rather wide for a dissertation and that it would be a good idea to collaborate with another student. Publish a message in the discussion board requesting a collaborator. Check your favourite categories and search your personal space.
- 2 Access course notes on database queries. Select and download to listen the podcast on database updating. Watch a video demonstrating the updating of a database. Post a topic in the discussion board requesting more information on database updating.
- 3 Read the course notes on how to create scripts to automate the procedures done on a database. Download the examples on that topic. Watch a video of the part of the lecture where the tutor explains the procedure. Read a sample script. Answer some multiple choice questions to test your knowledge. Add a new category and place all the relevant information in it.
- 4 You enter Birkbeck Library, which is a library that offers personalised services. You are presented with an alert, informing you that you entered the library. Review it and check the privacy preferences before accepting to send your personal details to get personalised services.

One hour was allocated for each participant to complete the tasks.

4.4 *Experimental procedures*

The following procedures were applied:

- 1 participants were informed about the idea behind the creation of the prototype
- 2 participants watched a demonstration of the prototype, in order to become familiar with the available tools and options
- 3 participants were observed while they were carrying out the tasks, and clarifications were given when requested
- 4 participants were asked to complete the exit questionnaire.

4.5 *Data analysis*

To investigate the users' views, the data collected from the closed statements of the questionnaire were coded for analysis in OpenOffice Calc. The outputs of the frequency tables were examined for each group of the design features. Among 61 closed statements, 36 items have shown important meaning to the usability of the application.

4.6 *Discussion of the results*

Table 1 provides an overview showing the user ratings for each one of the heuristics. The design of the application was generally well perceived by the participants: most of the issues identified were characterised as 'superficial' or 'not a problem at all'. Some users felt that although they were given tools to control and customise the application and its features, these were not friendly enough, or that the extra flexibility provided to facilitate mobility and discovery of resources could compromise their freedom and privacy (see 'User control and freedom' in Table 1). These issues together with other usability problems that caused concern are discussed in the sections below. These are organised along the same four dimensions used in Section 2, where the initial design of the application was described, as they relate to the screen size; navigation in the information space; communication and information sharing and mobility, location awareness and discovery.

Table 1 Results from the heuristic evaluation

<i>Usability heuristic</i>	<i>Learners ratings</i>				
	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>
Visibility of the system status	2	4	11	28	127
Match between system and the real world	0	0	13	45	198
User control and freedom	7	2	16	19	123
Consistency and standards	0	0	4	15	156
Error prevention	1	0	3	9	86
Recognition rather than recall	0	0	6	25	55
Flexibility and efficiency of use	0	0	1	8	30
Aesthetic and minimalist design	0	0	9	37	83
Help users recognise, diagnose and recover from errors	0	0	4	20	84
Help and documentation	0	0	1	11	46

4.6.1 Issues related to the screen size

There was a feeling that it was natural to use menus to navigate in the application, exactly like doing generally to navigate through all the preferences of the phone. One participant noted that the system has a learning curve, but after getting familiar with, it is easy to use. Three participants felt like they needed to spend more time using the application in order to be sure about the functionality of some options, and whether they help or confuse the user. One participant said that it was quite confusing to understand where she was in the personal space, while two others noted that they felt lost some times. Three other users noted that it would be nice if they had some functionality similar to the breadcrumbs appearing in web pages, because, as one mentioned, they needed to remember where they have been before to know exactly where they are. Two comments, by two participants, were received regarding the title of each screen being confusing. According to one participant it was confusing to have as a title of the screen both the name of the category the user is in and the name of the ancestor, while the other argued that the title did not fit the screen most of the times and therefore was contributing towards a feeling of being lost in the application space. It is evident that there is a need for a screen that shows to the user the exact position in the personal space. This would present the depth in the hierarchy and the parents of the category being viewed, or the trail followed to reach that category, and would give the option to go up in the hierarchy or back in the trail. That way the title of each screen would be the name of the category that the user is currently in, which would make the title shorter to fit most of the mobile screens. In addition, another option can be given to the user to view the title of the screen if needed. In the same vein, one participant observed that there is no 'home' button, or option in the soft key menus, that would take the user to the root category of the taxonomy.

Regarding the menus, a number of users noted that in some cases they are quite long ($N = 4$), with 'more options than needed' as noted by a participant. A consequence of having long menus is that it makes the actions that appear in the middle of the list difficult to reach while navigating using the up and down arrows, as one participant noted. Others argued that they would like to be able to change the list of options by themselves ($N = 3$) and not only automatically by the system. Finally, a participant said it could be beneficial if the system would remember the option used before and reselect it every time the user enters the same screen in the application. Three participants agreed that it would be better if similar sources were clustered together. Similarly, two participants said that they would prefer to get the search field at the top of the root menu list and not at the bottom.

Another problem faced with respect to menu items was that in some cases their description did not fit in the screen ($N = 5$), and some users asked if it is possible to make the fonts smaller ($N = 2$). This problem was presented mainly with the Symbian models, as it seemed that the implementation of JME was a bit problematic with the fonts of the form elements. A solution would be to give the option to the users to change the font size, if it is required. Due to some restrictions of the forms in JME, the Lightweight UI Toolkit (Sun Microsystems, 2008) could be used in order to change the appearance and functionality of the standard form objects, or a Canvas object could be used to draw form objects from scratch. Three users mentioned that it would be better if entering a menu only required one click and not two clicks as in the case of use of radio buttons in forms. One user proposed to use two-click activation of menus and items that the phone needs to download from the server and therefore there will be a charge. Two other participants

faced similar problems with the generated soft-key menus. Adding many actions to particular elements in a form makes the soft key menus slow to access using the up and down keys. Also, another user noted that she was not able to see the 'Back' option when she was typing in a textfield, but instead 'Clear' was appearing, forcing her to have to clear the field before being able to go to the previous screen. This is an issue that appeared on phones that did not have a dedicated key for deleting characters, but instead were using a special key, which was used for other options too. A solution to the above problems would be to draw new form elements from scratch, so that they fit different screen sizes and are more flexible when it comes to choosing font sizes. Also, the activation of the options could be done by using a 'Go' button.

A number of participants ($N = 5$) agreed that mnemonics are very helpful navigating through the menus quickly. Two of these users asked if it is possible to change the default mnemonics to combinations they want and remember better. The mnemonics used in the system were the keys 1–9, giving access to the first nine links in a screen. This seemed sufficient at the time of the creation of the prototype since the list of links is automatically arranged so that the most frequently used items are put at the top.

Participants ($N = 2$) also noted that the concept of custom categories was not clear without explanation. One of them said that he thought each custom category was a shortcut for a specific part of the space, while the other found it difficult to add parts of the personal space in a custom category.

It was very important for some participants ($N = 2$) to be able to stop a procedure, like downloading a podcast or a video, before it finishes. They argued that they might have selected to download something by mistake, and stopping the procedure would minimise the fees they would have to pay for accessing something by mistake. One of these users mentioned that if she would be asked by the system whether it should proceed online to download the podcast, it would be possible to stop the application in that screen before actually going online.

4.6.2 Facilitating navigation in the information space

Regarding the search features of the application, it was very important for some participants ($N = 4$) to be able to view which are the words used in the search, and whether they typed them or they came from the list of words used before. Also, they would find useful ($N = 2$) to be able to exclude some of the words used in the search. Finally, they would like ($N = 2$) to be able to find out in which context they used some keywords that are recommended by the system. Concerning the percentage of results that comes from each category in the search results, only one participant did not find it helpful, while all others thought it helps them by narrowing down the number of links they have to choose to follow.

Few participants found the user preferences screen difficult ($N = 2$) or too technical ($N = 1$), containing jargon they didn't understand until they asked ($N = 1$). At the same time, many participants ($N = 6$) asked to have more user preferences they could change, making the application more customisable by the user. Some of them asked to be able to set up the application so that no affirmation dialogs appear ($N = 2$), while on the other hand, four participants asked to be able to set up the application to ask them every time before going online. In fact, informing the user that the application will go online was a big discussion during most of the evaluation sessions. Currently, it is very expensive to access the internet from a mobile device, as access is charged by the amount of traffic

generated. The authors believe that the charging policy for access to the internet by mobile carriers is a big drawback for the flourishing of m-learning, probably as big as the usability issues around the use of mobile phones. Hopefully, with the increase of usage by mobile customers, carriers will adopt flat rate fees that are competitive with broadband services.

4.6.3 *Facilitating communication and information sharing*

The use of the discussion board was found to be straightforward by all the participants. The only objections were regarding whether the user would be able to save a draft of a message later ($N = 2$), and if the system was going online every time, it needed to get the list of participants ($N = 1$). The way this feature was implemented was to show the cached names immediately, and always go online to check if there is a need for a refresh in the cache. This behaviour can easily change so that the refreshing of the cache is a procedure the user initiates. It is also evident that due to the fragmented use of the application, there is always a need for the application to save the current status, so that in case of any kind of interruption, the user can go on from where he/she was before.

Many participants misunderstood the popularity index, which was used to show how many other users have visited particular content categories. Seven participants said that the wording 'popularity index' did not help them understand what the feature was until they asked for information about it. Only two of them didn't find the popularity index helpful, with one having misunderstood that the number was how many times he visited the category. Some others ($N = 2$) would like to be able to sort the categories by the popularity index.

4.6.4 *Supporting mobility, location awareness and discovery*

Most of the participants liked the idea of being able to continue with their quizzes later either through the mobile phone or by transferring the data to their personal computer. Three participants were worried about theft of their information if their mobile is stolen. Also five participants were unsure about having the Bluetooth of their device always on to enable the services discovery of the application, while 11 of them were nervous for the case they would press 'Yes' by mistake when they will be asked by a service if they want to send their user profile. Regarding the user profiles stored in the device, it is true that if a malicious user has direct access to the phone, the only way to protect the data is by encrypting them before saving them. On the other hand, regarding the Bluetooth vulnerabilities, this is a big problem. The only secure solution is either to use a hidden/non-discoverable mode for the Bluetooth, which would make the idea of being discovered by a service unusable, or to have an option for the user to initiate discovery of services in the surrounding area, instead of having the Bluetooth always on. Finally, regarding sending user profile information by mistake, the implementation of P3P by the application means that there are two screens that the user has to submit. The first has a 'Yes' and a 'No' button, but the second requires selection of parts of the user profile, and by default, none of the fields is selected. This way if the users select to send information, no information is selected and therefore sent.

4.6.5 Difficulties and problems

Results collected from open-ended questions also showed that users encountered difficulties with some features of the mobile application. Representative comments are presented in Table 2, highlighting areas for further improvement. It seems that these comments are aligned to the relevant findings presented in the previous subsections, which reinforces the usefulness and reliability of the results.

Table 2 Difficulties and problems encountered

<i>Representative user comments</i>	<i>Area of problem/difficulty</i>
“Need for functionality similar to website breadcrumbs”	Screen size
“No ‘home’ button to take the user to the main screen”	Screen size, navigation in the information space
“Clustering of similar sources together”	Screen size
“Smaller fonts for smaller screens”	Screen size
“Manual configuration of mnemonics”	Screen size
“No affirmation dialogs”	Navigation in the information space
“Sort by popularity index”	Communication and information sharing

5 Development of design guidelines

Mobile learning will not be fully accepted by lifelong learners until usability issues have been addressed in depth to bring up-to-date interface design. The findings reported in the previous section show that designing a mobile information space with an effective UI has an important impact on users’ attitudes to its use. Eventually, ease of use and user-friendly features are two key factors determining whether a lifelong learner will use frequently the application for everyday tasks relevant to learning. The findings can feed into the development of a framework for designing applications for mobile learning in line with other attempts in the literature (see Section 2 and references within). Table 3 summarises the major points of the empirical evaluation by providing the initial design considerations (c.f. with Section 2 and Dimakopoulos and Magoulas, 2009), which were implemented in the prototype mobile application, examples of problems encountered by the users and the final set of the guidelines for usable mobile applications.

Table 3 Guidelines for usable personal information spaces for mobile learners

<i>Implemented feature</i>	<i>Problem</i>	<i>Design guideline</i>
Hierarchical menus	Lost in the hierarchy	Inclusion of information of the current position of the user in the space
Hierarchical navigation	Difficult to go to the ‘home’ screen if the user browsed deep in the hierarchy	Inclusion of a ‘home’ button that will be taking the user to the main screen

Table 3 Guidelines for usable personal information spaces for mobile learners (continued)

<i>Implemented feature</i>	<i>Problem</i>	<i>Design guideline</i>
Title for each page, showing the title of the parent category and the title of the current screen	Did not fit in the screen	Option to view the title of page in different screen if it does not fit in the screen
Automatic reordering of items in the menu, according to usage	Difficult to navigate to menu items in the middle of the menu when the menu is long	Option to let the user manually change the positioning of the menu items
Use of system font in the application	Information did not fit in all screens	Option to choose font size
Use of the keys 1–9 as mnemonics for the first nine menu items	When menus were longer than nine menu items, there were items not been assigned mnemonics	Implementation of mnemonics and screen to modify mnemonics shortcuts
Long downloading processes of video and audio content	The users could not stop the process	Button to stop or cancel a process
Confirmation dialogs and alerts in order to keep the user informed about the state of the system	Users felt that it slows them down	Option to accept automatically all the dialogs presented, speeding the browsing speed and confirmation before going online
Implementation of prompts before getting online	Inform the user that charges will apply	Prompt asking the user whether to continue online
Automatic acceptance of default actions in dialogues	Minimise use of keypad	Option that lets the user accept all dialogs silently
Information about the number of times other users have visited a particular category	UI not making use of this information	Option to sort menu items by the number of visits other users visited a particular category
Use of Bluetooth as a mechanism for intelligent servers to discover the mobile phone	Bluetooth vulnerabilities	The user launches the process of finding an intelligent server using Bluetooth

6 Conclusions

In lifelong learning, learners' population is diverse, making it difficult to address their needs using conventional e-learning technologies. Additional tools that will facilitate anytime anyplace access to learning resources and opportunities are needed to engage learners with the lifelong learning process and generate a sense of community with peers and teachers.

To this end, we designed a personal information space for lifelong learners on the move working along the line proposed in Dimakopoulos and Magoulas (2009). A prototype was developed using Java Mobile Edition, and the usability of our prototype application was evaluated to increase our understanding of how personal information spaces for mobile learning are perceived by mobile lifelong learners.

The findings of the evaluation and the guidelines proposed can be potentially useful to derive further research on practical use of mobile phones as a tool that facilitates learning and accessing educational materials anywhere, anytime, helping learners to become more productive. It appears that a usable personal information space for mobile lifelong learners is possible to be created and used by everyday lifelong learners in order to support their autonomy and independence beyond the desktop.

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References

- Aalto, L., Göthlin, N., Korhonen, J. and Ojala, T. (2004) 'Bluetooth and WAP push based location-aware mobile advertising system', *Proceedings of the Second International Conference on Mobile Systems, Applications and Services*, Boston, MA, pp.49–58.
- Ackerman, M.S. and Cranor, L. (1999) 'Privacy critics: UI components to safeguard users' privacy', *Proceedings of the Computer Human Interaction Conference (CHI '99), Extended Abstracts on Human Factors in Computing Systems*, Pittsburgh, PA, pp.258–259.
- Baajour, H., Magoulas, G.D. and Poulouvassilis, A. (2007) 'Designing services-enabled personalisation for planning of lifelong learning based on individual and group characteristics', in P. Brusilovsky, M. Grigoriadou and K. Papanikolaou (Eds.), *Proceedings of Workshop on Personalisation in E-Learning Environments at Individual and Group Level, 11th International Conference on User Modeling (UM 2007)*, Corfu, Greece, 25–29 June, pp.8–15.
- Baluja, S. (2006) 'Browsing on small screens: recasting web-page segmentation into an efficient machine learning framework', *Proceedings of the 15th International Conference on World Wide Web*, Edinburgh, Scotland, 23–26 May, pp.33–42.
- Bealle, R. and Lonsdale, P. (2004) 'Mobile context aware systems: the intelligence to support tasks and effectively utilise resources', *Proceedings of Mobile HCI 2004*, Glasgow, UK, pp.240–251.
- Berri, J., Benlamri, R. and Atif, Y. (2006) 'Ontology-based framework for context-aware mobile learning', *Proceedings of the 2006 International Conference on Communications and Mobile Computing*, Vancouver, BC, Canada, 3–6 July, pp.1307–1310.
- Blekas, A., Garofalakis, J. and Stefanis, V. (2006) 'Use of RSS feeds for content adaptation in mobile web browsing', *Proceedings of the 2006 International Cross-Disciplinary Workshop on Web Accessibility (W4a): Building the Mobile Web: Rediscovering Accessibility?* Edinburgh, UK, 22–22 2006, W4A, Vol. 134, New York, NY: ACM Press.
- Brar, A. and Kay, J. (2005) *Privacy and Security in Ubiquitous Personalized Applications* (Tech. Rep. No. 561), School of Information Technologies, University of Sydney.
- Brusilovsky, P. and Rizzo, R. (2002) 'Map-based access to multiple educational on-line resources from mobile wireless devices', *Proceedings of the 4th International Symposium on Mobile Human-Computer Interaction*, Pisa, Italy.
- Brusilovsky, P., Chavan, G. and Farzan, R. (2004) 'Social adaptive navigation support for open corpus electronic textbooks', in W. Nejdl and P. De Bra (Eds.), *Proceedings of the Third International Conference on Adaptive Hypermedia and Adaptive Web-Based Systems*, Eindhoven, The Netherlands, 23–26 August, pp.24–33.

- Buchanan, G., Jones, M., Thimbleby, H., Farrant, S. and Pazzani, M. (2001) 'Improving mobile internet usability', *Proceedings of the 10th International Conference on World Wide Web* (pp.673–680), Hong Kong, May 2001. ACM Press.
- Business Wire (2005) 'Europe's mobile market penetration is set to breach 100% in 2006 or early 2007', Available at: http://findarticles.com/p/articles/mi_m0EIN/is_2005_Nov_22/ai_n15865133. Accessed on April 2008.
- Chang, S.F., Zhong, D. and Kumar, R. (2001) 'Real-time content-based adaptive streaming of sports video', *Proceedings of the IEEE Workshop on Content-Based Access to Video/Image Library*, Hawaii, Los Alamitos, December, p.139.
- Chen, S.Y. and Macredie R.D. (2005) 'The assessment of usability of electronic shopping: a heuristic evaluation', *Int. J. Information Management*, Vol. 25, pp.516–532.
- Cohen, D., Herscovici, M., Petruschka, Y., Maarek, Y.S. and Soffer, A. (2002) 'Personalized pocket directories for mobile devices', *Proceedings of the 11th International Conference on World Wide Web*, Honolulu, Hawaii, 7–11 May, pp.627–638.
- Davis, S.M. (2002) 'Research to industry four years of observations in classrooms using a network of handheld devices', *Proceedings of IEEE International Workshop on Wireless and Mobile Technologies in Education (WMTE 2002)*, Vaxjo, Sweden, August 2002, pp.31–38.
- Dimakopoulos, D.N. and Magoulas, G.D. (2006) 'A personalised mobile environment for lifelong learners', *Proceedings of IADIS International Conference on WWW/Internet 2006*, Murcia, Spain, 5–8 October, pp.31–38.
- Dimakopoulos, D.N. and Magoulas, G.D. (2009) 'An architecture for a personalised mobile environment to facilitate contextual lifelong learning', in H. Ryu and D.P. Parsons (Eds), *Innovative Mobile Learning: Techniques and Technologies*, Information Science Publishing, pp.232–254.
- Froehlich, P., Baillie, L. and Simon, R. (2008) 'Feature: realizing the vision of mobile spatial interaction', *Interactions*, Vol. 15, No. 1, pp.15–18.
- Fu, L., Salvendy, G. and Turley, L. (2002) 'Effectiveness of user testing and heuristic evaluation as a function of performance classification', *Behaviour and Information Technology*, Vol. 21, pp.137–143.
- Holtzblatt, K. (2005) 'Customer-centered design for mobile applications', *Personal and Ubiquitous Computing*, Vol. 9, No. 4, pp.227–237.
- Jaques, R. (2006) 'Western Europe reaches 100 per cent mobile penetration', Available at: <http://www.vnunet.com/vnunet/news/2148744/western-europe-reaches-100-per>, Accessed on April 2008.
- Jeffries, R., Miller, J.R., Wharton, C. and Uyeda, K.M. (1991) 'User interface evaluation in the real world: a comparison of four techniques', *Proceedings of CHI 91*, pp.119–124.
- Kantner, L. and Rosenbaum, S. (1997) 'Usability studies of WWW sites: heuristic evaluation vs. laboratory testing', *Proceedings of the 15th Annual International Conference on Computer Documentation SIGDOC '97*, pp.153–160.
- Keegan, D. (2001) 'The future of learning: from e-learning to m-learning', Available at: <http://learning.ericsson.net/leonardo/book.html>, Accessed on April 2008.
- Kinshuk (1996) 'Development of a user-friendly interface for the creation of user elements', *Int. J. Electrical Engineering Education*, Vol. 33, No. 4, pp.344–352, October (ISSN 0020-7209).
- Krishnan, A. and Jones, S. (2005) 'TimeSpace: activity-based temporal visualisation of personal information spaces', *Personal and Ubiquitous Computing*, Vol. 9, No. 1, pp.46–65.
- Kukulska-Hulme, A. (2002) 'Cognitive, ergonomic and affective aspects of PDA use for learning', *Proceedings of the European Workshop on Mobile and Contextual Learning*, Birmingham, UK, June, pp.32–33.
- Kules, B., Kustanowitz, J. and Shneiderman, B. (2006) 'Categorizing web search results into meaningful and stable categories using fast-feature techniques', *Proceedings of the 6th ACM/IEEE-CS Joint Conference on Digital Libraries*, Chapel Hill, NC, pp.210–219.
- Lave, J. (1988) *Cognition in Practice*. Cambridge: Cambridge University Press.

- Lee, Y.E. and Benbasat, I. (2003) 'Interface design for mobile commerce', *Communications of the ACM* 46, Vol. 12, pp.48–52.
- Levi, M.D. and Conrad, F.G. (1996) 'A heuristic evaluation of a world wide web prototype', *Interactions*, Vol. 3, pp.50–61.
- Lindquist, D., Denning, T., Kelly, M., Malani, R., Griswold, W.G. and Simon, B. (2007) 'Exploring the potential of mobile phones for active learning in the classroom', *Proceedings of SIGCSE'07*, Covington, Kentucky, 7–10 March, pp.384–388.
- Liu, T. and Choudary, C. (2004) 'Real-time content analysis and adaptive transmission of lecture videos for mobile applications', *Proceedings of the 12th Annual ACM international Conference on Multimedia*, New York, pp.400–403.
- Luchini, K., Quintana, C. and Soloway, E. (2004) 'Design guidelines for learner-centered handheld tools', *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, Vienna, Austria, pp.135–142.
- Nardi, B.A. (1996) *Studying Context: A Comparison of Activity Theory, Situated Action Models, and Distributed Cognition. Context and Consciousness*. MA: The MIT Press.
- Newcomb, E., Pashley, T. and Stasko, J. (2003) 'Mobile computing in the retail arena', *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, Ft. Lauderdale, pp.337–344.
- Nielsen, J. (1994a) 'Heuristic evaluation', in J. Nielsen and R.L. Mack (Eds.), *Usability Inspection Methods*. New York, NY: John Wiley & Sons.
- Nielsen, J. (1994b) 'Guerrilla HCI: using discount usability engineering to penetrate the intimidation barrier', Available at: http://www.useit.com/papers/guerrilla_hci.html, Accessed at August 2008.
- Nielsen, J. and Molich, R. (1990) 'Heuristic evaluation of user interfaces', in J.C. Chew and J. Whiteside (Eds.), *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems: Empowering People*, Seattle, Washington, 1–5 April, pp.249–256.
- Parsons, D., Ryu, H. and Cranshaw, M. (2006) 'A study of design requirements for mobile learning environments', *Proceedings of the Sixth IEEE International Conference on Advanced Learning Technologies*, Washington, DC: IEEE Computer Society, pp.96–100.
- Rachtham, P. and Zhang, X. (2006) 'Podcasting in academia: a new knowledge management paradigm within academic settings', *Proceedings of the 2006 ACM SIGMIS CPR Conference on Computer Personnel Research*, Claremont, pp.314–317.
- Sharples, M. (2000) 'The design of personal mobile technologies for lifelong learning', *Computers and Education*, Vol. 34, Nos. 3–4, pp.177–193.
- Smyth, B. and Cotter, P. (2002) 'Personalized adaptive navigation for mobile portals', *Proceedings of the 15th European Conference on Artificial Intelligence*, Lyon, France, pp.608–612.
- Su, L.T. (1991) 'An investigation to find appropriate measures for evaluating interactive information retrieval', *Doctoral Thesis*. Rutgers University.
- Sun Microsystems, Lightweight UI Toolkit (2008) Available at: <https://lwuit.dev.java.net/>, Accessed on August 2008.
- Tabard, A., Mackay, W., Roussel, N. and Letondal, C. (2007) 'PageLinker: integrating contextual bookmarks within a browser', *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '07)*, San Jose, CA, pp.337–346.
- Taylor, C. (2007) 'Global mobile penetration to reach 75% by 2011', Available at: http://www.theregister.co.uk/2007/10/26/mobile_penetration_research/, Accessed o April 2008.
- W3C, A P3P Preference Exchange Language 1.0 (APPEL1.0) (2006a) Retrieved on 31 July 2007, from <http://www.w3.org/TR/P3P-preferences/>.
- W3C, Platform for Privacy Preferences (P3P) Project (2006b) Retrieved on 31 July 2007, from <http://www.w3.org/P3P/>.
- Wagner, E.D. (2005) 'Enabling mobile learning', *EDUCAUSE Review*, Vol. 40, No. 3, pp.40–53.

- Wallace, B. (2006) '30 countries passed 100% mobile phone penetration in Q1', Available at: http://www.telecommagazine.com/newsglobe/article.asp?HH_ID=AR_2148, Accessed on April 2008.
- Waycott, J., Scanlon, E. and Jones, A. (2002) 'Evaluating the use of PDAs as learning and workplace tools: an activity theory perspective', *Proceedings of the European Workshop on Mobile and Contextual Learning*, Birmingham, UK, June, pp.34–35.
- Ziefle, M., Schroeder, U., Strenk, J. and Michel, T. (2007) 'How younger and older adults master the usage of hyperlinks in small screen devices', *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, San Jose, CA, 28 April–3 May, pp.307–316.