Dynamic Composition and Personalization of PDA-based eLearning – Personalized mLearning

Aoife Brady, Owen Conlan, Vincent Wade
Knowledge and Data Engineering Group,
Trinity College, Dublin,
Ireland.

E-mail Aoife.Brady@tcd.ie, Owen.Conlan@cs.tcd.ie, Vincent.Wade@cs.tcd.ie

Abstract: With the increasingly demanding schedules of formal and casual learners and the proliferation of terminal devices available for content delivery, learners are demanding ubiquitous access to their learning. The multi-modal nature of the variety of devices employed by these learners will necessitate that learning experiences can be started on one device and transitioned seamlessly to another as the learner changes the context of their learning. This movement of learning experience between devices, which may have dramatically different capabilities, presents a usability challenge to ensure our learners do not feel their learning experience has been adversely affected. Personalized eLearning offerings can be tailored not only to the learner, but also to the device they are using. Generally, the evaluations that have been carried out of personalized eLearning systems have concentrated on systems that are delivered via devices, such as desktop computers, that have generous screen real estate available for rendering the personalized courses. When screen real estate and characteristics such as bandwidth are limited appropriate personalization becomes much more important. This paper examines the usability of dynamically composed eLearning experiences on Personal Digital Assistant (PDA) devices.

INTRODUCTION

According to [Kukulska-Hulme, 02], usability is typically defined as being the effectiveness, efficiency and satisfaction with which specified users can achieve identified goals in particular environments. In order to get away from the traditional "one size fits all" attitude to eLearning, where every user is presented with the same content in the same order, an approach which takes into account the user's aims and prior knowledge, encompassing their tasks, pre-empted the development of systems which would be capable of adapting to individual users. These systems are known as adaptive hypermedia systems. [Brusilovsky et al, 02] outlines that a distinctive feature of an adaptive system is an explicit user model that represents user knowledge, goals, interests, and other features that enable the system to distinguish different users. The user model is used to provide an adaptation effect that tailors interaction to different users in the same context. An adaptive system automatically adapts to the user given a user model, whereas an adaptable system requires the user to specify exactly how the system should be different. Adaptive Hypermedia and web systems are essentially collections of connected information items that allow users to navigate from one item to another and search for relevant items. The adaptation effect in this reasonably rigid context is limited to three major adaptation mechanisms - Adaptive content selection, Adaptive navigation support and Adaptive presentation. While this paper touches on all three of these mechanisms it is particularly concerned with the presentation of Adaptive Hypermedia.

Presentation of content and navigation structures has to be considered in developing an eLearning application that is targeted for use on many types of terminal devices from which the learner may be accessing learning content. Wireless mobile devices are becoming increasingly widespread, with more and more people choosing to access the Internet and various Web services while on the move. This has directly influenced the growth in mLearning [Sharples, 00] where people wish to access eLearning resources from their mobile devices. This opens up a whole new range of design issues for eLearning interface designers .For example, the smaller screen real estate and decreased processing power of PDAs could adversely affect access to eLearning solutions.

These, and other, restrictions of such devices make them a challenging environment on which to deliver personalized eLearning experiences. Many of the adaptive hypermedia techniques employed in current personalized eLearning systems will be equally applicable for personalized mLearning. The primary difference between personalized eLearning and personalized mLearning is the medium through which the learning is presented and the presentation of navigational structures and learning content. The mobile nature of mLearning means that the content delivered should not only be tailored towards the learner's need, but also to their current situation or learning context. In order for this context, and in particular the device the learner is using, to be catered for in mLearning the presentation axis of adaptation should be considered. In many personalized eLearning systems the presentation axis is often seen as less significant when compared to adaptive content selection and adaptive navigation support. In mLearning, however, its significance increases substantially as it is the mechanism through which the personalized learning experience is formulated.

This paper describes the architecture and implementation of dynamically composible eLearning courses for PDAs. The first section of this paper will discuss some current Adaptive Hypermedia Systems, and also some systems that have taken into account some of the issues dealing with automatically configuring interfaces for specific devices. The architecture of the Adaptive Personalized eLearning Service (APeLS) [Conlan et al, 2002] that has been developed in the Knowledge and Data Engineering Group at Trinity College, Dublin will then be described briefly, including the specific changes made to a personalized Structured Query Language (SQL course running on APeLS to enable it for Personalized mLearning. The penultimate section will discuss the initial experiment that was conducted to evaluate the feasibility and usability of using APeLS to deliver mLearning using mobile-enabled PDAs. The paper will conclude with a Future Work section.

STATE OF THE ART

The goal of this section is to provide a background in which this trial and evaluation of eLearning on a mobile device, or mLearning, has been carried out. It briefly reviews Adaptive Hypermedia (AH), including a discussion of a number of Adaptive Hypermedia Systems (AHS). It also describes some of background relating to designing content and interfaces for PDAs.

Adaptive Hypermedia

Brusilovsky [Brusilovsky, 96] provides the following definition for adaptive hypermedia: "By adaptive hypermedia systems we mean all hypertext and hypermedia systems which reflect some features of the user in the user model and apply this model to adapt various visible aspects of the system to the user. In other words, the system should satisfy three criteria: it should be a hypertext or hypermedia system, it should have a user model, and it should be able to adapt the hypermedia using this model." To achieve this view adaptive hypermedia combines research efforts in the area of user-modeling, adaptive systems and hypermedia.

A hypermedia system is a collection of linked nodes (hyperdocuments), which have links through which the student can traverse to other nodes. When applied to eLearning AHS support the premise that different people learn in different ways and at different rates. In AHSs the learning experience can be tailored to their specific capabilities and past history. The techniques frequently employed in achieving this tailored learning are adaptive navigation structuring, adaptive content selection and adaptive presentation. Studies have shown that users of educational AHSs are faster, more goal-oriented and take fewer steps to complete a course. It was also noted that they are less likely to repeat the study of content that they have already covered [Conlan, 00].

A general-purpose Adaptive Hypermedia Engine [De Bra] may be viewed as being comprised of at least the following three elements:

- **Domain Model** – Consists of concepts and the relations that exist between them. Typically the domain model gives a domain expert's view of the domain
- **User Model** – Consists of relevant information about the user
- **Adaptation Model** – Consists of a set of rules or triggers, which indicate how various user actions update the user model and affect how the pages are adapted accordingly

AHSs apply different forms of learner model to adapt the content and links of hypermedia pages to the user. In many AHSs there tends to be separation of the learner model and the content model, but the narrative or pedagogical model is usually embedded in the content or the engine. In these cases, adding new or different pedagogical models to the content model is more difficult and involves a re-authoring of the content model. This results in learning content that is difficult to reuse or an engine that is domain specific. One means of enhancing the educational impact of eLearning courses, while still optimizing the return on investment, is to facilitate the personalization and repurposing of learning objects across multiple related courses [Conlan, 02].

The AHA project [De Bra, 01] was designed to implement a system that extends Web servers with adaptivity functionality in a transparent manner. A module registers users automatically and adapts the content and navigation structure to the information stored in a user model which is maintained by the system. This module is application independent and the source of the content may not necessarily be internal to the system.

The AVANTI [Avanti] project was aimed at catering multimedia information to the information needs of different users by adapting the content and the presentation of web pages to each individual user. A domain model, as well as user models which contained information about the characteristics of individual users, groups of users and various usage environments were maintained by the system and used in the adaptation process. Adaptation was invoked at the content level and at the user interface level. This dual adaptation effect allowed the system to optimize the way the content was applied and presented. The AVANTI system was aimed at providing personalized information across a wide range of users, with differing knowledge and abilities. The information it conveyed was hypermedia information about a metropolitan area.

The Adaptive Personalized eLearning Service (APeLS) [Conlan et. al., 02] approach taken to implement an adaptive education system is to provide a generic model for integrating the learner model (which describes the pertinent learner characteristics), content model (which describes the pedagogical qualities of the content and the narrative model (which describes a mechanism for combining the content to produce a coherent educational courseware component).

To achieve a high level of adaptivity the models require a high level of detail. Any models which are used as the basis for the learner or content models will need to be augmented to support the level of adaptivity hoped to be achieved. The principle metadata which needs to be added to all the models are more focused pedagogical elements. These should be pertinent to how the adaptive engine can combine the models to provide effective and coherent course material to the user. Elements containing information about the users' preferences should be reflected in all the models. The adaptive engine provides the facilities for reconciling the content, learner and narrative models to produce individualized content. The system is an adaptive metadata driven engine that composes, at runtime, tailored educational experiences across a single content base.

The TCD system has a clear separation of content, learner and narrative models, and a generic adaptive engine that employs a multi-tiered AI model to achieve effective adaptation to the learners requirements. The approach is to have very little semantics actually embedded in the adaptive engine itself. The adaptive engine reconciles, at runtime, the personalized course. The dynamic building of the course is controlled by each learner via appropriate pedagogic instruments. This approach enables multiple narrative models to be constructed to fulfill different learning goals, while these goals may be achieved from a common repository of content.

User Interface Design

Usability is defined as the measure of the quality of a user's experience as they interact with a system [Usability]. In order to establish basic human factor goals, a study of the user community and their set of tasks is necessary. Five of these which are important to evaluate are [Shneiderman, 98]:

- Ease of learning: How quickly can the user learn to use the interface?
- Efficiency of use: How fast can a user perform his/her tasks once they know the system?
- Retention over time: Can users who have used the system before instinctively use it when they come again?
- Error frequency and severity: How often are errors made by users and how easy is it for them to recover?
- Subjective satisfaction: How much does the user like using the system?

Half of all software support calls are due to poor usability [Nielsen, 00]. Users' satisfaction with a system increases when that system is easy to use. Ease of use increases when the system follows a consistent usage pattern and provides a familiar look-and-feel to the user. Users don't like to have to undergo training in order to be able to use a system. Systems must focus on user satisfaction, allowing the users to be able to relax, enjoy and explore the various features the system offers [Shneiderman, 02].

PDA Interface Design

It was reported in [comScore, 02] that 9.9 million Internet users in the U.S. use a personal digital assistant (PDA) or cell phone to access the Internet. [CompIndAl, 02] projected that 48% of Internet users in 2005 will be mobile Internet users. The World Wide Web consists of a huge number of pages for people to browse for work or pleasure. Unfortunately, most of these pages are designed to be displayed by computers with a large and high resolution monitor [Chu, 01]. When viewing pages on a device with a small and low resolution screen, display problems arise, making the experience very unsatisfactory for the user.

Therefore, the presentation of information on a small screen device provides many usability challenges. Some which have to be taken into account, according to [Usability] are as follows:

- Instructions and other similar text should be used sparingly and only when necessary
- Links should be brief and contain only necessary key words
- As with web pages, specific options should be presented before general options
- PDA users expect to find web-like interfaces on their handhelds
- Due to low screen resolution and small screen size, long narrative descriptions are not effective

The Dygimes [Coninx et. al., 03] project stems from a desire to create multi-device interfaces. This results from several observations of the growing trend of mobile devices. One of these observations is that the reuse of existing interfaces on new devices is problematic, specifically when the interface is constrained by hardware or software issues. The user also grows familiar with a "brand" of user interface design, which puts a pressure on user interface designers to create a consistent look and feel across several devices. In the framework developed in Dygimes, the design of the interface and the application code is separated, with smooth integration of the functionality and the interface supported. Therefore the resultant interface can be used on many devices, using standard functionality. This allows flexible reusability of existing designs. In the framework, the user interface is less dependent on device-specific properties, and is implemented through the use of XML-based UI descriptions. Task models, interaction models and context-dependent mapping rules are combined with these high-level XML-based UI description in order to generate interfaces which are device and system independent [Dygimes].

The Pebbles project [Pebbles] is exploring how handheld devices, such as Personal PDAs and mobile phones can be used if they are interacting with other electronic equipment, such as other handheld devices, appliances or normal desktop PCs. Appliance are becoming more advanced as more and more functionality is added. With the increase in functions often the interface to the appliance becomes more complex and harder to use. The Pebbles project proposes that separating the interface from the appliance may help the users to interact with the appliance. The idea is that every user would carry a personal universal controller (PUC) [Nichols, et. al, 02], a device which would allow the user to interact with all of the appliances or services in his/her environment. In order to control an appliance, the PUC communicates with the appliance, downloads the details of the functions of the appliances and automatically generates a remote control that is suited to the user and his/her PUC.

ARCITECTURE

The Adaptive Personalized eLearning Service (APeLS), and more specifically a personalized SQL course based on APeLS, is used as the basis for the personalized PDA-based eLearning System trialed and evaluated in this paper. This section briefly describes APeLS and the specific implementation required to apply the multi-model, metadata driven approach for adaptive PDA-based eLearning. APeLS is an adaptive system that is designed in accordance with the multi-model, metadata driven approach [Conlan et al, 02]. It supports the separation of the models that impact upon the personalization process. While the approach supports a multitude of models the three core models of learner, content and narrative are usually included. The learner model describes information about the learner that is pertinent to the personalization of the material; the content model describe the learning resources and the narrative model describes the concepts and pedagogical strategies that may be employed to teach a specific domain. It is important to note that the models remain discrete and separate. This, and the candidacy abstraction layer [Dagger et al, 03], facilitate their reuse.

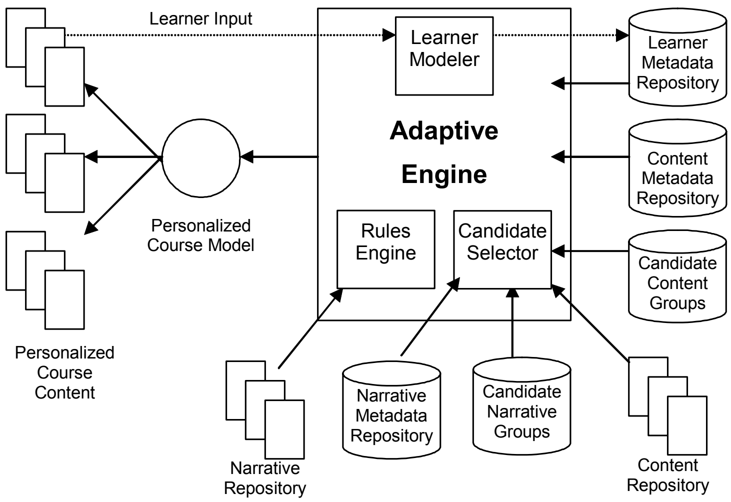

Fig 1. Architecture of APeLS

The ability to describe the narrative of a course independently of the content used to teach it enables the same narrative to be used in different versions of the course. For example, the PDA-based SQL course and the standard desktop version share the same narrative. The candidacy abstraction layer enables multiple versions of content for each concept in a course. Candidate selection is performed just in time as the course is being delivered to the learner. A separate model is employed to facilitate this selection process – the environment model. This model primarily describes the device the learner is accessing the personalized course from. This enables the candidate selection process to choose the most appropriate piece of learning content for a given concept and for the device the learner is using. Knowledge of the learner's device also enables the most appropriate navigation paradigm to be employed. Figure 1, below show the APeLS architecture.

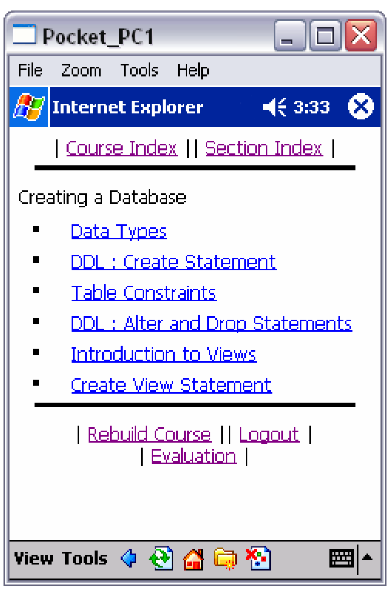

Fig 2: Sample Table of Contents

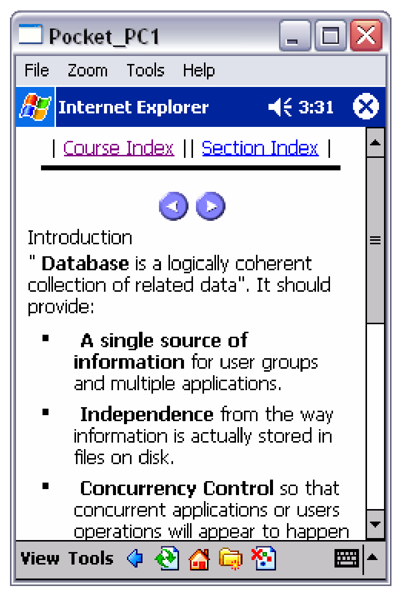

Fig 3: Example of Course Content

Potentially the only difference between delivering a personalized course for a single terminal device and for two different devices is the inclusion of additional content in candidate groups where the original content available was unsuitable for both devices. In the case personalized SQL course a minimal amount of the original learning content needed to be changed – this usually consisted of changing content that had images. The other area of the presentation that need some subtle changes was the interface placed around the content to facilitate navigation of the course.

Figures 2 and 3, above, show the results of the initial manipulation of the presentation for rendering on a PDA. Figure 2 shows a typical table of contents in the system. The table of contents is dynamically generated for the specific learner based on their prior knowledge of SQL (gathered through the pre-test instrument, Figure 4). It is generated based on information stored about the user in the learner model, such as their prior knowledge of the subject and their learning goals. As the navigation on the PDA is limited the the minimum necessary number of links to enable the user to get wherever is needed in the course. The user can access the *Course Index* and *Section Index*; can return to the initial questionnaire which evaluates his/her knowledge of the course, thus adapting the course to their needs, through the *Rebuild Course* option. The users can also *Logout* and can click on the *Evaluation* option in order to complete the questionnaire that was required at the end of the trial.

Figure 3 shows a page of content in the course, which introduces the concept of a database. Again the navigation structure is a simpler version than that of the original course. At the top of the content, the *Forward* and *Back* options can be seen. These allow the user to navigate through the pages on a particular topic. The bottom of the page also has *Forward* and *Back* links as well as an indicator as to which page in the sequence the user currently is. The links in the first diagram are also available to the user at the bottom of this page. The corresponding page in the original implementation of the course provides many additional links to the various other topics in the section as well as a textual description to the location of the user in the course. For this implementation, it was felt that this made the smaller PDA screen too cluttered and difficult to follow.

TRIAL AND EVALUATION

APeLS is being used in Trinity College, Dublin to teach the fundamentals of Structured Query Language (SQL) to seven undergraduate courses [Conlan and Wade, 04]. At present it is assumed that the personalized course will be viewed on a full size monitor and the presentation was implemented towards this. As an initial trial into the evaluation of the needs of mobile users of this tool, manual changes were made to the layout and presentation of the course on screen (described in the Architecture section).

Due to the nature of the original course, it was interesting to note that on first viewing the content on a PDA, the presentation of the content was usable and readable. One of the main issues identified with the original course, when displayed on a PDA was, the need for the removal of horizontal scrolling of content, as well as the need to minimize the amount of vertical scrolling. The major changes to the original course involved the resizing of HTML tables, the removal of redundant , links and the resizing of components to make the content easier to view. *Forward* and *Back* options were placed at the top of the content as well as the bottom to give the user the ability to navigate quickly through content pages without having to scroll to the bottom each time.

Evaluation

Human Computer Interaction (HCI) deals with the interactions between computers and the people who use them. According to [Lyng, 00], various principles and design rules have been derived for HCI. Principles are the goals from which design decisions are built, and reflect knowledge about human perception, knowledge and behavior. Some of the principles that have emerged over the years are:

- Naturalness: A natural dialog is one which does not cause the user to alter his/her approach to the task in order to interact with the system.
- Consistency: A consistent dialog ensures that expectations, which the user builds up through using one part of the system, are not frustrated by different conventions used in another part.
- Non-redundancy: A non-redundant design requires the user to enter in only the minimum information for the system's operation.

- Supportiveness: The supportiveness refers to the amount of assistance the dialog presents to the user in running the system. It has three major aspects:
    - The quantity and quality of instructions provided
    - The nature of the error messages produced
    - The confirmation of what the system is doing
- Flexibility: The flexibility of a dialog refers to how well it can cater for or tolerate different levels of user familiarity and performance.

The goals of the evaluation were to test the satisfaction of the learners with PDA based eLearning delivered through APeLS, and examine the efficiency with which they could navigate through the course. The evaluation also provided an initial investigation of the technical efficiency of the system, giving an indicator as to how long the development of a more advanced adaptive layout control will take (see the Future Work section).

The trial was carried out on a group of staff and postgraduate students from the Department of Computer Science in Trinity College, Dublin who had not used either the original personalized course or the APeLS system before. Some had previous knowledge of SQL, while others had no previous exposure to it. None had any experience of learning on a PDA. They all completed the trial on a Compaq IPAQ Pocket PC running Internet Explorer. At the start of the trial, the users had to complete an initial instrument to initialize the system with his/her knowledge of SQL (Figure 4).

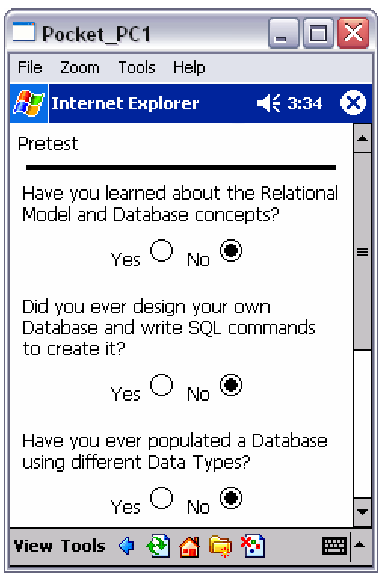

Fig 4: Prior Knowledge Instrument

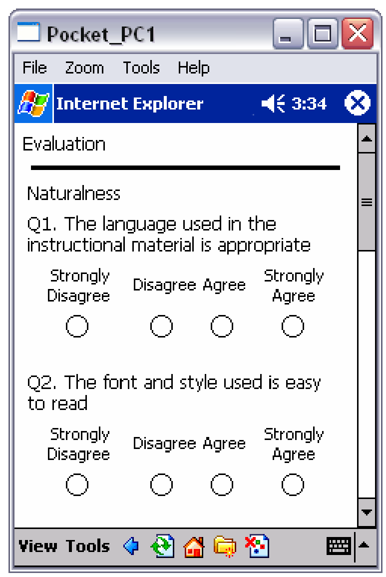

Fig 5: Portion of the Evaluation Questionnaire

The evaluation questionnaire was developed in Trinity College, Dublin as part of Mary Lyng's [Lyng, 00] research. The evaluation questionnaire developed addresses five principles in the evaluation of the adaptive SQL course. This questionnaire was used again as part of this trial to evaluate users' reactions to the presentation of the course running on a PDA. The users were asked to complete the questionnaire when they had completed their personalized SQL course. A screen shot showing a portion of the questionnaire can be seen in Figure 5.

To evaluate the *Naturalness* of the system, the following questions were posed:

1. The language used in the instructional material is appropriate
2. The font and style used is easy to read
3. The screen is not cluttered

4. The instructional material reads from left to right allowing for easy eye movement
5. Any colour, graphics, animations and highlighting used are appropriate
6. The text is distinguishable from the background
7. The meaning of icons used are intuitive to the User
8. The User does not require to perform a lot of scrolling to read the instructional material

To evaluate the *Navigation* usability of the system the following questions were posed:

1. Link items are distinguishable from text
2. Visited and unvisited link items are distinguishable
3. Navigation and direction through the instructional material is intuitive
4. Navigation is consistent across modules
5. Navigation is consistent between modules
6. Navigation is easy to use

To evaluate the *Supportiveness (User Support)* provided by the system, the following questions were posed:

1. Any error messages used are clear and detailed enough
2. Instructions provided are adequate
3. Instructions are available at all times
4. Examples provided are useful
5. There are an adequate amount of examples
6. The current state of the interface is easily perceived

To evaluate the *Consistency* of the system, the following questions were posed:

1. There is a consistent use of terminology
2. There is a consistent use of font and style
3. There is a consistent style used for error messages
4. There is a consistent use of colour
5. There is a consistent use of navigation and direction facilities
6. There is a heading on each screen and it is in a consistent position

To evaluate the *Non-Redundancy* of the system, the following questions were posed:

1. There is an adequate amount of instructional material on each screen
2. There is no repetition of instructional material
3. The direction provided to get through each module is sufficient and not superfluous

To evaluate the *Flexibility* of the system, the following questions were posed:

1. The Quit button is obvious and available at all times
2. The User can choose to go to any module desired at any time

For each question, the users were given four options to choose from. The user was asked whether they *strongly disagree, disagree, agree* or *strongly agree* with each statement.

Initial Results

When the users completed the evaluation questionnaire, the replies to the questions were stored in a text file. A summary, broken down into the relevant sections, of the initial results follows:

- *Naturalness* - Overall the users seemed to be happy with the naturalness of using the system. The primary issue the users highlighted was that there seemed to be too much scrolling necessary to view the contents of the course. Another feature that some users proved unhappy with was that they felt the PDA screen was too cluttered. A lot of steps have been taken to reduce the cluttering but obviously a lot of work is left to do. This result demonstrates the difficulty of delivering sufficient learning material to the learner without over-filling the screen. They also felt that the colors and highlighting used were not always appropriate. This issue arises from the limited capabilities of Internet Explorer browser used on Pocket PC for the trial.
- *Navigation* - The users seemed happy with all of the features mentioned in this section, with no major problems reported. The only noticeable issues were that some users felt the navigation and direction was not intuitive enough, with some finding the links indistinguishable from the text.
- *User Support* - They were generally happy with the support provided by the system, with some people feeling that instructions were not available to them at all times.
- *Consistency* - The users were very satisfied with this section, with no major problems regarding the consistency of the system.
- *Non Redundancy* - Again, all of the users agreed that the redundancy was minimal throughout their use of the system.
- *Flexibility* - There was a very mixed reaction by the users to their satisfaction with the flexibility of the system, with most feeling that they had trouble locating a *Quit* option at all times. They also found that they couldn't necessarily go to whatever module they wanted at any given time.

Overall, the results obtained back from the trial were favorable. The users felt that the personalization instrument was usable and they had no difficulty rebuilding the personalized SQL course to suit their requirements. The also found the navigation easy to use, though there were some issues highlighted relating to the length of content pages. These issues give an indication of some of the challenges in delivering personalized eLearning to a PDA and help to define the direction the design and implementation of the interface needs to proceed in in order to provide a usable and intuitive user interface to this system for use on a PDA.

FUTURE WORK

The goal of this initial trial and evaluation of PDA-based eLearning was to investigate the feasibility of using a common layout paradigm for multiple terminal devices. The ultimate goal of this research is to examine the prospect of applying adaptive techniques to the layout of content and interfaces on a variety of different devices and towards different user needs. If user interfaces are adapted for users based on their tasks and individual preferences, they must be of a quality that is comparable to manually constructed interfaces. This paper has examined some of the usability issues associated with using PDAs as a terminal eLearning device for personalized eLearning content. In TCD the future work in this area will explore adaptive layout while ensuring user satisfaction and usability is maximized.

REFERENCES

[Avanti] AVANTI Project, http://www.ifac.cnr.it/avanti/contents/over.htm

[Brusilovsky, 96] Brusilovsky, P. "Methods and Techniques of Adaptive Hypermedia", User Modeling and User-Adapted Interaction, 6, pp. 87-129, 1996.

[Coninx et. al., 03] Coninx, K., Luyten, K., Vandervelpen, C., Van den Bergh, J., Creemers, B. "Dygimes: Dynamically Generating Interfaces for Mobile Computing Devices and Embedded Systems". In proceedings of the 5th International Symposium, Mobile HCI 2003, Udine, Italy, September 2003

[Conlan, 00]Conlan, O. "Novel Components for Supporting Adaptivity in Education Systems - Model-based Integration Approach." Multimedia 2000, Los Angeles.

[Conlan at al, 02] Conlan, O.; Wade, V.; Bruen, C.; Gargan, M. Multi-Model, Metadata Driven Approach to Adaptive Hypermedia Services for Personalized eLearning. Second International Conference on Adaptive Hypermedia and Adaptive Web-Based Systems, Malaga, Spain, May 2002

[Conlan and Wade, 04] Conlan, O., Wade, V. Evaluating the Multi-model, Metadata-driven Approach to producing Adaptive eLearning Services, Submitted to AH2004. (2004)

[CompIndAl, 02] "Internet Users Will Top 1 Billion in 2005. Wireless Internet Users Will Reach 48% in 2005", Press Release, March 21st 2002, Computer Industry Almanac Inc. http://www.c-i-a.com/pr032102.htm

[comScore, 02] "Ten Million Internet Users Go Online Via A Cell Phone Or PDA, Reports comScore Media Metrix", Press Release, August 27th 2002, comScore Networks. http://www.comscore.com/press/release.asp?id=87

[Chu, 01] Chu, Kelvin Kam Wing "Universal Usability in Practice: Users With Small Screens – Less that 640 X 480". http://www.otal.umd.edu/uupractice/small_screen, April 2001

[Dagger et al, 03] Dagger, D.; Conlan, O.; Wade, V. An Architecture for Candidacy in Adaptive eLearning Systems to Facilitate the Reuse of Learning Resources. In proceedings of World Conference on E-Learning in Corporate, Government, Healthcare and Higher Education, Phoenix, E-Learn 2003.

[De Bra, 01] De Bra, P. "AHA! Adaptive Hypermedia for All", project proposal. http://www.nlnet.nl/project/aha/200106-aha-proposal.html

[Dygimes] Dygimes Project, http://www.edm.luc.ac.be/english/research/publications/136.html

[Kukulska-Hulme, 02] Kukulska-Hulme, A. (2002) "Cognitive, Ergonomic and Affective Aspects of PDA Use for Learning", presented at the European Workshop on Mobile and Contextual Learning, University of Birmingham, 20-21 June 2002

[Lyng, 00] "Experience Improving WWW based Courseware through evaluating User Satisfaction", M.Sc. in Computer Science, Trinity College, Dublin

[Nichols, et. al, 02] Nichols, J., Myers, B., Harris, T.K., Rosenfeld, R., Shriver, S., Higgins, M., Hughes, J. "Requirements for Automatically Generating Multi-Modal Interfaces for Complex Appliances," IEEE Fourth International Conference on Multimodal Interfaces, ICMI'02. Pittsburgh, PA. October 14-16, 2002. pp. 377-382

[Nielsen, 00] Nielsen, J. "Designing Web Usability". New Riders Publishing, 2000

[Pebbles] Pebbles Project, http://www-2.cs.cmu.edu/~pebbles/

[Sharples, 00] Sharples, M., The design of Personal Mobile Technologies for Lifelong Learning. In Computers & Education, 34, 177-193, 2000

[Shneiderman, 98] Shneiderman, B. "Designing the User Interface; Strategies for Effective Human-Computer Interaction", Addison Wesley Longman, March 1998

[Shneiderman, 02] Shneiderman, B. Leonardo's Laptop: Human Needs and the New Computing Technologies. MIT Press, 2002

[Usability] U.S. Department of Health and Human Services: Usability. http://www.usability.gov/