The Use of Learning Styles in Adaptive Hypermedia

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Abstract

Computer-based learning has become a common phenomenon in the modern age. Many distance-learning systems distribute educational resources on the Internet and indeed entire study programmes are now widely available online. Such a large amount of content and information can be intimidating to learners, who may exhibit different individual characteristics, such as variation in goals, interests, motivation and/or learning preferences. This suggests that a uniform approach taken by learning environments to deliver materials and resources to students is not appropriate and that personalisation of such materials/resources should address users' differences to provide a customised learning experience, thus enhancing its effectiveness, lowering drop-out rates and maintaining high student motivation.

This thesis addresses the latter issue of learning preferences, specifically investigating learning styles as an adaptation mechanism for personalised computer-based learning. A number of previous studies indicated the positive effect that this kind of adaptation provides, but under closer examination these were not conducted in a scientifically rigorous manner and thus their findings are somewhat limited.

This research utilises a quantitative and highly objective approach to investigate visual/verbal and sequential/global learning styles in different user groups. Three user trials were carried out to discover whether there were any benefits to using these learning styles for studying in an adapted environment.

Overall, no statistically significant benefits were found and these findings now shed doubt as to whether learning styles are indeed an effective mechanism for personalised learning.

CHAPTER 1:

INTRODUCTION

In today's society there is a growing number of online learning environments and educational resources, used by people all over the world. There seems to be much diversity in these learning tools, in terms of where and how they are used, what the subject matter is, the level at which they are pitched and the quality of the content, for example. But how do people learn in these online environments? How might we expect them to utilise these resources? Should we be treating all our pupils in one virtual "class" all the same way, even when we know they are in fact very different from each other in the "real world"? Can we – and should we – be providing differentiated, or adapted, learning materials to address these differences? These are the questions that inspired this research: a real need to find out what might make online learning more effective and to prove this in a quantitative manner. Conversely, this work also examines potential preconceptions about student differences and advises caution where no educational benefit can be shown.

The work presented in this thesis draws on the fields of education, psychology and computer science. It seems that the answers to the research questions asked here can only truly be sought by combining the theories and practices of these disciplines; each, in isolation, is not sufficient.

Cross-disciplinary research seems to be a rapid growth area within academia in recent years and the advantages are obvious: greater affordance of technical innovation [185]; better integration of knowledge via discovery and dissemination of findings across subject areas [146]; and enrichment of international research activities [146]. There has lately been a considerable expansion in the number of research papers of an interdisciplinary nature; Braun and Schubert provide evidence of exponential growth of such papers in the scientific domain (doubling every 7 years), in contrast to the usual growth rate of scientific fields of interest (doubling every 15-20 years) [35].

From the field of education come theories and processes of learning, such as computer-based learning; distance learning; Vygotsky's social constructivism [209, 210] and behavioural paradigms such as Bloom's taxonomy [26]. It is critical to understand how web-based technologies such as community-created knowledge repositories (e.g. wikis) and enhanced communication (e.g. blogs and social networking websites) impact upon modern learning opportunities and augment them. It is likewise essential that such technologies or pedagogical approaches are not implemented because they are novel or in accordance with the latest fad, but because they genuinely provide additional benefit to the learning experience.

Personalisation of web-based learning is an important issue for researchers in the educational and computer science domains. A core aspect of personalisation is what exactly should be customised: what features of the user can be modelled computationally and how should this information then be used? A recent trend involves an idea from cognitive psychology that relates to a person's "learning style": the way in which that person prefers to obtain or perceive information and how it is then processed in a cognitive framework in order for it to have meaning and be retained in memory. There is a wide variety of studies that have utilised learning styles as an adaptation mechanism in computer-based learning systems but few of them have been rigorously tested. For these systems, there is no statistically significant evidence that suggests they offer any specific benefit to users, although most of them offer small-scale qualitative and/or anecdotal indication of a positive effect upon users.

The challenge thus seems clear: if these systems are indeed an effective way of improving learning, the approach employed by them should stand up to empirical investigation. An objective stance must be taken and no expectations employed by the researcher until firm evidence lends support to one hypothesis or another. This research aims to provide a thorough examination of the issue of learning styles as a means of personalisation for computer-based learning and presents empirical evidence garnered from user trials to support or refute the hypotheses in question. Ultimately, the crux of this body of research can be summed up as: just because we *can* provide personalisation to a person's learning style, does it mean that we *should*?

1.1 Background to this work

Much of this work builds upon earlier projects developed in the last two decades at the University of Nottingham. Dr Peter Davies, director of the IBiS[1] research group in the School of Biology, was an early adopter of multimedia and worked on a Laserdisc project in the 1980s called "Images of Life". This was a collection of biological multimedia, consisting of several thousand still images and several hundred movie clips and was motivated by a personal desire to find a better way of storing images than, for example, a box of 35mm slides. The "Images of Life" Laserdisc was coupled with the IBiS system (after which the group was named), which provided interactivity in the form of a basic navigation system. By the means of mouse clicks and drop-down menus, users could browse particular biological or geographical information pertaining to the media that they were engaging with at the time. This information was limited to a series of particular topics though, since there was not enough storage available to cater for

[1] Abbreviation of Interactive Biological information Systems.

all the available media. The hardware used for the project was a substantially modified BBC Model B computer, that contained a hard disk, a mouse, a rudimentary Graphical User Interface (GUI) and hardware video overlay, that merged the digital computer display with the analogue Laserdisc video. The media information was created and edited using Microtext (an authoring system for BBC Computers). It used a hierarchical classification system similar to that of TELCLASS[2] but was much more limited as it could not categorise concepts. A number of copies of "Images of Life" were made available to libraries and archives; likewise, the interactivity provided by IBiS was shown to a wide variety of people, including publishers, in order to demonstrate the potential of the system. However, these two systems suffered from the decline in popularity of Laserdiscs and corresponding growth area in DVDs and as a result are not widely used now.

Much of this important early work fed into a subsequent project: a multimedia CD-ROM named the "Multimedia Encyclopaedia of Mammalian Biology" (MEMB), based on Grzimek's "Animal Life Encyclopaedia" [105] and published by McGraw Hill, who had been impressed by the IBiS system. Unlike many other multimedia encyclopaedias produced on CD-ROM at that time that often constituted merely pages of scanned text from the original book, MEMB was truly a mix of media types. It utilised not only text and images but also video and sound. Some early personalisation was introduced, so that the user could arrange the elements on screen to their liking; likewise, a search facility was provided so that the user could find specific concepts by using a thematic keyword [196]. The development of MEMB also involved the use of "chunks" of content within a semantic framework, a concept later employed by both the Scholar's Desktop and WHURLE systems.

Scholar's Desktop was produced following the success of MEMB. It contained a series of courseware tutorials relating to biological topics and encouraged an independent, reflective learning approach amongst its users [34]. Scholar's Desktop also allowed students to create their own path through different topics and pages and provided for different types of learning, such as deep and surface strategies. It was used as part of a "Biodiversity" undergraduate module, which utilised a blended learning approach of mostly computer-based multimedia learning with several face-to-face guest seminars. The module was delivered to undergraduates for the first time in 1996; the focus on computer-based learning as the main teaching resources was considered unique at the time and highly innovative, both within the university itself and Higher Education as a whole. It also facilitated many of the benefits seen by today's digital learners such as freedom from geographical and temporal restrictions, since the main software

[2] TELCLASS is a TV programme classification scheme developed by the BBC in 1979 to index the BBC's video collection [91].

was available on CD and could be installed locally, as well as being available for use in the School of Biology's computer lab.

In the "Biodiversity" module, Scholar's Desktop was accompanied by a software system called "Knowledge Tree". This system combined the functionality of a bulletin board with a hierarchical concept-oriented database to support discussions at both a student/student and also student/tutor level [31]. It was inspired by Ackerman and Malone's "Answer Garden" system [2] but with several important modifications such as catering for peer-to-peer interaction.

In 1999, the module became jointly convened at both the University of Nottingham and Hong Kong University, under the auspices of an inter-institutional collaboration called the Virtual School of Biodiversity (VSB) [202]. Scholar's Desktop became a component of local Learning Support Centres (LSCs), where each LSC was a website based at either Nottingham or Hong Kong, to support the students at each institution[3]. As part of the module, students at both universities had to work with each other in international groups (i.e. composed of members from both Nottingham and Hong Kong) to produce an assessed deliverable. This group work aspect displayed some of the problems common to distributed learning, where cultural and technological disparities between the student populations were exacerbated by a 9-hour time difference. Another aspect of the project was the way in which students learned differently – both within each local population and between the different institutions – discussed in a panel presentation at the 2001 Association for Learning Technology (ALT) conference [117]. An exploratory longitudinal study had also been carried out, investigating deep and surface learning styles[4] in the students, but the quantitative data was insufficient to analyse statistically. There did however, seem to be a trend in the development of deep learning from surface learning in the majority of students from the start to the end of the course, especially in the students from Hong Kong University. At the time, it was thought that the independent, constructivist approach facilitated by the computer-based integration of teaching and learning might have fostered a deeper appreciation of the subject matter in the students.

However, in terms of software development, Scholar's Desktop was less than ideal: the content was "locked in" through the system's own mark-up language and subsequent compiled code and there was also no concession made for different user models or personalisation mechanisms. The different ways of learning were in fact limited by the constraints of the system. To remove these limitations (and to take advantage of the growing popularity of, and benefits offered by, the World Wide Web) it was decided to produce a web-based version of the Scholar's Desktop. Developed by Dr Tim Brailsford and Dr Adam Moore at the University of Nottingham, the resulting system ("WHURLE") became the delivery vehicle for cross-

[3] See http://ibis.nott.ac.uk/vsb/Virtschl7_2B.htm for details.
[4] The model used was that of Biggs' Study Process Questionnaire [21, 22].

institutional learning via the VSB. The strengths of WHURLE lie in reusable content and its open architecture, so that content can be parsed from the original Scholar's Desktop units and then re-purposed in WHURLE where needed. It has been successfully used by a number of students, initially via the VSB but also in other universities across the UK [201].

WHURLE also allows adaptive presentation of its content through easily-modified filters [32, 33, 150]. Recent research examined the use of a hybrid model of adaptation, based on the user's knowledge within a specific domain, so that the appropriate range of material might be seen by beginning, intermediate and advanced users [231, 232, 233]. However, it was felt that this was possibly an over-simplified view of the learning process and that a more useful user model might accommodate learning preferences (or "styles") to provide a higher level of pedagogical sophistication.

1.2 Research objectives

This research investigates the impact of using aspects of learning styles to provide personalisation in computer-based learning environments. It provides empirical evaluations of how different user groups studying certain subjects interacted with e-learning systems that provided content that was adapted to support different learning styles.

A crucial feature of this research is that it was conducted from a strictly objective viewpoint so that the experimental work therein was not tainted by any subjective bias.

The objectives of this research are as follows:

a) to investigate how learning styles can be used to provide personalisation for students in computer-based learning.
b) to conduct user trials amongst groups of learners who engage with e-learning systems that employ learning styles as the main adaptation mechanism.
c) to utilise a strong quantitative approach in the experimental design and statistical processing of data from the user trials.

1.3 Contribution of this research to the state of the art

The research reported in this thesis has made some important contributions to knowledge in the area of adaptive hypermedia.

The major contribution of this work results from the empirical studies carried out, which state, for some user groups using some aspects of learning style personalisation, there do not seem to be any statistically significant benefit. More specifically, these conclusions relate to the adaptation of e-learning materials to visual/verbal learning style in undergraduate and taught postgraduate students at university and sequential/global learning style in Year 5 and 6 primary school pupils.

The minor contribution resulting from the research concerns the experimental approach utilised with these studies. As a discipline, computer science has traditionally been lacking in thorough empirical studies, certainly when contrasted with other scientific domains. It was decided early on in this research that quantitative evaluations were essential to determine whether the methods of adaptation under investigation were beneficial to their users. The methodologies used in this research are thus a secondary, yet still important, contribution to the field since these techniques are either not widely practiced or are not conducted to an appropriately high quality. The methods employed throughout this research aim to rectify these shortcomings. In addition, the research extracts and interprets patterns in weblog data to determine aspects of user behaviour, in a way that has not been done before in the area of adaptive hypermedia.

1.4 Overview of the thesis

Although rooted in computer science, in particular the area of adaptive hypermedia, this research has complex interactions with cognitive psychology and theories of learning. The literature review (Chapters 2, 3 and 4) attempts to present a balanced introduction to these themes, together with a reminder of experimental techniques used to elicit data in user trials.

The following sections (Chapters 5 and 6) detail two studies that investigated the idea of matching and mismatching students' learning styles to their learning environment. These studies tested various hypotheses that suggested that matched learning would be beneficial to students and mismatched learning would be disadvantageous. The findings, however, showed no statistically significant difference between experimental groups.

The last chapter (Chapter 7) discusses the outcome of the user trials and the resulting conclusions that can be drawn from them. Finally, the impact of this research is considered in a wider capacity, including the process of learning as a "wicked problem" and the complications that arise from comparable educational studies.

1.5 Summary

There are many studies that attempt to quantify the impact of using learning styles within an educational framework. However, there is a paucity of research in which empirical data is presented to support or refute the benefit of doing so, particularly where the data sets are sufficiently large to be able to analyse statistically.

As scientists, we must base our knowledge on firm evidence garnered from quantitative research; we require empirical verification to support or reject formal hypotheses. The fundamental belief centred in this work is that a theory must be proved before it can be accepted. The concept of learning styles is a very appealing one but their educational benefit has not yet been established. This research is thus a primarily quantitative study into the supposed benefits of learning styles as a method of personalisation for computer-based learning. It seeks to re-address the balance of carefully controlled user trials and allows the collection and analysis of empirical data to endorse the findings of the studies herein.

To date, six publications have arisen from this research (see Appendix F for details), including two that have won "Best Paper" awards in their respective conferences.

The main findings of this research have inspired debate amongst those academics that currently work with learning styles for adaptation mechanisms, since the results are largely negative and thus do not advocate this approach (in direct contrast to previous early studies). Some colleagues from other institutions have disagreed with the conclusions of the work, whilst a somewhat larger number have agreed with the findings and approved of the methodology employed. A large amount of satisfaction has come from the deliberations that this work has evoked, since without informed arguments and debates, there can be only limited expansion in knowledge of the research community as a whole. This ideal is best exemplified in the words of Albert Einstein:

"*The important thing is not to stop questioning*."

CHAPTER 2:

THE CHANGING FACE OF LEARNING

2.1 Introduction

The previous chapter gave a broad overview of the concepts and ideas explored in this thesis and provided a comprehensive historical perspective leading up to the work itself.

In this next chapter, the issue of learning is focused upon, particularly in respect to how it has changed as a result of increased deployment of computers and the Internet as educational tools.

2.2 The use of computers to support learning

As the number and use of computers has increased over the last 40 years, they have been gradually incorporated into educational settings. Initially used for teaching typing and word-processing, computers and software have evolved dramatically so that online education is now a reality for many students across the world. This electronic learning (or “e-learning”) is delivered by a variety of educational establishments to both local and remote students. Some universities offer entire degree courses online, such as the University of Illinois[5] in the USA. This form of distance learning is gaining in popularity and many thousands of students register for online courses every year. There is also a growing area of mobile learning, or “mLearning”, that uses mobile devices (such as mobile telephones and PDAs) as the main platform for the provision of the learning experience, either via a web browser or other, often bespoke, software [133]. These terms are further expanded upon in Section 2.4.

Many computer productivity suites used for teaching school pupils in the UK focus on task-based transferable skills [81], such as word-processing; creating and manipulating spreadsheets; and using the keyboard and mouse. In recent years, pupils have also been encouraged to use the Internet for gathering information, especially in relation to projects on a specific topic and for using interactive applications such as educational games. Computers are also useful for supporting pupils with emotional or behavioural difficulties [119] since they result in increased motivation, help develop personal and social skills and also aid in the communication and expression of ideas.

[5] http://www.online.uillinois.edu/

Much educational software is supplied on DVDs or CDs, although such applications often include a series of web links, to be used in conjunction with the DVD/CD, or as an extension to the software. Initial computer use within schools was limited to standalone machines and thus CDs, floppy disks and later, DVDs were the only way of loading software onto them. With the advancement of networking, many schools have a computer suite that consists of several PCs on a local area network (or LAN), allowing the provision of intranets in addition to a relatively fast Internet connection. Software is loaded onto the main server, and distributed over this network. Pupils often have their own account on the server and are able to save their work in a private user area that is only accessible to them and the network administrator [17]. This is echoed in Higher Education, where many students log on to their university or college network and use a variety of applications, accessed through central servers or LANs.

This greater involvement of the Internet and web-based technologies has enhanced the way in which pupils and students can use educational technology to carry out their studies. Not only is there a wealth of information immediately accessible, there are also communication systems (both synchronous and asynchronous), online communities and even dedicated learning environments.

Virtual Learning Environments (VLEs) and Intelligent Tutoring Systems (ITSs) are two classifications of dedicated learning environments. They are usually web-based and accessed via a username and password. VLEs such as Moodle[6], BlackBoard[7] and WebCT[8] are used by many educational establishments to create an online environment to support their students (these systems discussed more fully in Section 2.5). For example, they typically include functions to view and print off lecture notes; a timetable or schedule for lectures or assignments; a discussion forum for staff members and/or students to post messages to; a chat room; an electronic submission system for coursework and email support from lecturers or other members of staff [116].

An Intelligent Tutoring System is a computer application that seeks to provide personalised instruction or tutoring through a variety of technologies, such as artificial intelligence (AI) and expert systems. It is dependent on three things: the knowledge of the learner, the subject to be studied (knowledge of the domain) and the way it is to be taught (knowledge of teacher strategies) [218]. REDEEM [4] and ELM-ART [48] are examples of ITSs that have been used successfully by a variety of different users.

Adaptive Hypermedia (AH) is a slightly different paradigm from that of ITSs: it seeks to provide a personalised learning experience for users, but the process is much more user-driven (compared to system-driven) than with an ITS [39]. AH systems attempt to give the user more

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[6] http://moodle.org/
[7] http://www.blackboard.com/
[8] http://www.webct.com/

control than traditionally seen in ITSs, where the underlying methodology of the system tends to "lock" users into a pre-determined course. The user model that is integrated into AH systems tends to be more flexible than those seen in ITSs. Historically, both kinds of systems have evolved in parallel, but in different disciplines: ITSs have emerged from the fields of psychology and AI, whilst adaptive hypermedia has resulted from computer science (specifically, the areas of hypertext and user modelling) [42]. The two approaches are not mutually exclusive however, and there is much overlap between these areas of research. The next section examines the historical developments that have enabled modern learning environments to come into being and the key contributions made by a diverse but highly dedicated assortment of engineers, mathematicians, psychologists, educationalists and computer scientists.

2.3 The innovations underpinning modern learning environments

2.3.1 Distance learning

One of the key features of modern web-based learning environments is the capacity for users to learn remotely, from a different geographical area, explained more fully in Section 2.4. However, distance learning is not a new phenomenon and there is evidence to suggest it dates back as early as the early eighteenth century, where Caleb Phillips, a teacher of shorthand, placed an advertisement in the Boston Gazette on 20th March, 1728, offering to send weekly lessons via the postal system to students who lived in the US and who wished to learn shorthand [29]. This was the start of what later became correspondence courses, a method of learning carried out by postal communication.

In the twentieth century, the postal mode of learning was supplemented by use of radio transmissions, audio recordings and eventually television programmes. Simonson *et al* state that, in the 1920s, nearly two hundred radio stations were involved in distance learning courses across the USA [189]. The Western Reserve University was the first American university to offer television-based courses in the 1950s [189].

In the UK, the founding of the Open University (OU) in 1969 created the cornerstone of modern British distance learning [113]. The OU offered entire degree courses, delivered through distance learning and fully exploiting the most commonly-used forms of communications technology. Their innovative teaching model and commitment to high-quality learning experiences inspired similar programs in institutions across the world, raising the profile and prestige of distance learning [29].

2.3.2 The role of computers and networking

Another key feature of learning environments is the way in which teaching and learning can be delivered and/or enhanced by computers and the way in which they are interconnected.

This concept of linking together related concepts was first envisaged by Vannevar Bush in his article ‘As We May Think’, published in 1945. He discussed the idea of a personal library management system, or ‘memex’, which would contain a large amount of information stored by the user, as a supplement to an individual’s memory. This information would be mechanized to allow for rapid searching and the construction of a knowledge ‘trail’ that would allow the user to link together a number of pieces of information [51]. One of the key concepts of the memex was associative indexing: this meant that a piece of information could, upon request, select another piece of information. The memex was never built but it gave rise to the concept of linked information, which later developed into the principles of hypertext and hypermedia.

This idea of information networks and connecting disparate information was further explored by Ted Nelson and Douglas Engelbart.

Ted Nelson is widely accredited with coining the term ‘hypertext’, meaning “*a body of written or pictorial material interconnected in such a complex way that it could not conveniently be presented or represented on paper*” [154]. His Xanadu Project, started in the 1960’s, is a vision of the world’s first hypertext system for authoring and publishing text and other media. Xanadu presented several important concepts, the most important of which was transclusion. Transclusion is the virtual inclusion of part of a document inside another document – i.e. reusable hypermedia. Nelson also addressed the issue of copyright and payment systems; he stated that transclusion could occur through a system of micropayments to the authors of the documents, who in turn would have copyright control over their own publications. He also created the term hypermedia and defined it as “… branching or performing presentations which respond to user actions, systems of prearranged words and pictures (for example) which may be explored freely or queried in stylised ways. Like ordinary prose and pictures, they will be media; and because they are in some sense ‘multi-dimensional,’ we may call them hyper-media, following mathematical use of the term ‘hyper’.” [156].

Douglas Engelbart, best known as the inventor of the computer mouse, has also been a pioneer of computer-enhanced learning and thinking. Engelbart has suggested that the level of current technology influences how we are able to manage information; this in turn will impact upon our capacity to develop future technical innovations [88]. He established the Augmentation Research Center at SRI International in the 1960s, where he designed and developed a collaborative hypermedia system named NLS (oNLine System), later known as Augment [89]. This was demonstrated at the 1968 Fall Joint Computer Conference in San Francisco and later became known as “the Mother of All Demos” due to its smooth technical delivery and the presentation of new innovations such as the mouse; the use of windows and display editing; document version control; hypermedia with integrated email; shared screen teleconferencing; context-sensitive help; distributed client-server architecture and extensible, user-programmable tools [89, 128]. It was an extraordinary occasion, becoming a landmark event in the history of computer networking and machine-augmented communication. Engelbart also developed early user-interface designs long before the personal computer became popular; these were pre-cursors to the graphical user interface created by researchers at Xerox PARC.

These visions of information networks were extremely forward-thinking, especially given that the hardware to support them had yet to be constructed. Linking together computers so that they could communicate with each other did not occur until the late 1960's, when researchers at ARPA (the Advanced Research Projects Agency) in the USA created ARPANET, a computer network to allow academics at different universities or research institutes to send and receive data to one another. Initially a series of 4 nodes linked together by a telephone line (one of the nodes being Engelbart's research lab at SRI), the size and range of ARPANET grew relatively quickly: in 1972 there were 23 nodes and in 1981 there were over 200 nodes, with a new host added every month [106]. ARPANET and other similar networks that had evolved subsequently (such as SERCnet – a network between British academic and research sites and IPSS – International Packet Switched Service, the first international packet switched network) started using the TCP/IP protocol to communicate in a standardised manner and this network of networks became what is now known as the Internet.

The World Wide Web, a system of interlinked hypertext documents, is one of the most commonly-used applications of the Internet. It was devised in 1989 by Tim Berners-Lee and Robert Cailliau at the European Physics Laboratory in Geneva (CERN) and was based upon Berners-Lee's ENQUIRE system [52][9]. The World Wide Web provided a standardised approach to sharing scientific information with other researchers and it was accessed via the first Web browser, initially called WorldWideWeb but later renamed Nexus to avoid confusion [19].

The emergence of the Mosaic web browser in 1993 (and later, its evolution into Netscape Navigator) helped popularise the Web and many people started to use the Internet to access web pages, find information and send email. In the last 10 years, the number of nodes attached the World Wide Web has grown exponentially and today millions of people across the world use HTTP, TCP/IP, FTP and Telnet protocols regularly to search for knowledge, communicate with friends and family, go shopping and carry out financial transactions. The emergence of "Web 2.0" applications have made social networking across the Internet easier than ever, with the emphasis on interaction and control of content by users themselves.

[9] Berners-Lee acknowledges that both the World Wide Web and ENQUIRE are based upon a simplified version of the linking model in Nelson's Xanadu.

In this new age of evolving data creation/modification, access and "intertwingularity"[10], it seems as if the early ideas of Bush, Nelson and Engelbart have finally been realised, at least in part.

2.3.3 Learning with computers

Computers have been used to support learning for several years. Generic applications such as calculators, spreadsheets and word processors were some of the early popular tools; as graphics capabilities of computers evolved, so did the software that exploited them. This lead to better user interfaces and image-rendering capacities which, when combined with the expansion of computer memory, facilitated much more complex applications, such as those that included multimedia i.e. a mixture of media types such as text, audio, still and moving images.

Educational software was quick to integrate multimedia both in terms of enhanced content and better engagement/interaction by the user. In its growth era of the 1990s, a new terminology emerged to define the ways in which computers and associated educational software could be used to support learning. These terms are now discussed below.

Computer-based learning (or *CBL*) is a phrase used to describe any kind of learning where computers form a key component of the experience. It is not used where learning is seen as a peripheral objective, such as word-processing a school report (unless the word-processing task is itself a learning experience) [221].

Computer-based training (CBT) tends to describe computer-based learning in a workplace environment, where the aim is to learn a particular skill or proficiency related to a person's occupation. It might include a tutorial on how to use a particular application or device, or it might show practical procedures such as those seen in aviation training [190].

Computer-assisted instruction (CAI) or *computer-assisted learning (CAL)* is another commonly-used term. It is used to describe a situation where computers are used as tools to support learning but they tend not form the predominant instructional method. They should be one of several resources that students can utilise in the attainment of the learning objectives pertinent to those circumstances, but not the central equipment (unlike computer-based learning or training) [158].

E-learning or *technology-enhanced learning (TEL)* are two much more recent expressions, often used in relation to *online learning* or *web-based learning (WBL),* where the primary mode of delivery and student/tutor interaction is via the web. However, e-learning and technology-

[10] "Intertwingularity" is a phrase borrowed from Ted Nelson, used to express the complexity of human knowledge and its interrelations [156].

enhanced learning does not necessarily include the web, although in reality they usually do, to a greater or lesser extent.

These terms, used to describe the role of computers within the educational experience, are used interchangeably and the amount of overlap between them is considerable. For ease of use, the phrase “computer-based learning” will be used throughout this thesis to encompass these approaches.

A related phenomenon is that of computers used for examinations, referred to as *computer-aided assessment (CAA), computer-based assessment (CBA)* or *e-assessment*. Again, the emphasis on computers as the main facilitator varies between these; likewise there is also much diversity in the specific applications used for assessing students. In many systems, computer-based learning and assessment is carried out via web applications; this is discussed further in Section 2.4.

Another aspect of learning with computers relates to the pedagogical perspectives that underpin it. Bloom’s taxonomy classifies learning objectives into three domains of learning: cognitive, affective and psychomotor [26]. *Cognition* deals with how the brain works and the cognitive processes involved in learning, such as comprehension and construction of knowledge. *Affective processes* describe emotional aspects of learning, such as motivation; user engagement; behavioural characteristics; and mental processing and organisation of concepts. *Psychomotor processes* are those that require the physical manipulation of tools or instruments [26]. Computer-based learning tends to lend itself better to the first two of these approaches, since psychomotor learning is not especially relevant here (unless the use of a mouse and keyboard is included in this category).

Additional pedagogies exist, such as *instructional design*, a curriculum-focused approach, usually developed by a central group or core tutor [59]. Laurillard's *conversational model* was developed primarily to support the use of technology and computers within Higher Education, and states that, to learn effectively at a higher level, a learner has to integrate the experiences and theories of other people, so that learning becomes a dialogue between teacher and student (although the roles of the teachers and students may vary, e.g. researcher; negotiator; collaborator; storyteller) [127]. A related approach is that of *social constructivism*, a collaborative approach originally postulated by Vygotsky in the 1930’s[11], whereby students make use of the social networks surrounding them and subsequent interpersonal exchanges, in order to create and organise knowledge and further develop their own potential.

Computer-based learning utilises aspects of many of these pedagogical approaches, such as social constructivism, as seen in the context of wikis, blogs and discussion forums. However,

[11] Although it is worth noting that Vygotsky’s ideas only achieved recognition in the West from the 1960s onwards, as evidenced by [210].

one of the growing concerns of those who work with computers to support learning is how to provide differentiation to cater for the variety of diverse learners. This is addressed in Chapter 3, where the concept of adaptive hypermedia is introduced. Before this is discussed, it is critical to first examine the way in which the Internet has shaped the course of computer-based learning.

2.4 E-learning and the influence of the Internet

The Internet revolution and emergence of the browser and other web applications have created new environments in which learning can take place, both formally and informally. There is now a large amount of information available to web users, so that the phenomenon of 'ubiquitous learning', where learning can happen at any time and anywhere, is enhanced and augmented by new technologies [70]. For example, a user might have access to the web via a mobile phone, wireless hotspot or a cybercafé [131]. Users are not necessarily engaged in a formal learning situation; rather, the search for knowledge and subsequent mental assimilation of such information is a type of learning that the user might not perceive as being an educational experience. It is a concept related to 'ubiquitous computing', where computing power and devices are almost invisibly embedded into everyday objects and accessed via intelligent interfaces, so users do not have to consciously think about their interactions with them [130].

Distance learning has exploited this new method of communication very successfully and many thousands of students across the world are engaged in distance learning programmes at any one time. Distance learning, often referred to as distance education, is when students do not have to be physically present at a particular geographical location in order to participate in their education. It is distinct from *open learning*, where the student has control over the time and the place of learning; distance learning is defined as the student and instructor being separated by time (although not necessarily) and place. Many distance learning programmes utilise an open learning methodology[12], but the two concepts can be mutually exclusive [151].

Distributed learning is similar to distance learning, but whereas the latter concentrates on a central body of teaching resources/tutors and a disparate body of students, distributed learning is when there is a central body of students and instructors that make use of a diffuse set of resources, such as those found on the Internet [73]. Distributed learning is at its most powerful when there are several distributed-learning groups that are geographically distinct but collaborate to form an alliance with one other, such as the Virtual School of Biodiversity (mentioned previously in Chapter 1).

[12] such as the Open University: http://www.open.ac.uk/about/ou/

Another term commonly in use is that of blended learning. This is a combination of two or more approaches to learning, typically utilising face-to-face instruction with some form of technology-based materials and resources [8].

A number of applications have gradually evolved in order to make online learning much easier to facilitate and more scaleable. A *virtual learning environment (VLE)* is a software system that helps to manage a computer-based learning course; the term is often used interchangeably with *managed learning environment* or *MLE*. A number of commercial and free VLEs exist; these are discussed further in Section 2.5. VLEs usually exist as a web platform and typically have different types of login for administrators, teachers and students. The services provided by a VLE typically include course content pages (created by the teachers); course administration facilities; synchronous and asynchronous communication tools such as email, instant chat, blogs and bulletin boards; and access control [28, 37].

A *learning management system* or *LMS* is a similar type of application to a VLE but it goes beyond computer-based learning, such that much of the management of the learning process is facilitated by the software in addition to the functions seen in a VLE. In this way, student registration through training workflow, online assessment, management of ongoing professional development and training resource management are all made available to those using the system [12, 142].

Some other terminologies used in relation to computer-based learning are *computer-supported collaborative learning (CSCL)* and *computer-supported cooperative work (CSCW)*. These two related phrases describe how computers can be used to facilitate social interactions between students that might be separated by time, distance or both time and distance [191]. These social interactions are used in distance learning and help expedite learning tasks that require groups of participants, via *computer-mediated communication (CMC)* [224].

It is clear then, that aside from an ever-expanding plethora of new vocabulary and abbreviations, the Internet has had a profound influence on the way in which learning occurs in today's society. Distance learning has broken down geographical and temporal barriers, so that education can occur at any time, any place, anywhere, provided the student has an Internet connection. This ubiquity has clear advantages for both students and teachers; however, in light of this changing face of learning, it is now more important than ever that the most appropriate systems and resources are utilised to provide a satisfactory level of support.

2.5 Discussion of existing virtual learning environments (VLEs)

2.5.1 Overview

Most VLEs implement a number of similar elements, such as a course syllabus; administrative information; student registration and tracking facilities and teaching materials (course content and additional resources, such as reading lists and links to other resources on the Internet).

In addition, they often have the facility to provide multiple-choice quizzes, which are scored automatically (usually for self-assessment); communication tools such as email, bulletin boards and/or a chat room; and also the ability to produce various course statistics and documentation on the usage and performance of the system. They also tend to have authoring tools associated with them, to allow teachers and other non-technical authors to create and modify content with relative ease, and allow for multiple courses to be supported across the same institution .

The following sections present and discuss some of the most widely-used VLEs, concluding with a summary of the main issues.

2.5.2 Blackboard

Blackboard Inc. is a software company based in Washington USA, founded in 1997, that develops and licences several commercial e-learning products to millions of users across the world, in over 80 countries and more than 3000 institutions [25]. Figure 2.1 below shows the Blackboard interface, as demonstrated on the Blackboard web site:

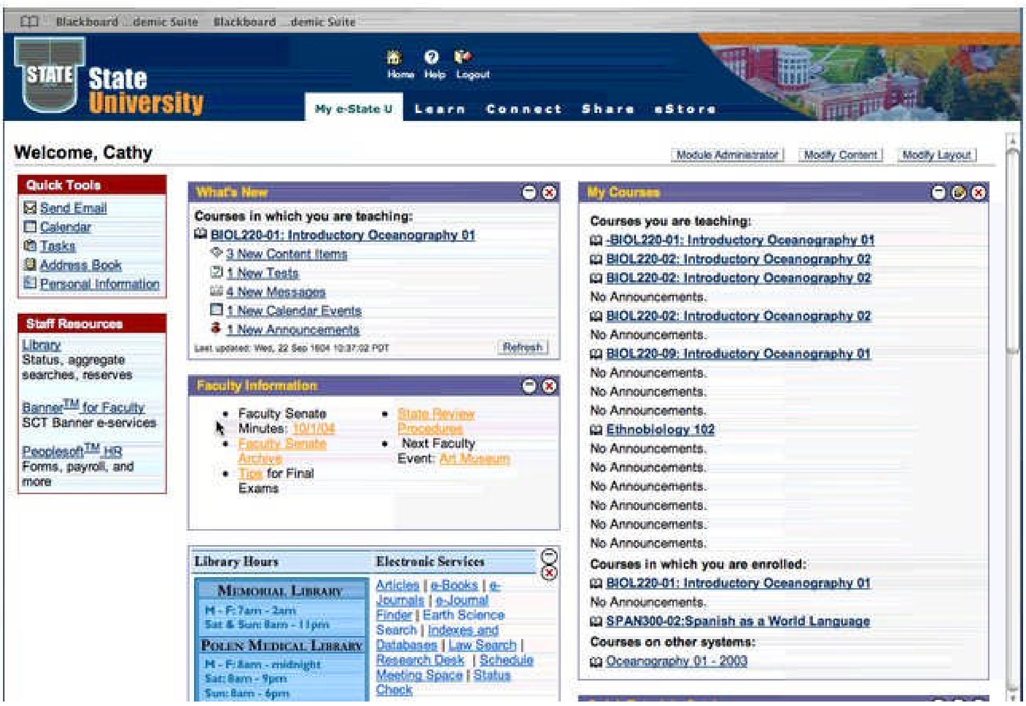

FIGURE 2.3: Screenshot of Blackboard interface
(Copyright © 1997-2007. Blackboard Inc.)

Institutional installations of Blackboard are accessed via a web browser; there are two suites (Blackboard Academic Suite and the Blackboard Commerce Suite) that consist of five software applications. Blackboard's users include colleges, universities and schools, in addition to publishers of course textbooks and various student-focused retailers. The Academic Suite consists of the main teaching materials, learner-centred activities and related applications, whilst the Commerce Suite supports commercial transactions on-campus, off-campus and online.

Blackboard software is closed source, although there is the possibility to extend functionality through an open architecture (called Building Blocks), provided by the company. Extensions such as integration with Google Scholar and the ability to incorporate podcasts are examples of how Building Blocks have been used by developers [24]; however, no extensions have been yet created that relate to adaptive content or presentation based on defined user models (at the time of writing).

2.5.3 WebCT

Originally developed as open source software at the University of British Columbia in 1996 and made commercially available in 1997, WebCT was bought by Blackboard Inc. in 2006. Although the two product lines are still "intact and supported", the Blackboard brand is being further developed in the future to integrate the best features of both products into a standards-compliant "product set" [23]. A screenshot of the WebCT interface is shown in Figure 2.2 below.

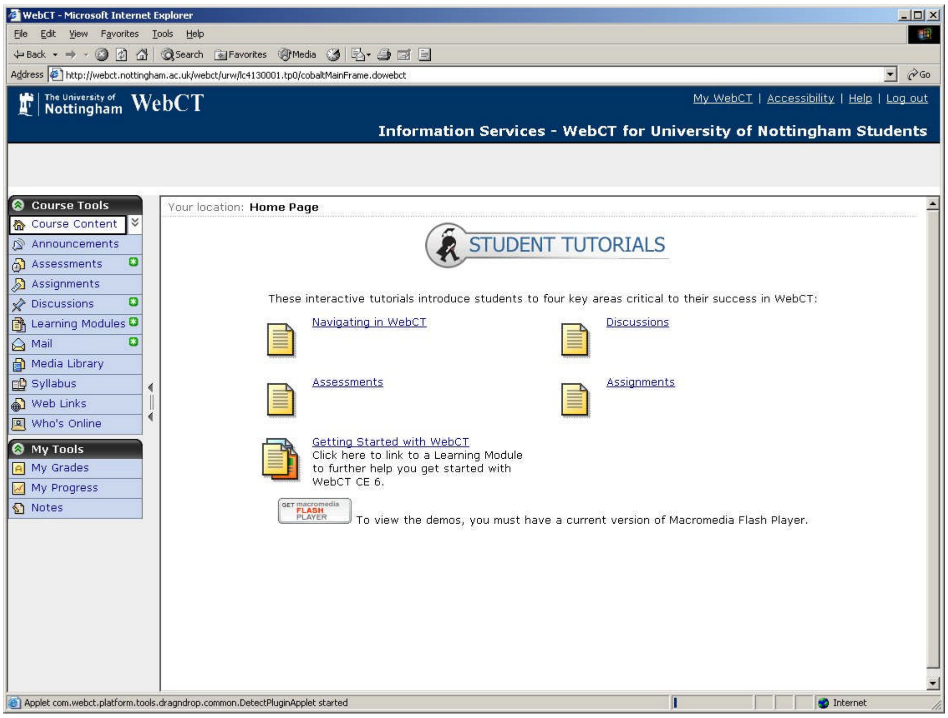

FIGURE 2.2: Screenshot of WebCT interface
(Copyright © 1997-2007. Blackboard Inc.)

WebCT was developed to make the creation of web-based learning environments easier. It was one of the earliest commercial VLEs to become popular and by 2002 it allegedly had over 10 million student users in 80 countries [223].

Part of the WebCT software incorporated electronic publishing, with a number of textbook publishers providing access to digital copies of their books in a WebCT format (subject to a small charge, payable by students).

WebCT has been subject to much criticism in recent years, specifically aimed at problems with its usability; the software is immensely powerful and flexible, meaning that there might be several different ways of doing the same thing. In addition, there are technical issues relating to using it in multiple tabs or browser windows (although this has apparently been fixed in WebCT Vista); reliance on "correctly-installed" Java for user interactivity [135]; problems using standard Back and Forward buttons and other browser navigation tools; and an overuse of browser framesets leading to inaccessibility issues [92]. WebCT has had many additional problems in terms of conforming to accessibility guidelines, particularly in the support of screen readers [92].

2.5.4 Moodle

Moodle was created by Martin Dougiamas and made available for general release in August 2002. He created it as an alternative to WebCT, for which he had been system administrator at Curtin University of Technology, in an attempt to address the limitations and his personal frustrations with WebCT. In 2003, the company moodle.com was formed in order to provide additional commercial support where needed, although download, general support and use of the software remains free under GNU Public Licence. The number of users has grown significantly over time and as of September 2007 there are nearly 14 million users and over 32 000 registered sites from 192 countries [149]. Figure 2.3 on the following page shows a screenshot of a typical Moodle course.

Moodle differs from WebCT and Blackboard in a number of aspects, not least its underlying pedagogical model. Dougiamas was keen for Moodle to support a number of educational theories, having been heavily influenced by the theory of social constructivism during his doctoral studies in the 1990s [148]. In comparison, WebCT and Blackboard were not developed with any specific learning theories in mind; their evolution stemmed from a need to provide better online resources and communication tools to students. The ideals of Moodle to recognise the value of contributions by learners themselves, in addition to teachers, had meant that students can comment on, or even contribute to, entries in a database of material or collaborate in a wiki. However, it is important to realise that Moodle does not enforce this constructivist approach, since it can be used for simple delivery of content.

FIGURE 2.3: Screenshot of Moodle interface
(Software copyright © 1999 onwards, Martin Dougiamas)

The rapid evolution of Moodle since its first public release has been enabled by a plethora of open source programmers that have all contributed to improving and enhancing the software for others to enjoy. Their participation has also enabled bugs to be fixed in a timely fashion.

A crucial aspect of Moodle is the presence of its large online community providing a sizeable body of support. Initially a small group of enthusiasts providing limited advice and suggestions, the growth of this community has paralleled the expansion of the user base, many of whom are now contributors. Moodle is fully extensible, with a large number of modules, plugins and themes. It is also able to import courses from WebCT and Blackboard [222].

2.5.5 Sakai

The Sakai CLE (Collaboration and Learning Environment) was developed by a community of academic institutions, commercial organisations and individuals. Like Moodle, it is a free open-source software platform, used for teaching and learning; portfolio support; ad-hoc collaboration and research. It was built and is maintained by the Sakai community, and includes a set of generic collaborative tools with some optional add-ons for specific Sakai applications. A number of new tools are currently being developed, including a blog tool, shared whiteboard and podcasting functionality [178].

Sakai is slightly different from the other VLEs previously discussed in this section, since it is intended as a tool for collaborative research, in addition to its course management system. To support this functionality, there are customisable settings for various system tools, so that different roles have different settings for these tools. There is also help with mailing list distribution and archiving, amongst other features. Figure 2.4 shows a screenshot of a Sakai installation at the University of Missouri.

The Sakai Foundation is a group of affiliated institutions, both academic and commercial, that work with open source software initiatives and standards organisations, to encourage the building of communities and promote the wider adoption of open standards [179].

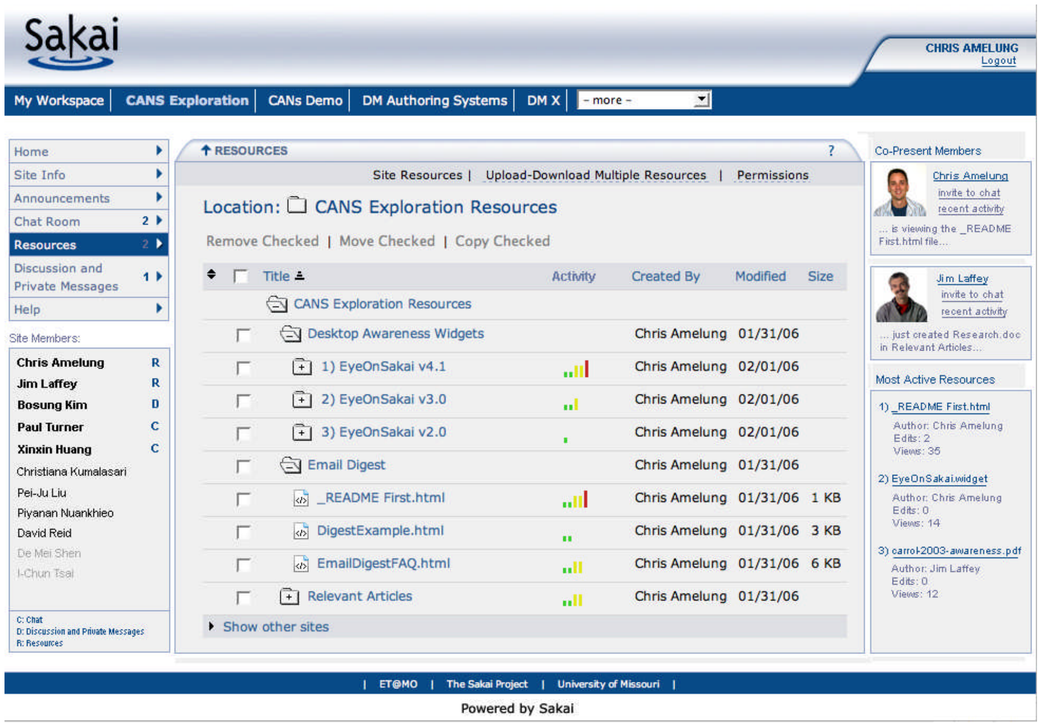

FIGURE 2.4: Screenshot of Sakai interface
(Image: Copyright © 2007 – Curators of the University of Missouri)

2.5.6 Other systems

A number of other commercial and freely-available VLEs exist, with similarities to those systems already discussed. ATutor is another noteworthy system, since its developers assert that it is the only fully-accessible LCMS (learning content management system) available in today's market, including both commercial and free VLE systems; this is evidenced by [60]. As seen in other systems, many third-party applications have been developed for it and distributed to users.

A recent innovation is the conceptualisation of Sloodle (www.sloodle.com), a new project involving a collaboration between Second Life (an Internet-based virtual world) and Moodle. It is still in the early stages of development, but the project has obvious potential to make online learning even more interactive and socially immersive than ever before.

2.5.7 Conclusions

When the software planning and development phase of this work began, a number of limitations existed in current VLEs that resulted in their use being unsuitable for exploring the questions relating to this research.

The main issue was that none of the commercial or open source VLEs provided any kind of adaptation to support the variety in characteristics, such as cognitive preferences or motivation, shown by different users. Thus, in order to provide adaptivity to users, the systems' source code would need to be modified, which was either not available to developers or was integrated into other parts of the software and would hence be difficult to debug.

In addition, a number of features such as the enhanced communication provision and various administration functions (such as course syllabus; notifications about the course etc) seen in these VLEs were not required for users of the systems and it was thought that these might incur undesirable system overheads in terms of installation and system maintenance.

Lastly, there was a cost implication in purchasing some of the available VLEs. The University of Nottingham currently has a site licence for both WebCT and Blackboard and there are ongoing costs associated with this. To buy a different commercial VLE would have been prohibitively expensive for a small research project such as this.

It thus seemed likely that no available VLE that could be obtained either at the start or throughout this period of research, that would have provided a satisfactory testing ground with which to explore the issues of adaptive e-learning and the user modelling therein.

2.6 Summary

This chapter has explored the field of computer-based education and e-learning, the latter being a term more specific to the concept of using the Internet to support learning, rather than the use of computers and technology in education *per se*.

Commonly-used vocabulary and phrases have been presented and explained, together with a detailed discussion of the ideas underpinning online learning. The work carried by Bush, Nelson and Engelbart has also been explored, including the way in which their combined vision inspired the creation and expansion of the Internet. A number of popular virtual learning environments have been presented and discussed, together with an evaluation of their suitability for use within this research.

In the following chapter, the notion of adaptive learning is presented, together with an overview of the research and development of software deployed in this area.

CHAPTER 3:

USING ADAPTIVE HYPERMEDIA (AH) SYSTEMS FOR EDUCATION

3.1 Introduction

In the previous chapter, an overview was presented to address the way in which learning is changing and evolving, as technology (particularly computers and the Internet) exerts an increasing influence upon pedagogic processes.

This chapter examines the history and development of adaptive hypermedia, specifically focusing on its origins within educational computer-based learning and its subsequent progression in this area.

3.2 Overview of adaptive hypermedia

Hypermedia systems are being increasingly employed for educational purposes, especially with the advent of distance and distributed learning [72]. One of the fundamental tenets of education is that students are different and hence learn in a variety of different ways [118, 184]. Some of these differences may be preferences for certain ways of working, for example, in the evening rather than first thing in the morning. Alternatively, learners may prefer to use different types of resource in order to acquire knowledge, for example, a web-based encyclopaedia rather than a paper version. Another approach examines how information is presented to the user, such as its structural hierarchy or the way in which concepts are represented in text or images/diagrams.

Thus, it follows that any material used for pedagogical purposes should be adaptive (or adaptable), in order to cater for these differences. *Adaptive hypermedia* (AH) is a technique used to provide a personalised learning experience that draws on computer-driven ITSs, and student-driven VLEs.

3.3 Computer-based learning in non-adaptive systems

A learner can be defined as someone who seeks to "*gain knowledge, comprehension, or mastery of through experience or study*" [9]. At the most basic level, typical learners might be children; however there is now an increasing number of learners at the adult level, both in and out of academia. The UK Government's investment in lifelong learning has led to a changing approach to when and how education takes place, with many learners studying new programmes at a later stage in life [206]. Learning has shown to occur in many everyday situations, both as a formal and informal process [134].

Learners wish to become more knowledgeable and gain a better understanding of certain subjects; this then, can be said to be their primary need. There are different levels of knowledge or understanding; academic institutions have always attempted to impart a deep appreciation of said subjects, in contrast to a surface learning approach, which only gives a limited understanding and retention of the study material [139].

In order to gain this knowledge and understanding, learners carry out a number of processes, such as asking questions, participating in the discussion of ideas and attempting to relate theory to real-life situations [126]. They also carry out investigative or analytical practices, reflective thinking and articulation related to their learning [26, 127].

These processes are still carried out in today's educational settings, but a greater emphasis on lifelong learning brings additional requirements, which must be supported by educational resources. Studying is increasingly taking place in informal settings, where the learning must be flexible and also must fit in with the demands of daily life. If learning is to be made accessible to this highly diverse group of students, then these resources must also be made accessible, and should accommodate many different types of learner. To date, this has always been one of the failings of computer-based learning; the materials are made accessible, but with a "one-suits-all" approach. Individualised learning experiences are often not possible and there is a huge range in the quality of such digital resources – a range that parallels the diversity of students using the resources. A lecturer may simply upload their PowerPoint lecture slides to a website; these slides may well be coupled with a poor user interface or navigation system and will not necessarily add anything to the lecture itself.

The traditional "chalk-and-talk" approach of teaching and the old-fashioned mode of lecturing are clearly very limited in the way in which knowledge and understanding is imparted to students. Both of these are examples of passive methods of information transmission, which rely on basic visual aids (usually text) and a narrative by the instructor. Because of these inefficient methods, computer-based learning has been made popular as a supplementary resource, or even as a complete replacement for such passive activities. Unlike an instructor in front of a class of students, it should be possible to make such computer resources much more tailored to flexible learning. Many resources already exist on the World Wide Web, or can be offered via CD; this creates more flexibility of *when* learning takes place. However, a lot of the material does not otherwise cater for the differences inherent in each student in terms of *how* learning takes place. This important issue of modelling and assessing user characteristics is discussed further in Section 3.5.

3.4 Hypermedia and the need for adaptivity

The use of hypermedia is now commonplace in computer-based learning and allows information to be presented in an interactive, non-linear manner whilst accommodating a rich variety of multimedia, enhanced communication and integrated links.

However, this kind of powerful yet flexible learning environment is not without its problems. One such issue has already been mentioned: the “one-size-fits-all” approach, where a group of learners with potentially high variability across a number of factors that might affect learning are all given the same educational content in a standardised framework.

There are other difficulties that users have experienced when using hypermedia systems for learning, including disorientation (being “lost in hyperspace”); difficulties in understanding the material; increases in cognitive overhead; problems with accessing different levels of content; and inefficient learning strategies [107, 108].

The consequences of these problems tend to be confusion; frustration; and reduced effectiveness of the learning environment and browsing strategies, in terms of comprehension and construction of knowledge. These tend to affect novices (students who are unfamiliar with the topic) more so than those students who already have some familiarity with the topics being studied [57]. There have also been issues with high drop-out rates and lack of engagement by users with the learning environment [71].

Thus it seems clear that hypermedia systems have many inherent problems that can affect students at various stages of learning. Adaptive hypermedia has been proposed as a step towards solving some of these problems and improving the functionality of such systems. There is a variety of different implementations and frameworks (methods) for how this adaptation is carried out, discussed most comprehensively in [40] and [42]. The two main methods presented by Brusilovsky in the aforementioned papers are *adaptive navigation* and *adaptive presentation*, examined in greater detail in Section 3.6.

3.5 Adapting to the features of the user

The user model can be based on various different characteristics of the user. Brusilovsky defines these features as “*users’ goals, knowledge, background, hyperspace experience and preferences*” [40].

Users’ goals or tasks relate to what the user is aiming to achieve, whether these objectives are based on information retrieval or for some educational purpose, such as a problem-based learning activity. It is a very dynamic characteristic and often changes both within and between individual sessions. It is possible to define both high-level goals (such as learning about a specific concept) and low-level goals (such as solving a particular problem). Along with user knowledge, this is one of the main characteristics upon which most adaptive techniques are based. It is often supported via adaptive navigation methods (see section 3.6.1).

A *user's knowledge* is defined as their existing knowledge within a specific domain, and many educational AH systems use this criterion to perform adaptation. Knowledge is often represented by either an overlay model [53, 207] and/or a stereotype model [18, 172]. A commonly-used technique for user modelling, the overlay model measures a user's knowledge in a particular topic, considered to be a subset of the total information contained in that domain. The stereotype model assigns a user to a specific group, with knowledge being customised for that group. Each user belongs to only one group at any given time and cannot move to a different group until certain conditions pertaining to the new group are met. A combination of stereotype and overlay user modelling can be utilised to provide a more flexible approach to knowledge adaptation [76, 112] and this has been implemented by Zakaria *et al* at the University of Nottingham [231, 232, 233].

The features of *background* and *experience* with hypertext systems are connected to a user's knowledge; these dimensions are fundamentally different though. Background is a more generic aspect than knowledge, which includes any relevant experiences outside of the specific knowledge domain, such as the user's occupation; related work experiences; and user's perceptions. Experience is a measure of familiarity that explicitly addresses hypertext structure and navigation, independently of other factors such as knowledge of a particular subject.

Lastly, *user preferences* may be profiled in order to provide explicit criteria for adaptation. Such inclinations may be general or specific, i.e. may be dependent or independent of the page or system itself. These preferences have to be expressed by the user rather than by the system, and are most heavily used by information retrieval systems.

3.6 Methods of adaptation

As previously mentioned, there are two main ways in which adaptation can be performed in adaptive hypermedia systems: adaptive navigation and adaptive presentation. These are summarised in Figure 3.1 and then explored in more detail.

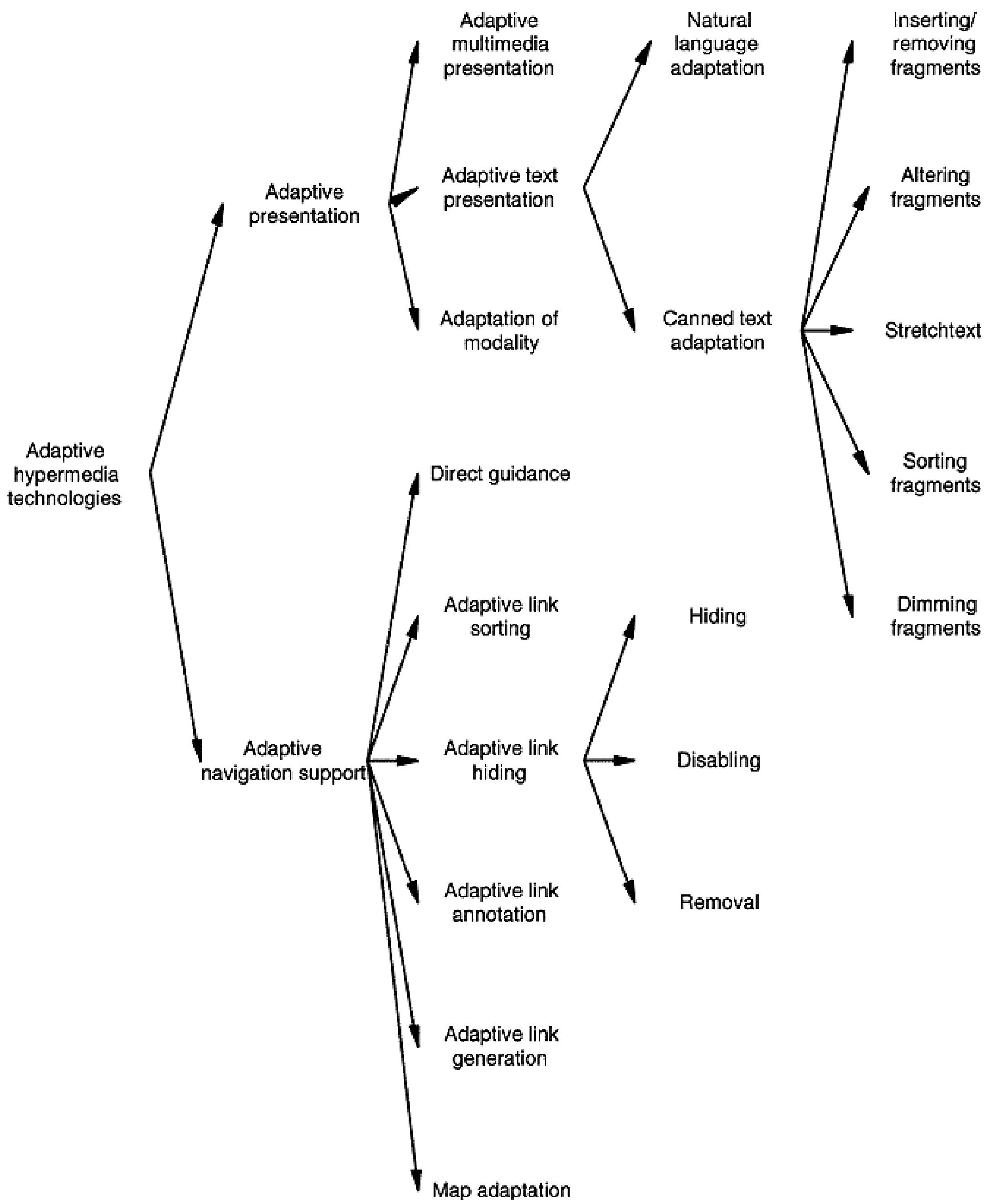

FIGURE 3.1: Taxonomy of adaptation techniques in AH
(taken with permission from [42] and updated from [40])

3.6.1 Adaptive navigation

The aim of adaptive navigation is to provide the user with help in finding their way around the hypermedia environment. The presentation of links is modified in response to various user characteristics (such as those discussed in Section 3.5), via a series of different processes.

Brusilovsky [40, 42] mentions four kinds of link presentation that can be adapted:

- *Local non-contextual links*: any kind of link, presented on a page in a hypermedia system, which does not have specific contextual relevance to the page.
- *Contextual links*: these are embedded links presented via key words in text or in image "hotspots", that cannot be separated from the page content.
- *Links from index and content pages*: usually non-contextual, contents and index pages often contain only links and hence can be seen to be a unique page type.
- *Links on both local maps and global hyperspace maps*: maps tend to represent networks of nodes connected by arrows. Users can thus navigate straight to a node by clicking on a representation of it (the equivalent of a link); the arrows, representing links, are not clickable and thus not actually used for direct navigation.

The ways in which these links can be adapted can be divided into six categories: direct guidance; adaptive link sorting; adaptive link hiding; adaptive link annotation; adaptive link generation; and map adaptation [42].

Direct guidance, the simplest method, is when the system presents the most suitable node for the user to visit next, based on parameters from the user model. It can be used with all four types of links mentioned above. However, it is somewhat limited as it offers a binary approach to user assistance: either click the link or not – and if not, there is no further support. It does not allow for additional help or for any deviation from the suggested route. For these reasons, it can be less helpful when used in isolation from other methods but is useful in some situations, for example when a sequence needs to be followed in a particular order.

Adaptive link sorting is when links are presented to the user in a particular order, based on a set of user criteria, so that the most relevant links are given at the top of the page, gradually reducing in significance as the user goes down the page. It is only useful when used with non-contextual links, where the ordering process can reduce navigation time, as seen in web-based information sources such as encyclopaedia, or in information retrieval (IR) systems [120]. It is not relevant for the other types of link and is a potential hindrance for novice learners since research has shown that it is better for them if they encounter stable navigation systems [80], compared to a dynamic menu of links that could be experienced with this method.

Adaptive link hiding is a commonly-used technique, the basis of which is to hide links to less relevant or inappropriate pages, thus restricting the user's navigation space. The criteria used to determine whether a page is relevant or not is governed by the user model. For example, a link might be hidden if it points to some advanced material when the user has not studied the basics of the topic. It can be used with all four types of links and can reduce the cognitive overload of the user, since they do not need to consider which links are most (or least) appropriate for them. It provides greater stability than adaptive link sorting, since links are usually added to an existing navigational structure, but not re-ordered or deleted. Further work on link hiding has been carried out by De Bra and Calvi [75], who employed two further variations: link disabling and link removal (in addition to link hiding).

Adaptive link annotation allows links to be enhanced with additional data to give the user some information about the state of the linked node. The enhancement can be carried out by visual prompts (e.g. different colours or size of font or different icons) or by textual cues. The simplest example of this is can be seen in many web pages, where a visited link is presented in a different font colour to a non-visited link, by the browser. It can be used successfully with all four kinds of links and is more powerful than link hiding, since link hiding is another binary state (the link is either hidden or not) whereas link annotation has been used with up to six different states [112], based on criteria determined in the user model. It does not prevent cognitive overload in the same way that text hiding does, but a form of annotation known as "text dimming" can provide a good compromise: the user can ignore dimmed, less relevant links whilst still navigating to those nodes if they choose to, thus maintaining greater control than if the links were hidden. The concept of text dimming also crosses over somewhat into the realm of *adaptive presentation*, which is discussed in Section 3.6.2.

Map adaptation addresses the way in which hypermedia maps (both local and global) can be adapted to the user and has historically not been well implemented. The aforementioned methods can be used to modify such maps but they do not inherently change the structure of the map or its form.

Lastly, *adaptive link generation* examines the way in which new, non-authored links are dynamically generated. It is considered a type of navigation support but different from those methods previously mentioned, which tend to apply to links that already exist at the time of authoring. Link generation has existed in intelligent hypertext systems for several years, but the recent work relating to adaptive creation of local and global links [27, 79, 137] and adaptive similarity-based navigation [50] suggest that this should be included along with other methods of adaptive navigation.

It is important to note that an adaptive hypermedia system does not necessarily utilise just one of these methods in isolation but may well combine two or more of these approaches in order to provide greater functionality or to integrate more complex user modelling.

3.6.2 Adaptive presentation

A further technique in providing adaptation to the user is in the form of content representation. Originally carried out mostly through variations in adaptive text presentation, this now includes adaptive multimedia presentation and adaptation of modality.

Adaptive multimedia presentation is related to, but different from *adaptive modality*. The former suggests that different types of multimedia (e.g. images) can be adapted to user characteristics, as seen in techniques developed by Maybury [140] and André and Rist [10]. However, these procedures have not been fully implemented in large hypermedia systems. Adaptive modality refers to the distinction between different media (still images; video; audio etc) and how each type can often be used to represent similar information. Thus certain media types or subsets of media can be presented to the user, according to the characteristics of the user model. These characteristics might include user preferences or learning style.

There are many techniques for a*daptive text presentation* since this was the focus of much early adaptive hypermedia research. This approach can be subdivided into two groups: *natural language adaptation* and *canned text adaptation*. Natural language adaptation is not classified further and Brusilovsky mentions that although natural language generation systems may include portions of canned text, it is the underlying basis for such systems that provides for their inclusion in this category [42]. Canned text adaptation is categorised into five main types: inserting/removing fragments; stretchtext; altering fragments; sorting fragments; and dimming fragments. Fragments of text might be inserted or removed depending on the rules specified by the user model (for example, if they appropriate for the user's knowledge level or not). Stretchtext (an idea originally conceived by Ted Nelson [155]) allows text to be dynamically extended or shrunk so that either more or less detailed information is shown on screen, hence a more advanced student need not be shown basic material. Text may be altered according to user profile (for example, to give different examples based on a user's occupation) or sorted differently so most relevant or appropriate text is shown at the top of the page. Fragment dimming, akin to link dimming, can be used to give a visual cue on the appropriateness of a specific portion of text.

3.7 AH in educational systems

There are several AH systems developed for educational purposes, commonly referred to as Adaptive Educational Hypermedia, or AEH, systems. These systems base their user models largely on existing knowledge, and adaptation occurs at both content level (adaptive presentation) and/or link level (adaptive navigation) [39].

The remainder of this section discusses the approaches employed across a variety of different AEH systems.

3.7.1 Adaptive navigation systems

Adaptive navigation is used to implement adaptation in many AEH systems. They are summarised in Table 6.1, which gives information about the adaptation mechanism used in each system and also what characteristics are taken into account in terms of the user model.

TABLE 3.1: Overview of selected AEH systems that utilise adaptive navigation techniques

System:	Type of adaptive navigation:	User model addresses:				
		Goals	Knowledge	Background	Hyperspace experience	Preferences
ELM-ART [48]	Adaptive link annotation; adaptive link sorting		✓			
ISIS-Tutor [45]	Direct guidance; adaptive link annotation; adaptive link hiding.		✓			
ITEM/PG [47]	Adaptive link annotation		✓			
HyperTutor [165]	Direct guidance; adaptive link hiding		✓		✓	
SHIVA [234]	Direct guidance		✓			
Hypadapter [112]	Adaptive link hiding		✓			✓
AHA! [75]	Adaptive link annotation; adaptive link hiding.		✓			
Netcoach [213]	Direct guidance; adaptive link annotation.	✓	✓			✓
Interbook [49]	Direct guidance; adaptive link annotation.		✓			
CHEOPS [96]	Link removal.		✓			
TANGOW [54]	Link disabling; adaptive link sorting.	✓		✓		✓

From the information contained in this table, it can be seen that most AEH systems that utilise adaptive navigation support do so by addressing the knowledge aspect of the user model. The most commonly-used techniques are direct guidance and adaptive link annotation.

3.7.2 Adaptive presentation systems

In a similar fashion to Table 6.1, Table 6.2 gives an overview of AEH systems that implement adaptive presentation. It is worth noting that some systems appear in both Tables 6.1 and 6.2, indicating that they employ both forms of adaptation.

TABLE 3.2: Overview of selected AEH systems that utilise adaptive presentation techniques

System:	**Type of adaptive presentation:**	**User model addresses:**				
		Goals	Knowledge	Background	Hyperspace experience	Preferences
Anatom-Tutor [16]	Altering fragments.		✓	✓	✓	
C-Book [121]	Inserting/removing fragments; altering fragments.			✓		
Hypadapter [112]	Sorting fragments.		✓			✓
AHA! [75]	Inserting/removing fragments; altering fragments.		✓			
Metadoc [30]	Stretchtext.		✓			
TANGOW [54]	Altering fragments.	✓		✓		✓
WHURLE-HM [232]	Inserting/removing fragments.		✓			

In this type of modification, it can be seen that inserting/removing fragments and altering fragments are the preferred methods. User's knowledge remains the most popular aspect of the user model to be addressed.

3.8 Pedagogical limitations of current user models

Teaching and learning in schools and colleges has traditionally been facilitated by streaming students into existing knowledge/ability groupings. It is therefore no surprise that a lot of educational software, online school-based resources and AEH systems parallel this method of instruction and tend to accommodate students of a specific knowledge or ability level. (There are obviously some differences, such as the more immediate temporal shift that can occur in

AEH to move students between streams compared to school classes in the real world, allowing for more flexibility in differentiation).

However, this model of contextual knowledge is relatively simplistic from a pedagogical perspective; it classifies students into a category but requires continual updating as the student gains knowledge. It also does not allow for other aspects of the learning process, such as the way a student approaches their learning from a psychological perspective.

Recent educational thinking has led increasingly towards a more direct cognitive approach that rationalises the learning preferences of students. This is more satisfactory for addressing multiple learners' needs since it allows a large variety of preferences to be catered for, within specific knowledge domains, and may contribute to an enhanced learning experience [198]. Some recent work has been carried out by Bajraktarevic [14, 15] that uses learning style theory to create the user profile, thus employing the "user preference" aspect in contrast to "existing knowledge". There is much literature in the fields of psychology and education relating to learning styles, and this mode of adaptation may be more beneficial to learners than those simply based on domain knowledge. There is a large variety of learning style theories and tools that can be used to categorise learners. Chapter 4 introduces these main concepts and presents some additional AEH systems that have implemented learning style adaptation and also discusses the criteria for choosing which approach to use.

3.9 Methodology

The concept of user testing is an extremely important one and the final part of this chapter discusses the methodology that should be employed in order to achieve a quality-assured, rigorous set of quantitative and qualitative data that can be analysed to investigate the effect of any interventions made by AEH systems.

3.9.1 Designing and planning user trials

Robson states that "*design is concerned with turning research questions into projects*" [176], so naturally it follows that the research question must be clear and unambiguous at the start of any experimental design. Once the research question has been clarified, the design of the project must be considered: is it to be an experiment, a survey or an observational piece of work? A research project might combine aspects of all three. Whatever the methodology chosen, there are several important factors to take into account. These include making sure that there are adequate levels or groupings in the design; ensuring sufficient "clean" sample sizes[13] (including

[13] Mertens [144] recommends no less than 15 participants in the smallest grouping.

making allowances for participant unreliability or incomplete/inaccurate data); choice of appropriate dependent variables; and initial pilot-tests of any planned trials [162].

Data collection is an important aspect of any study but commonly-used scales and measures are often not scrutinised as closely as they should be. Two essential components of such scales are their *reliability* and *validity*. Reliability is a measure of how free the scale is from random error. It is judged by *temporal stability* (also known as test-retest reliability – high scores mean it is more reliable) and also *internal consistency* (the level at which different components of the scale are assessing the same traits, commonly measured by Cronbach's alpha coefficient) [157, 162]. Validity refers to how accurately a scale measures what it is intended to measure, and the main ways of doing this involve *content validity*, *criterion validity* and *construct validity*. Content validity relates to how well a particular measure reflects the wider content domain. Criterion validity examines the connection between the scores of a scale and some other specific standard. Construct validity tests the scale against theoretically derived hypotheses that relate to the variable/s under examination. The way in which construct validity is explored is by examining associated constructs (convergent validity) and disparate ones (discriminant validity) [162, 192].

Reliability and validity therefore provide useful information about the appropriateness of selecting various scales or measurements for use within research projects. Other considerations include the preparation of questionnaires, such as response types and the wording of questions so as to avoid jargon, loaded or complex words and questions, and any cultural or emotional bias. Pallant suggests that, where possible, questionnaires should also include provisos for "don't know" or "not applicable" [162].

Of course, scales and measurements form only one aspect of a research project. Historically, the scientific method of research involves observations and formulating/testing hypotheses by gathering and processing quantitative and qualitative data. Scientific objectivity is achieved by first of all presenting a "null hypothesis", that states that there will be no statistically-significant differences in quantitative data gleaned from disparate experimental groups or conditions. A number of alternate hypotheses can then follow, which suggest what these differences might be. These alternate hypotheses can be specific (for example, an increase in one factor might lead to an increase in the independent variable, i.e. what is being measured) or more general (for example, one particular group might have a higher score than another). Empirical evidence is required to support or refute these hypotheses, which results from the statistical analysis of quantitative data. The resulting statistics reveal the significance, or otherwise, of such data. Probability values are commonly utilised as a measure of significance, with a required value of 0.05 or less (i.e. 5%, or the probability of 1 in 20); in other words, if $p>0.05$, the finding is not statistically significant and could have resulted by chance rather than the intervention under examination. Probability values are ascertained by statistical testing, which is discussed in the next section (3.9.2) on data analysis.

There are also several different frameworks of experimental design, classified as *fixed*, *flexible* and *multiple design strategy* [176]. Fixed designs tend to involve surveys and experiments; their principal characteristic is that much of the design specification is decided upon well in advance of the study. They are based upon well-developed theoretical frameworks so the researchers are aware of existing issues and how to control for various aspects of the experiment. Fixed designs are very much *quantitative*, whereas flexible designs tend to be *qualitative*. They are flexible in both in terms of the data that are typically collected from such work and also in the approach used, where less advance preparation takes place and the research plan typically evolves and grows as the work is carried out. Flexible designs can also accommodate quantitative methods in addition to qualitative, whereupon they tend to be referred to as *mixed-method* or multiple design strategies. There has traditionally been some dispute over which approach is more "scientific", with scientific disciplines tending to be rooted in fixed design methodology and sociological domains preferring flexible procedures. Robson states that these techniques are not mutually exclusive in scientific studies, provided that they are carried out in a systematic and responsible manner [176]. The studies presented in Chapters 5 and 6 utilise mostly quantitative designs with a small amount of qualitative methodology.

3.9.2 Data analysis

Once a body of data has been gathered from the research study, it must often be cleaned and processed before it can be analysed. Data cleaning involves screening the data set and resolving any problems with missing or incomplete data. Often, this means excluding such data from the overall analysis since they might not be a fair representation of that particular case or participant: for example, if a questionnaire is administered at two different time periods yet the user is only present at the first session, the second questionnaire could not have been completed and thus a comparison between the two would be meaningless.

Data may also need to be processed or transformed from one unit into another. For example, the number of web pages seen by a user might need to be calculated as a percentage of the whole number of web pages overall, or it might need to be converted into a unit of frequency.

Once the data set has been cleaned and processed, it can be analysed statistically. This is usually done using one of a number of statistical software packages. The software used for data analysis throughout this research was SPSS.

The statistical tests that are carried out on the cleaned data to provide probability values vary according to what kind of data is being analysed, how many groups or levels there are and also what the specific research question is. Generally speaking, statistical techniques either explore *relationships between variables* or *differences between groups* [162, 176]. Relationships between variables are often examined via correlations, multiple regression or factor analysis [162]. A Pearson correlation assesses how strongly two variables relate to each other and whether this is a positive or negative association. A more sophisticated technique is multiple regression, where the relationship of a set of independent variables can be predicted against a continuous dependent variable. Factor analysis is a data reduction procedure, where a large grouping of variables can be condensed into a smaller, more manageable data set, which is then used for comparison.

Differences between groups can be investigated using t-tests, Analysis of Variance (ANOVA), Analysis of Covariance (ANCOVA) and Chi-square (χ^2) tests. If there are only two groups, or two sets of data, the mean score of a continuous variable can be analysed using t-tests. If there are two or more groups, a one-way ANOVA can be carried out: it studies the influence of a single independent variable on the dependent variable, although additional *post-hoc* testing is required to determine in which of the groups the difference appears. If there are two independent variables, a two-way ANOVA can be used; this allows testing of an interaction effect between the two variables. Multivariate analysis of variance testing (MANOVA) can be used when group comparisons are required based on several unique (but associated) dependent variables. ANCOVA is a method by which an additional confounding variable needs controlling for, so that any differences between groups can be seen once this extra factor is taken into account [162]. Finally, Chi-square (χ^2) tests can determine if the distribution of a discontinuous variable is the same in 2 or more independent samples.

Further guidance on the empirical evaluation of user models and adaptation mechanisms can be found in publications by Brusilovsky [44], Chin [58] and Weibelzahl *et al* [215, 216, 217].

3.9.3 Other considerations

Two final issues need mentioning here; they are separate points but somewhat related. The first concern is that of the Hawthorne effect. This is a phenomenon akin to a placebo effect, whereby the behaviour of test subjects is temporarily altered because they are aware that they are participants in a study and hence expect to be given some special treatment that would help them perform certain tasks more effectively. It is named after a factory called the Hawthorne Works, where a series of productivity experiments were carried out on factory workers between 1924 and 1932. A variety of different interventions into physical working conditions were introduced in the factory, such as modifying the light levels. These interventions, regardless of what they were, had the net result of increased productivity – but in both the experimental and the control groups [100, 212]. It seemed that any change perpetrated by the researchers caused this increase; it was not necessarily caused by any specific intervention. This has an impact upon the way in which any kind of user testing is carried out in other situations, since it has been shown that merely having been selected for some kind of different treatment can in fact have a positive effect on participants. In reality, this is very difficult to control for since, for ethical reasons, taking part in a user trial must be voluntary and by informed consent. However, measures such as using a control group or a crossover design (where different groups all experience the same interventions, but at different times in the research) help to reduce the potential consequences of the Hawthorne effect. It is also counteracted by using relatively homogeneous experimental groups, which neutralise the natural variability shown by individuals.

The other concern relates to causality. A strong correlation between variables does not signify that one causes – or is caused by – the other, but merely that the relationship exists. The reason for that association might be due to some other factor that has not been taken into account by the research.

It is thus critical to be cautious when statistically significant results are found as a result of a specific intervention and to show due regard for other factors that might contribute to these findings.

3.10 Existing evaluation studies of adaptive educational hypermedia

This penultimate section provides a survey of the state of the art in quantitative evaluation of adaptive hypermedia in education, focusing specifically on those that are driven by learning style adaptation.

From studies of the published literature, there seems to be a paucity of rigorous user evaluation in adaptive systems. Studies tend to be fairly small in terms of sample sizes and rarely are statistical measures of significance used. Effect size is almost never published, to the detriment of such studies. In most situations, systems are tested on a group of users who might possess some kind of bias (either implicit or explicit), such as the undergraduate students who engage with a system designed by the lecturer of their course. Such users might be expected to have favourable expectations of this software, which could result in a “self-fulfilling prophecy” whereby they perform well in the system because they expect to; the observer/novelty (a.k.a. Hawthorne) effect thus obscures any objective use of the system.

The survey of these studies is now divided into two parts: the first sub-section (3.10.1) investigates the use of evaluations in adaptive hypermedia from a broad perspective whilst the second sub-section (3.10.2) describes their application to systems that utilise learning style as the predominant adaptation mechanism. A concluding section (3.10.3) provides a summary of the information presented from these investigations.

3.10.1 Adaptive educational hypermedia (AEH) systems in general

The AEH systems presented in Tables 3.1 and 3.2 were investigated further to determine which of them had associated user trials based upon quantitative methodologies. Out of 15 systems, 8 of them (ITEM/PG [47]; SHIVA [234]; Hypadapter [112]; CHEOPS [96]; Tangow [160]; Anatom-Tutor [16]; C-Book [121]; WHURLE-HM [232]) did not appear to have any published data relating to empirical testing of the effectiveness of its adaptation mechanism.

Of the seven remaining systems, there was much variation in the depth of the empirical evaluations carried out. User trials have been carried out with four systems (ELM-ART [214], Hypertutor [205], Interbook [43] and AHA! [193, 194]) that resulted in the publication of some quantitative data, however these are mostly related to how users interacted with the different aspects of the system and are displayed as raw data or percentages, rather than statistical results.

Only three evaluations actually used statistical testing to show the effectiveness of their systems: ISIS-Tutor, Metadoc and Netcoach. The research on ISIS-Tutor [46] presents ANOVA and T-test statistics but sample sizes were small and there were not enough participants for these results to be valid. User trials from MetaDoc [30, 41] show statistically significant results at the 1% level, using ANOVA and further post-hoc testing (Tukey) to determine where the differences were. However, sample sizes are not given so it is unknown as to whether this evaluation was statistically valid. In addition, for both the ISIS-Tutor and MetaDoc user trials, there was no mention of effect size or how this might have been calculated. By stark contrast, the Chi-square (χ^2) and t-test analyses shown in the Netcoach evaluation [217] are extremely rigorous, using large statistically-valid sample sizes and displaying careful experimental planning. The evaluation data shows both probability values and effect size. This last study is the only general AEH user trial found to be of reasonably high quality with respect to quantitative experimental design and data analysis.

3.10.2 Learning style adaptation in AEH systems

Further investigations were carried out into those AEH systems that specifically utilise learning style as their adaptation mechanisms, looking particularly at those systems discussed in Table 4.1 in the next chapter.

Out of those ten systems, there were six (ILASH [14]; MOT [195]; OPAL [64]; AHA! [195]; CS-383 [55]; Tangow [164]) that did not seem to have published any quantitative evaluations. Two systems (AES-CS [203] and INSPIRE [163]) presented some empirical data in the form of bar charts; pre-test/post-test scores – together with the difference between then and also standard deviations – but no statistical testing was carried out and sample sizes were relatively small (n=10 and n=23, respectively).

Two systems did show statistical testing and this was done reasonably well. Bajraktarevic's empirical study [15] used 21 students, split into two groups and employing a crossover design.

T-testing was used to generate test statistics and probability values. However, there was fairly high standard deviation shown throughout for most of the test scores and no effect size was calculated for any of the data analyses. The best example of statistical testing carried out in a learning-style-driven AEH is exemplified by Wolf with his work on the iWeaver system [230]. His research shows meticulous care and attention to experimental design and data analysis. Like Bajraktarevic, he also uses paired T-tests to produce test statistics and probability values but additionally takes into account other factors such as effect size in considerable detail. However, the full extent of Wolf’s work has only been published fairly recently and was not available when the research presented in this thesis was being carried out. Bearing this in mind, it is very encouraging to see the importance of high-quality user evaluations and related statistical analyses being realised by researchers working in parallel to each other, in different parts of the world, within a similar time frame.

3.10.3 Summary of quantitative evaluation studies carried out in AEH systems

From an review of the published data concerning quantitative evaluation of adaptive educational hypermedia systems, in particular those driven by learning style adaptation, it is clear that not enough is currently being done to test the effectiveness of adaptation mechanisms. Of the 24 different systems examined, only 5 of them had been tested with statistical techniques and of these, only 2 (those carried out with Netcoach and iWeaver) could be considered to be high-quality studies.

This apparent lack of quantitative studies in relation to adaptation mechanisms makes the justification of the research objectives (especially part c, as stated in Section 1.2) even stronger. It is clear that a systematic experimental approach, utilising quantitative methods and statistical analysis of data, must be employed in order to find out objectively, whether the adaptation technique is an effective means of providing personalisation to users.

3.11 Learning styles in computer-based learning

This chapter has examined the way in which adaptive hypermedia systems have developed, including an overview of different adaptation techniques and also the types of characteristics that feature in user models. The limitations of existing user models have been introduced, together with discussions of the methodology employed for effective user trials.

Chapter 4 investigates the application of learning style theory as a new adaptation mechanism that addresses the “preferences” aspect of user modelling. It presents an overview of learning styles and the ways in which they have been utilised in a number of existing systems. The subsequent chapters (5 and 6) then present the results of two respective AEH systems in which learning styles have been implemented as the underlying user model.

CHAPTER 4:

LEARNING STYLES IN COMPUTER-BASED LEARNING

4.1 Introduction

Chapter 3 presented a detailed survey of adaptive hypermedia systems, particularly those used for educational purposes. Various aspects of adaptive hypermedia were discussed, such as the characteristics found in user models and also the different methods of adaptation and their implementations in extant systems.

This chapter examines the concept of learning styles as an aspect of user modelling and introduces several different categories and theories of learning style, as employed by a variety of current AEH systems.

4.2 Overview of learning styles

There are many learning styles recognised today. Zhang [235] mentions at least 30 ways of labelling ‘style’ constructs, and many practitioners create their own learning style tools, usually from a mixture of existing methodologies. This has resulted in the formation of diverse cognitive/learning style theories. Some of these are based upon imprecise educational and psychological ideologies, and have very limited practical utilisation. Some researchers use the terms ‘cognitive style’ and ‘learning style’ interchangeably and, under some circumstances, there is a distinction to be made between them, as discussed next in Section 4.3.

4.3 Ambiguities of learning style terminology

There is much jargon within the field of learning styles. De Bello notes that there may be as many theorists as there are definitions [74].

“Learning style”, “cognitive style”, “learning skills”, “learning strategy” and “approaches to learning/studying” are common terminology and the expressions are often used interchangeably. This can lead to much confusion when trying to understand the work of other researchers, especially for those who are new to the field [109]. It is clearly beneficial to researchers and others involved in this area of work to discuss this complex terminology, so that their differences and similarities to each other can be compared. It is also necessary to clarify the particular nuances of the language being employed throughout this research and the work of others.

4.3.1 Learning style

Learning style can be defined as the preferences of an individual in a particular learning situation [3]. It is a deep-seated inclination to do something in a specific way, which is not context-based and may be applied to many different subjects and tasks. For example, a student may prefer to receive information in a primarily visual form compared to a verbal representation.

4.3.2 Cognitive style

Cognitive style is a psychological construct which relates to the ways in which individuals process information, usually with sub-divisions into such categories as field-dependence/independence and reflexivity/impulsivity [198]. Cognitive style is sometimes regarded as an aspect of learning style [56].

4.3.3 Learning skills

These are disparate actions or techniques that are employed by a learner in a specific situation to remember a particular bit of information. Such techniques might include the use of mnemonics or continuous repetition of numbers/text [3]. Learning skills tend to be more flexible and have greater variety than cognitive or learning style, since there can be many different practices utilised to learn specific concepts, either on advice from a tutor or from the students themselves.

4.3.4 Learning strategy

A learning strategy can be said to be an intermediary between learning style and learning skills, where an individual will use a number of learning skills together in a particular scenario. These strategies tend to be context-based and are thought to be teachable; this is in direct contrast to cognitive and learning styles, which are already well-established within learners [3] and is a more holistic approach than learning skills.

Interestingly, Cassidy mentions an analogy of “motherboard/software” when describing the style/strategy interface. This is intended to illustrate that style is a persistent characteristic that is “hard-wired” into a person’s cognition. Strategy, on the other hand, is a more variable property that is related to individual circumstances [56].

4.3.5 Approaches to learning/studying

Some theories of learning style or cognitive style mention “approaches to learning” or “approaches to studying”. These tend to combine any of the above categories into a new learning style theory and/or instrument, and report on how they have been used in a particular educational setting. Biggs [20] gives a particularly comprehensive review of some of these inventories.

4.4 Types of learning style

Having discussed the ambiguous terminology in the area of learning styles, it is important to realise that this research examines learning styles as its main theory and technique of adaptation (as defined in Section 4.3.1) as distinct from cognitive style, learning skills/strategies or approaches to learning. There are many different theories of learning style and it is important that these be categorised into broad families, so as to avoid confusion between the different aspects of them.

Curry’s onion model is a good basis for demonstrating the different ways in which learning style can be classified. This architecture describes how learning or cognitive style (the terms are often used interchangeably) can be assigned to a particular layer in a radial system, similar in structure to that of an onion [68, 69]. Initially created with only 3 layers, Curry later modified this to include a fourth layer (social interaction, shown below as layer 2). This diagram is shown in Figure 4.1.

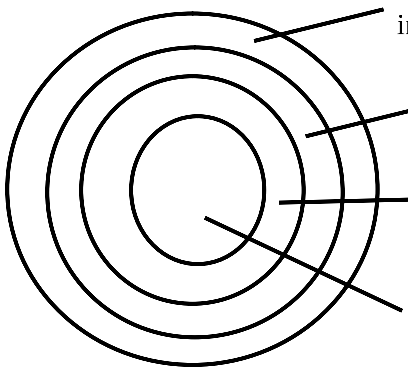

FIGURE 4.1: Diagrammatic representation of Curry’s onion model of learning style theories illustrating its four-tiered classification system

The layers refer to different aspects of learning style, and those most influenced by external factors (and most observable) are on the outermost layers. The innermost layers are considered to be more stable psychological constructs and less susceptible to change, however these are much less easily measured.

Examples of learning styles that can be assigned to Layer 1 include the Dunn and Dunn learning style model [87]. This consists of 21 different conditions arranged within 5 groups: environmental preferences; emotional preferences; sociological preferences; physiological preferences and psychological/cognitive processing preferences. Much empirical work has been done with this model within traditional educational settings, and there is a wealth of literature to support its successful use with 5-18 year olds in the American education system. However, the Dunn and Dunn model is controversial and many questions have been raised about its reliability. Rezler and Rezmovic's Learning Preference Inventory [171] is another model using this approach.

Layer 2, relating to how students interact with each other, overlaps with some of the Dunn and Dunn preferences but is best exemplified in Reichmann and Grasha's model. This approach classifies students into types such as independent, dependent, collaborative, competitive, participant, and avoidant [170].

The third layer, that of information processing style, examines a learner's intellectual approach to assimilation of new information. It reflects more stable models of learning style and includes many of the best-known theories and instruments. An example of these is Kolb's Learning Style Inventory [123], based in experiential learning and developed from Lewin's cycle of adult learning [129]. It states that learning is cyclical and that from concrete experience comes reflective observation, followed by abstract conceptualisation and then active experimentation, which leads back to concrete experience, although learners may enter the cycle at any stage. Kolb's work was further developed by Honey and Mumford for a commercial market to address learning styles in management. They created a typology of learners known as activists, reflectors, theorists and pragmatists [114].

Lastly, cognitive personality style forms the innermost layer; it seems to be the most robust component and is said to be a relatively permanent dimension. It seeks to measure an individual's personality, specifically related to how they prefer to acquire and integrate information. Learning styles such as Witkin's field dependence/field independence approach [226] examines the capability to extract details in a specific context. The Myers-Briggs Type Indicator (MBTI) [36] is based on Jungian psychology and assigns individuals into one of 16 categories, based on introversion/extraversion, sensing/intuition, thinking/feeling and judging/perceiving. It is used mostly in the commercial sector. Other examples include Riding and Rayners' Cognitive Styles Analysis (CSA), an amalgamation of many learning style theories [173] and used extensively by educationalists and psychologists. The Felder-Silverman Inventory of Learning Styles (ILS) can also be included in this layer although it overlaps somewhat with layer 3; it classifies learners on 4 axes: sequential/global, visual/verbal, active/reflective, and sensing/intuitive. It has been used successfully within several AEH systems (refer to Section 4.5 for details).

Coffield *et al* use an alternative classification, stating that there are problems with Curry's onion taxonomy. They criticise the theoretical nature of the model since it suggests that learning style stability is more influenced by psychoanalytic assumptions rather than quantitative evidence. Given the lack of evidence for this theoretical approach from longitudinal studies in twins, it seems that the onion metaphor is somewhat flawed, however attractive it seems [61]. Instead, Coffield *et al* suggest a continuum of learning style families, based on the ideas of Curry, Vermunt [208], Entwistle ([90] cited in [61]) and a number of learning style overviews written by other key figures (see [61] for details). The taxonomy used by Coffield *et al* is shown in Figure 4.2:

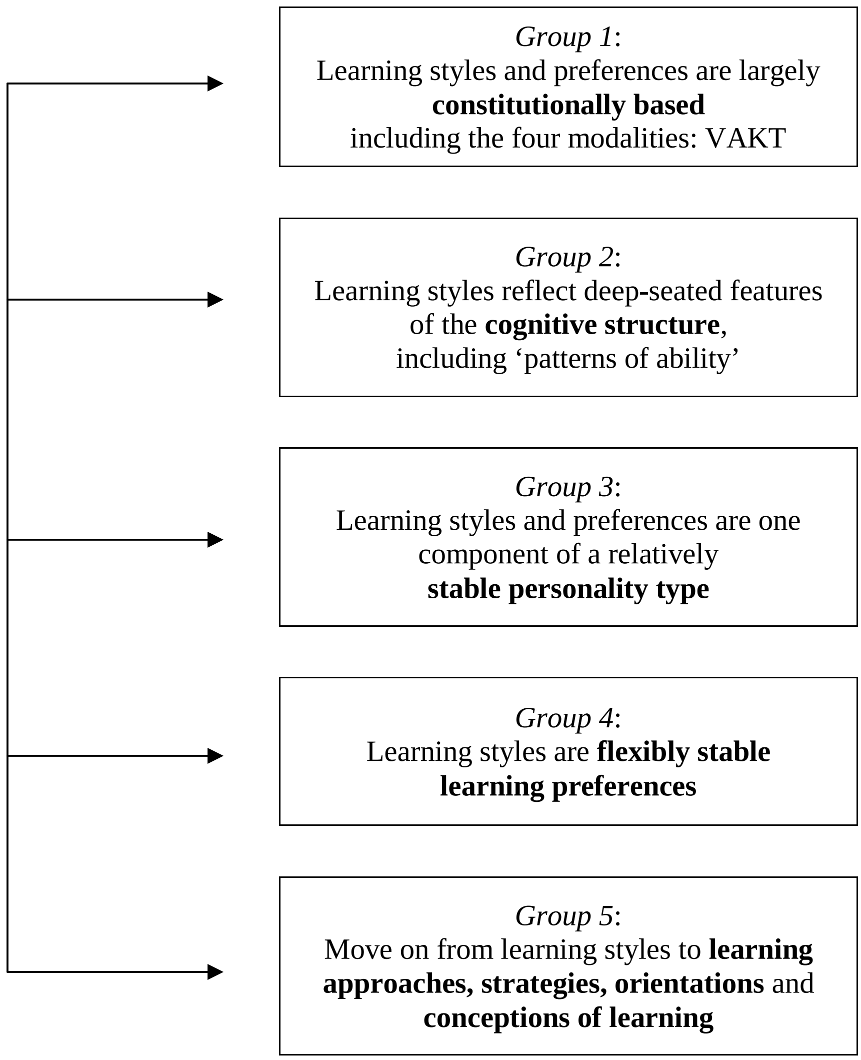

FIGURE 4.2: Families of learning style
(after Coffield *et al* [61, 62])

This continuum is based loosely around the concept of fixed versus dynamic learning styles. Group 1 includes the Dunn and Dunn model and clusters together those theories and instruments that consider learning style to be fixed, inherited traits that are influenced by genetics; these are approaches that consider learning style as something to be incorporated into teaching, rather than a characteristic that can be changed. Moving down the scale, there is greater impact of experience and environment, so that there is correspondingly larger attention to factors such as motivation, curriculum design, institutional and teaching approaches and the way in which students choose or use specific techniques for learning.

4.5 The use of learning styles within AEH systems

Several AEH projects have been developed, that employ learning styles as a means of personalisation. Table 4.1 summarises these systems, together with the learning style preferences that they utilise and the theoretical research/learning style models upon which they are based:

TABLE 4.1: AEH systems that incorporate learning styles

<table>
<tr><th>System:</th><th>Learning style preferences used:</th><th>Based on research from:</th></tr>
<tr><td>AES-CS [204]</td><td>Field dependence (FD) and field independence (FI)</td><td>Witkin and Goodenough [226]</td></tr>
<tr><td>ILASH [14]</td><td>Summarising, questioning</td><td>Hsiao [115]</td></tr>
<tr><td>iWeaver [228, 229]</td><td>Global, analytical, impulsive, reflective, visual, auditory, kinaesthetic</td><td>Dunn and Dunn [87]</td></tr>
<tr><td>MOT [195]</td><td>Diverger, converger</td><td rowspan="2">Kolb [123]</td></tr>
<tr><td>OPAL [64]</td><td>Abstract/concrete, active/reflective</td></tr>
<tr><td>AHA! [195]</td><td>Activists, pragmatists, reflectors, theorists</td><td rowspan="2">Honey and Mumford [114]</td></tr>
<tr><td>INSPIRE [103]</td><td>Reflector, activist</td></tr>
<tr><td>CS-383 [55]</td><td>Global, sequential, sensing, intuitive, visual, verbal, active, reflective</td><td rowspan="3">Felder and Silverman[14] [93]</td></tr>
<tr><td>Bajraktarevic et al [15]</td><td>Global, sequential</td></tr>
<tr><td>Tangow [164]</td><td>Sensing, intuitive</td></tr>
</table>

[14] There is much confusion over the naming of this model. Refer to section 4.6.6 for full details.

Of the learning style models mentioned in the table above, it can be seen that these utilise instructional preferences (Dunn and Dunn), information processing (Kolb; some of the Felder-Soloman aspects) and cognitive personality dimensions (Witkin and Goodenough, plus other Felder-Soloman aspects) of Curry's onion framework. Social interaction models of learning style have not been incorporated into any existing AEH systems and this seems a remarkable oversight, given the recent growth of social networking and enhanced interactions via the Web. However, from a historical perspective this is hardly surprising since much computer-based learning – especially distance learning – was carried out by individuals and hence social activities tended not to form part of any central learning activities. Some might also argue that adaptively-presented materials are highly individualistic and hence cannot be used by more than one person at a time. It is very possible that this is too simplistic an approach and that the social aspects of learning may need to be incorporated into computer-based learning for it to be truly helpful (this is discussed further in Chapter 7).

4.6 Learning style models and instruments

The previous section gave examples of AEH systems that have implemented learning style theory as an adaptation mechanism. There is a variety of models used and some major differences between them; these are discussed below. For each approach, there is a general description of the model; how it has been used within AEH and also a critical appraisal of the model itself in terms of validity and reliability.

4.6.1 Witkin and Goodenough

The origins of field dependence (FD) and field independence (FI) stem from Witkin's work in the 1960s [225] and falls within Group 2 of Coffield *et al*'s classification (refer to Figure 4.2). These cognitive constructs are related to the way in which learners perceive, organise and remember information. Those who are field dependent tend to have a holistic perspective and have difficulties separating minor details from the overall viewpoint. Field independence is the opposite; this is when learners are highly analytical and easily focus on specific details irrespective of the general environment. Studies suggest that field-independent learners may perform better than field-dependent learners when using a hypermedia system [169], although this phenomenon is found in other studies [110, 199, 200] that did not use hypermedia as the main technique employed in learning.

AES-CS (Adaptive Educational System – Cognitive Styles) has successfully modelled the FD/FI approach [204], based on work carried out by Witkin and Goodenough in 1981 [226].

Although early qualitative work proved encouraging, there has been no quantitative study of the efficacy of this system thus far.

Although the reliability and validity of this model are adequate [83, 227], there have been problems relating to other factors. Messick [145] states that assessment of FD/FI is more of a measure of ability than learning style; in addition, there is also strong correlation between FD/FI scores and those of mathematical and spatial ability [122]. Thus there seem to be some inherent difficulties in using this theory, which cannot be easily rectified.

4.6.2 Hsiao

The work carried out by Hsiao [115] is itself based on field dependence/independence, in combination with learning strategies of "questioning" and "summarising". This work, and the ILASH (Incorporating LeArning Strategies in Hypermedia) study by Bajraktarevic *et al* [14] hence suffer from the same theoretical problems mentioned previously in Section 4.6.1. In addition, the approach seems to be a peculiar combination of fixed traits (FD/FI being in Group 2 in Figure 4.2) and more flexible ones (learning strategies, as seen in Group 5 in Figure 4.2).

The ILASH study has also not been evaluated empirically and hence does not provide any further evidence to suggest whether this approach has any statistically significant benefit to users.

4.6.3 Dunn and Dunn

The Dunn and Dunn Learning Style Model [87] is widely used across schools and colleges in North America. It is a very flexible model that specifies 21 different learning styles categorised into five major strands (or "stimuli") of environmental, emotional, sociological, physiological and psychological/cognitive processing preferences [85]. However, these traits are said to be fixed preferences that are not susceptible to change; they are thus included in the Group 1 (constitutionally based) families from Figure 4.2.

Seven of these learning styles have been incorporated into the iWeaver AEH system: global, analytical, impulsive, reflective, visual, auditory and kinaesthetic [228, 229]. Although user trials have been planned (and possibly already carried out), the results of these have yet to be published, hence there is no data on whether or not this is an effective method of adaptation.

From a theoretical perspective, the Dunn and Dunn approach is highly controversial. There have been a number of studies carried out that indicate good reliability and validity [84]; however these seem to be mostly internal studies (i.e. those who have been "trained" or "certified" to use the model). Rita Dunn, one of the creators of the model, is dismissive of any external criticisms, regarding them as "biased", "secondary" or "third party" [61, 86]. There are very few independent reviews of the model or its implementation, although the ones that do exist point to key problems with the design and reliability of the main instrument used for measuring the user's characteristics and issues with external validity [61]. Another issue is the fact that this approach can stigmatise students into fixed categories (such as "visual learner" or "kinaesthetic leaner") does not reflect the often-dynamic processes of learning. Until further evidence emerges, the Dunn and Dunn learning styles model cannot be said to be scientifically robust [61].

4.6.4 Kolb

The Learning Style Inventory (LSI) [123] was created by David Kolb, a highly influential figure in the field of learning styles. Since its publication in 1984, the LSI has been used in many disciplines, including education, management, computer science, psychology, medicine, nursing, accounting and law [136]. The LSI falls into Group 4 of Coffield *et al*'s classification (Figure 4.2), that of "flexibly stable learning preferences".

The central doctrine of the LSI is that of experiential learning, inspired by the work of John Dewey, Kurt Lewin and Jean Piaget [11, 61]. Kolb's theory [123] states that people learn from experience, a cyclical process, represented in Figure 4.3 below.

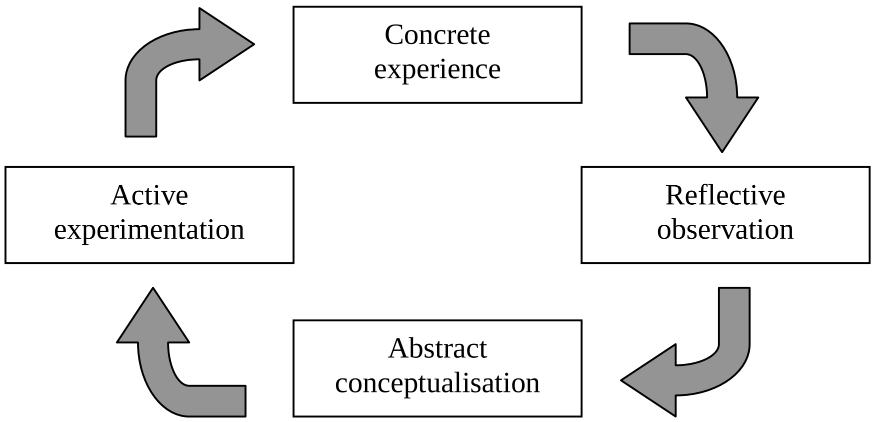

FIGURE 4.3: Kolb's experiential learning cycle

This is a continual process that requires learners to be able to resolve "*conflicts between dialectically opposed modes of adaptation to the world*" [61], hence the four different capacities to learn, as shown in Figure 4.3. Knowledge construction involves both the person and the environment they find themselves in, a combination of both personal knowledge and social knowledge.

Kolb describes four types of learning style that emerge from this cycle; these each correspond to a particular quadrant [61, 123]:

- Diverger (concrete/reflective): students with this learning style are imaginative and perceive situations from many perspectives; they are people-oriented and adapt by observation compared to direct action.
- Converger (abstract/active): students with a converging style are good at decision-making and problem-solving; they prefer resolving technical issues compared to sorting out interpersonal problems.
- Assimilator (abstract/reflective): these learners prefer inductive reasoning, logic and construction of theories; they are driven more by abstract ideas than by interaction with others.
- Accommodator (concrete/active): accommodators are those who are practical and get involved with unfamiliar and changeable circumstances. They are good at solving problems intuitively but sometimes seen by others to be overly proactive and somewhat impatient.

The diverger and converger aspects of Kolb's model have been translated into learning strategies in the AEH authoring system MOT (My Online Teacher) [195]. However, as with many other systems, there have been no published user trials that state any qualitative or quantitative findings resulting from this implementation.

The OPAL (OPen Adaptive Learning) system has also utilised Kolb's model [64], adapted by McCarthy [141], but there do not seem to be any published benefits from having employed this approach.

The reliability of the LSI has long been in dispute [77, 197, 220] and the latest version of it is still under examination.

4.6.5 Honey and Mumford

Honey and Mumford developed Kolb's model further and produced their own approach: the Learning Styles Questionnaire, or LSQ, which is now used commercially, mostly in management and human resources. Unlike Kolb's model, which explicitly asks users how they learn, the LSQ instead investigates general behavioural tendencies rather than learning in particular [114]. However, the four learning styles that are derived from the LSQ bear a strong connection to those of Kolb's ILS: activists (correlating to the "concrete experience" aspect of Kolb's experiential learning style), reflectors (reflective observation), theorists (abstract conceptualisation) and pragmatists (active experimentation). Since Honey and Mumford's work is derived from Kolb's, it follows that their work is also categorised in Group 4 of Coffield *et al*'s families of learning style (see Figure 4.2).

There have been some encouraging results published on the model's internal consistency [7] although there is a lack of evidence to address its validity. It has been implemented in two AEH systems: AHA! (Adaptive Hypermedia Architecture) [195] and INSPIRE (INtelligent System for Personalized Instruction in a Remote Environment) [103]. No user trials have yet been published by researchers working on AHA!, whilst Grigoriadou *et al* appear to have only carried out a small-scale qualitative evaluation of the INSPIRE system design that has not been made widely available.

4.6.6 Felder and Silverman

The Felder-Soloman Index of Learning Styles (ILS) was developed by Richard Felder and Barbara Soloman [94], based on a theoretical model of learning styles developed by Richard Felder and Lynda Silverman [93]. Felder-Soloman refers to the instrument used to assess users' learning styles (a questionnaire) whereas the conceptual basis is named Felder-Silverman. Unfortunately, the similarity between the names has led to them being used interchangeably in the literature; this is of no particular consequence but it is important to establish the subtle difference between them.

The ILS assesses learners on four dimensions: active/reflective; sensing/intuitive; visual/verbal and sequential/global. Reflective students prefer to think through new information and contemplate these ideas, whilst active students prefer a more "hands-on" approach and active experimentation. Sensing learners tend to be more imaginative and observational, and are good at brainstorming and viewing situations from different perspectives, while intuitive learners are problem-solvers and pragmatists, who prefer to deal with facts, technical tasks and the application of theories. Visual learners tend to favour graphically-represented data whilst verbal learners tend to choose textual information (either as audio or written text). Lastly, the sequential and global dimension reflects how information is organised for presentation to the learner. Global information is arranged so the student can gain an overview of the subject before studying the finer detail, to gain a broad conceptual view. Conversely, sequential information emphasises a structured, linear approach to learning, with the student looking at one topic at a time. The model as a whole falls into the same category as those of Kolb and Honey and Mumford, i.e. Group 4: "flexibly stable learning preferences" (refer to Figure 4.2).

Several AEH systems have employed this approach as an adaptation mechanism. Carver *et al*'s system (CS-383) has deployed all four dimensions, whilst the Tangow system [164] has implemented two axes (sequential/global and sensing/intuitive) and work by Bajraktarevic *et al* [15] has utilised only the sequential/global aspects. There are no published findings from user trials carried out with Tangow, however both the other studies have preliminary results of a positive nature.

Although no formal experimental data has been gathered from students' use of CS-383, the staff that have used it in support of their teaching state that they believe it has helped students gain a greater understanding of the concepts taught on the course. This is because that, whilst the course has grown more demanding and the concepts more difficult, the overall distribution of marks awarded to students has not changed [55]. This is anecdotal evidence at best, but a phenomenon that warrants further investigation.

Bajraktarevic *et al*'s study [15] is one of the more scientifically rigorous user trials published in recent years, although it could be argued that the sample sizes of the smallest sub-groups are too low to be used for statistical analysis. The user trials indicated that academic scores were significantly higher in students whose learning environment matched their learning environment, although there was no difference between browsing times of matched versus mismatched students, nor was there a correlation between browsing time and student performance.

In terms of reliability and validity, the ILS is one of the few instruments that scores moderately well. Studies by [95], [236] and [132] indicate acceptable standards for independence, reliability and construct validity for each of the four dimensions.

4.6.7 Other models

There are other minor variations on these in a number of other AEH systems, such as the approach utilised in Arthur [99], after Sarasin's model of audio, visual, tactile and text [181]. However Sarasin's model, like aspects of Dunn and Dunn's, seems highly derived from the well-known VAK/VAKT model (visual-auditory-kinaesthetic or visual-auditory-kinaesthetic-tactile), used by educationalists around the world and shown by Coffield *et al* and others to be fundamentally flawed [62, 66, 219].

However, the work done by Coffield *et al* [61, 62] indicates that there might be some potential in other learning style models that have not yet been implemented in AEH systems. The Cognitive Style Index (CSI) of Allinson and Hayes [6] has been shown to possess good internal consistency and strong measures of validity. It examines intuitive and analytic learning styles. Likewise, Apter's Motivational Style Profile (MSP) and Vermunt's Inventory of Learning Styles (ILS) also have superior reliability and validity, although they are not as robust as the CSI model [61].

However, each of these approaches has its limitations. The CSI model, designed for use with adults, only uses a single bipolar dimension, which is very broad and contains several diverse and loosely-connected characteristics. In addition, there is some evidence to suggest that these two extremes of intuition and analysis are not in fact opposite to each other (although they do possess a negative relationship). The pedagogical implications of the model do not seem to have been fully explored at the time of writing. Apter’s approach examines motivation and human behaviour but these are said to be general aspects of personality rather than specific learning style. In addition, the theory has not been fully implemented except in very specialised situations and there is no evidence for it having had a wider pedagogical impact as yet. Lastly, Vermunt’s ILS does not cater for preferences for representing information and also does not address motivation, emotional aspects or student attention, and is not applicable to all stages of learning. It is also context-dependent and cannot be used to confidently predict learning outcomes.

4.7 Conclusion

It seems apparent that there is an abundance of learning style theories and instruments that measure a range of cognitive and affective processes that may influence the way in which we perceive new information and construct knowledge. Several have inherent problems in the way that they assess users; some of them have inconsistencies in their theoretical underpinning whilst a few of them seem to have more in common with aspects of personality (hinting that they might only hold marginal influence on the direct process of learning). However, what is clear is that a number of these models have been used to provide personalisation of learning materials in AEH and these implementations have provided some initial positive results that now warrant further investigation.

In Chapters 5 and 6, this issue of learning style as a type of user model is explored further. Given the controversy surrounding learning styles and the conflicting evidence of whether they are beneficial or not, it was decided to adopt a classical scientific approach to test the research question of whether there would be any difference in matching or mismatching users’ learning styles to their AEH environment. The next two chapters present the studies carried out and the ensuing results that provide evidence to help answer this question and others that emerged from the work.

CHAPTER 5:

THE WHURLE PROJECT

5.1 Introduction

In previous chapters, the concept of adaptive hypermedia and user modelling has been explored, with particular detail to the theory of learning styles and how it can be applied to achieve personalisation.

Chapter 5 presents the work carried out in an adaptive framework named WHURLE (Web-based Hierarchical Universal Reactive Learning Environment), an AEH system that has been used to support student learning at the University of Nottingham.

The author was responsible for designing and developing a new adaptation filter that required modification of an existing XSLT stylesheet; this stylesheet was then extensively re-organised by the author to incorporate her newly-designed WHURLE interface. This interface also incorporated a PHP (Hypertext Preprocessor) front-end that was linked to an SQL database for the Phase I trials, thus providing the dual functionality of personalised learning and user tracking.

In addition, the author designed the lesson plans used for WHURLE-LS and created all the chunks used for the delivery of content in WHURLE-LS. In parallel with the software development, the author also designed and then carried out system evaluations, incorporating user trials and the gathering of quantitative and qualitative data to find evidence to support or refute the hypotheses under investigation.

5.2 The WHURLE framework

WHURLE [32] is an XML-based Integrated Learning Environment that is designed to deliver adaptive hypermedia content over the web. It does not, in itself, contain any particular user model; rather it is a framework in which any user model may be implemented. WHURLE is a server-side system, implemented largely in XSLT that is currently rendered into HTML using the Apache Cocoon web development framework[15].

[15] http://cocoon.apache.org

The "lesson" that learners experience using WHURLE is defined by a lesson plan, which provides a hierarchical listing of chunks, as well as adaptation information, references to one or more linkbases, and other metadata. Chunks are created by content authors, and it is these that contain the actual educational content. Chunks are the atomic units of the WHURLE system, that is, they are the smallest unit of content that makes sense as a conceptually self-contained whole [32]. In a declarative presentation a chunk usually consists of either a single media item (such as a paragraph of text) or several closely related media items (such as a captioned image) together with all of the meta-information that pertains to that media. Lesson plans are created by teachers who implement the learning experience (who may or may not be the same people as the content creators). Lesson plans consist of one or more hierarchical level definitions – each level may contain one or more pages or additional sub-levels (equivalent to sub-topics of the topic represented by the current level). Each page may contain one or more chunk. Where chunks are specified in a page, the specification also contains metadata that defines circumstances under which the chunk is to be presented as a part of that page. Page definitions may be viewed as a list of potential chunks, some or all of which may be presented to the end-user, according to the rules specified in the user model. In this way, the narrative experience is adapted to the needs of the user according to the contents of their user profile [32].

The mechanics of this are that a node-tree is generated from the lesson plan using XInclude [138]. This is initially processed by an adaptation filter [233] – an XSLT stylesheet that removes any chunks not required, according to the current user model and user profile, and it is this filter that implements the user model. The next stage in the XML pipeline is the display engine. This is an XSLT stylesheet that adds a navigational overlay (using information derived from the position of nodes in the lesson plan and the linkbase/s), and a user interface that is defined in a separate skin.

5.3 Modification of content in WHURLE

The default version of WHURLE contains a dummy adaptation filter, providing the means for a specific user model to be created. To date, one main user model has been written by Zakaria and Brailsford [231, 232, 233], named WHURLE-HM.

WHURLE-HM uses a hybrid paradigm that categorises a user on ability within knowledge domains (ref. Chapter 3) and is based on the overlay model [53, 207] and stereotype model [18, 172]. It combines aspects of both models and, in combination with an “information pool” of educational resources, provides users with personalised learning materials. Users fill in a questionnaire when they use a WHURLE-HM lesson for the first time; this rates their ability within that domain and the information is stored in an SQL database. Chunks within WHURLE-

HM contain attributes relating to the ability level of that chunk. What the user actually sees is adapted content based on the chunks that correspond to their stored data. Users are categorised into groups based on their prior knowledge (e.g. beginner) and although they can move to another group (e.g. intermediate), this cannot happen until they obtain the pre-requisite level of knowledge required for the new group.

This method of adaptation is a much better approach than a uniform presentation of information, where different users are all treated the same and will be given the same material, regardless of their existing knowledge or variation in learning preferences. However, it can also be seen as relatively simplistic, and possibly limited in its pedagogical value since it does not take into account the way in which learners may prefer to learn, in terms of their learning style (as discussed in the previous chapter). The adaptation filter was therefore developed further to incorporate learning style theory, an area of research that has become popular in recent AEH studies.

5.4 Using a learning style within the WHURLE framework

There is a problem with the number of learning style systems in use and a need to rationalise this [56], as discussed in Chapter 4. In light of this, it was decided to utilise an existing learning style approach for user modelling within WHURLE rather than attempt to create a new one. The process of deciding which learning style model was the best one to use was not a simple one, and there was much deliberation before an appropriate one was found. Learning style models currently in use with AEH systems are examined in detail in Chapter 4; these are investigated here with more specific regard to implementation within WHURLE.

There were a number of aspects to consider. For example, some of the theories previously mentioned are not easily implemented within e-learning systems; e.g. Gardner's Multiple Intelligences approach, or the Dunn and Dunn Learning Styles model. Gardner's Multiple Intelligence model covers aspects of cognition that are not necessarily suited to computer-based learning, such as interpersonal and naturalistic intelligences (interpersonal intelligence relates to how well a person can communicate with others, whilst naturalistic intelligence is the ability to recognise and classify objects in their environment). In addition, the limitations of the Dunn and Dunn model are due to the unsuitability of some of the learning style modifiers; these cannot be controlled by the computer and are not always appropriate to the educational settings where AEH is used, for example, mobility (a physiological preference) or any of the environmental conditions (such as light, temperature etc). The Dunn and Dunn approach has been implemented to a limited extent within iWeaver [229], an adaptive hypermedia tool; however, only certain aspects of this model have been utilised and it has not been employed in its entirety. Also, the

Dunn and Dunn approach can be affected by external factors that may influence the observed learners, which limits its suitability even further. However, what overshadows these issues is the overarching problem of unreliability and low validity, as evidenced by Coffield *et al* [62, 63]. Taking all these factors into account, it is clear that the Dunn and Dunn model is not suitable for use as a personalisation mechanism for learners interacting with AEH systems.

There are also commercial aspects to the current use of learning styles; many practitioners who advocate the use of their learning style will actually charge a fee for those who choose to use their model. Examples of these are the Dunn and Dunn model, MBTI (Myers Briggs Type Inventory), Kolb's experiential learning and Honey and Mumford's Learning Styles Questionnaire. This does not rule them out as useful learning style models but obviously this is a negative aspect when considering their suitability for use within academia – especially if there are many students involved. In particular, the INSPIRE system [104] has implemented Kolb's approach successfully and has had encouraging feedback from users.

Witkin and Goodenough's field dependence/field independence theory (implemented in AES-CS [204]) has been criticised for low internal validity, (i.e. the degree to which an evaluation tool is logically sound, with no conflicting factors) both in the theoretical basis and its assessment instrument and the suggestion that it is based more on ability than style [173]. Good internal validity is essential, since it will demonstrate the relative reliability of a learning style theory. The presence of any empirical data resulting from the use of any given learning style with actual learners is essential in order to determine its efficacy.

In order to select a specific learning style for use within WHURLE, it became clear that there were several criteria against which each approach could be assessed.

The criteria used were as follows:

1. The learning style approach can be catered for by computer-based learning.
2. The learning style methodology must be able to be modelled computationally.
3. There must be no, or very low, costs involved in using the tool (copyright, IPR etc).
4. The learning styles tool must have a good degree of internal validity (the extent to which an evaluation tool is logically sound, with no conflicting factors) and a theoretically-sound base.
5. It should be suitable for use with a variety of media used to represent information, such as images, text, animation, audio and video.

Table 5.1 shows how these criteria match up against a variety of learning style approaches that have been used in existing AEH systems and discussed previously in Chapter 4. There was only one learning style model that seemed to satisfy all the criteria: the Felder-Silverman ILS (as shown in Table 5.1). Because of this, and based on the positive results from other research that utilised this model, the Felder-Silverman model is the preferred choice for modelling users' learning styles within WHURLE.

TABLE 5.1: Evaluation of different learning style approaches

Model of learning style (alphabetical order):	**AEH systems that employ this model:**	**Does the learning style approach satisfy:**				
		Criterion 1	*Criterion 2*	*Criterion 3*	*Criterion 4*	*Criterion 5*
Dunn and Dunn [87]	iWeaver [229]	partially	partially	no	no	yes
Felder-Silverman ILS [93]	CS-383 [55]; LSAS [15]; Tangow [164]	yes	yes	yes	yes	yes
Honey and Mumford's Manual of Learning Styles [114]	AHA! [195]; INSPIRE [103]	yes	yes	no	partially	yes
Hsiao (summarising/ questioning) [115]	ILASH [14]	yes	yes	yes	no	yes
Kolb's experiential learning [123]	MOT [195]	yes	yes	no	no	yes
Witkin and Goodenough FI/FD [226]	AES-CS [204]	yes	yes	partially	no	yes

The Felder-Silverman Index of Learning Styles (ILS) assesses students on 4 bipolar axes: visual/verbal; active/reflective; sequential/global and sensing/intuitive (as discussed in chapter 4). These learning style preferences are measured via a 44-item questionnaire, resulting in a score of between 11 to -11 on each scale. However, modelling 4 different learning style preferences in a single system is complex and difficult to evaluate experimentally as separate factors, so it was decided to use a cut-down version of the ILS. Two of these categorisations (visual/verbal and sequential/global) are common to many other learning style models and this was the rationale for exploring these in more detail.

It was initially decided to implement a visual/verbal learning styles filter, since this was easy to model in a multimedia environment, where the learning style preference would be reflected in the mode of presentation. Students' learning styles could be assessed using the appropriate questions from the ILS questionnaire that measured visual/verbal preferences, resulting in a particular profile for each student that is stored in a database (see Appendix A). Using the existing WHURLE engine and a custom-written filter, students would be given personalised material through the integration of data from their user profile and metadata relating to the chunks in the lesson plan.

The output from the ILS questionnaire results in a user's score for particular learning style preferences, ranging from -11 to 11 for each axis. The intervening integers correspond to varying degrees of learning style preference, for example as seen in the visual/verbal axis:

- 9 to 11 = strongly visual
- 5 to 7 = moderately visual
- -3 to 3 = little or no preference
- -5 to -7 = moderately verbal
- -9 to -11 = strongly verbal

User responses to the questions are stored in a database, together with their resultant visual/verbal score. For ease of use, it was decided to re-code these scores into simpler categories, as shown below, whilst still retaining the original concept of positive and negative integers to reflect the bipolarity of the learning style dimension:

- 2 = strongly visual
- 1 = moderately visual
- 0 = little or no preference
- -1 = moderately verbal
- -2 = strongly verbal

These new codes were then stored alongside the original scores in the user profile to preserve both the raw and coded data.

5.5 Designing the learning style filter

The design filter used in WHURLE would have to take account of two things: the content to be adapted to the user profile, and the order in which it is presented. It is crucial at this point to implicitly define where the adaptation occurs; this is in the lesson plan itself rather than the chunks themselves. The chunks may be thought of as having more visual or verbal properties depending on what is contained within them (e.g. a photograph compared to some paragraphs of text), however it is the way in which these chunks are used that defines the personalisation of learning. The lesson plan contains a list of chunks relating to each page, tagged with metadata that relates to the stored user preferences from the database; conditional transclusion operates to present only specific chunks to the user that matches their profile. Thus, the implementation of learning style theory is a path expressed through metadata of a set of resource items (chunks), contained within the lesson plan.

Five different filter designs were proposed, that explored the combinations of these two main factors (content selection and ordering), as shown in Table 5.2. These designs are discussed in more detail in the following sub-sections.

TABLE 5.2: Proposed filter designs for WHURLE

Filter:	**Content:**	**Ordered:**
Filter 1	Limited	No
Filter 2	Flexible	No
Filter 3	Flexible	Yes
Filter 4	Complete	No
Filter 5	Complete	Yes

5.5.1 Evaluation of filter designs

5.5.1.1 Option 1: a limited, unordered approach to content

This approach is very rigid and does not allow for much negotiation of content. The user would be presented only with chunks with learning styles metadata that exactly matched their learning styles profile stored in the database. Ordering is not taken into account.

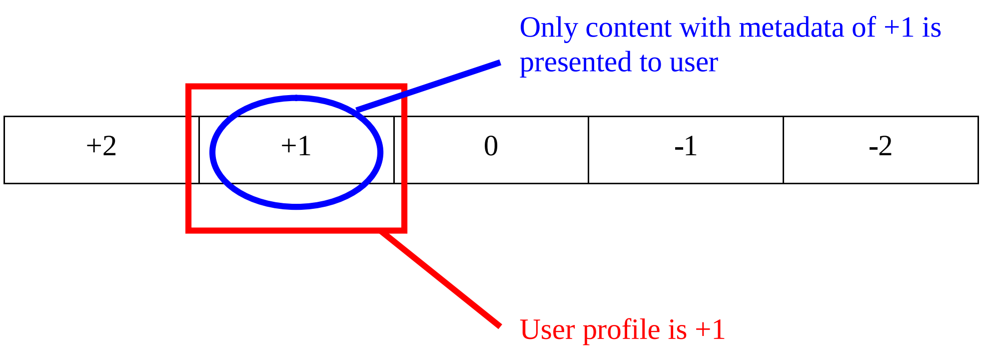

FIGURE 5.1: Diagram showing how the filter would work for Option 1

The boxes represent categories of user on the visual-verbal scale of the Felder-Silverman model, as implemented in WHURLE.

5.5.1.2 Option 2: a flexible, unordered approach to content

This approach is less rigid than Option 1 and does allow for a flexible content. The user would be presented with chunks with learning styles metadata that exactly matched their learning styles profile stored in the database, and also with chunks that are in the adjacent categories of the learning style interval scale. Ordering is still not taken into account.

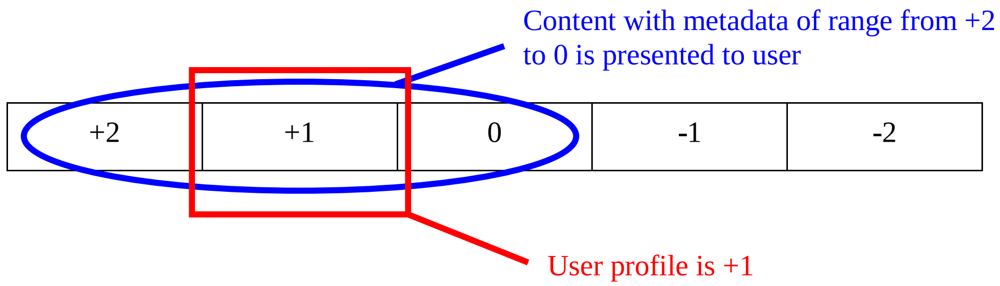

FIGURE 5.2: Diagram showing how the filter would work for Option 2

The boxes represent categories of user as in Figure 5.1.

5.5.1.3 Option 3: modified ordering of flexible content

Option 3 would provide content in the same way as for Option 2. The information presented to the user would be those chunks with learning styles metadata that exactly matched their learning styles profile stored in the database and also chunks that correspond to the adjacent categories of the learning style interval scale. Chunks assigned the same classification of visual-verbal metadata as stored in the user profile would be prioritised and placed at the top of the page, or on the first page of several. If this option were implemented, users would encounter a lesson with pages like this:

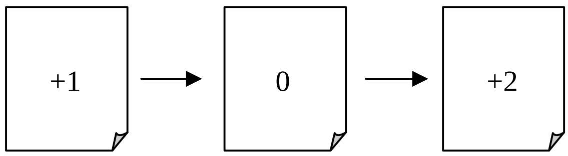

FIGURE 5.3: Diagram showing how the filter would work for Option 3

The pages represent pages of information, whose content has been matched with categories of user on the visual-verbal scale of the Felder-Silverman model, as shown in previous figures. The order is based on a user whose profile is +1.

5.5.1.4 Option 4: an unordered approach to total content

Option 4 would provide the user with all the information used for that lesson but with no regard as to how this material was ordered (in terms of presentational mode). All chunks available to the user for that particular topic would be presented to the user, in a mixture of modes.
Thus, users might see a series of pages as shown in Figure 5.4.

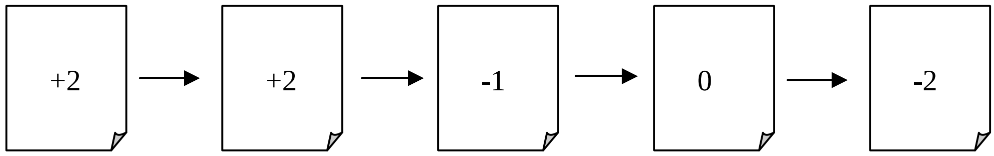

FIGURE 5.4: Diagram showing how the filter would work for Option 4

The pages represent pages of information, without due regard for ordering but with all the chunks available to be seen by the user.

5.5.1.5 Option 5: modified ordering of total content

Option 5 would provide the user with all the information used for that lesson (as in Option 4) but there would be an ordered approach to the presentation of material. Hence, chunks assigned the same classification of visual/verbal metadata as stored in the user profile would be prioritised and placed at the top of the page, or on the first page of several.

Thus, users might see a series of pages as shown in Figure 5.5:

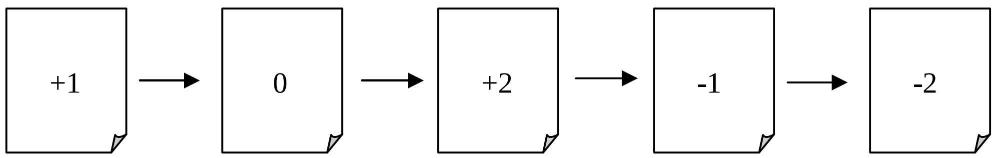

FIGURE 5.5: Diagram showing how the filter would work for Option 5

The pages represent pages of information, whose content has been matched with categories of user on the visual-verbal scale of the Felder-Silverman model. The order is based on a user whose profile is +1.

5.5.2 Conclusion

These filters all have their benefits and disadvantages. The main issue is not to overwhelm the user with too much data on the screen at once. It is also preferable to let the user – not the system – have control of the learning environment as far as possible and also the decisions about what content can and can’t be seen.

Each of the filters described above can thus be scored on these factors; see Table 5.3 for details.

TABLE 5.3: Evaluation of learning style filter designs

Filter:	**Amount of content presented to the user?**	**Ordering available?**	**User or system control?**
Option 1	Limited	No	System
Option 2	Flexible	No	System
Option 3	Flexible	Yes	System
Option 4	All	No	User
Option 5	All	Yes	User

Bearing these points in mind, and the fact that the filter will initially be used for providing material shown in different presentation modes, it seems that Option 3 is the best choice for modelling a preliminary learning styles filter. Not all the material will be available to the user, (since this is incongruous with the concept of providing learning materials personalised to a user's characteristics), but there is some flexibility over the inclusion of chunks that are not completely matched to the user's preferences. Ordering of chunks will ensure that the most appropriate chunks are seen first, with less appropriate ones following.

This initial experiment will also determine how users react to the lack of overall control afforded them by the system (in terms of the choice of learning materials seen) and whether they think this is a good thing or not.

5.5.3 Implementing the filter design in WHURLE

The WHURLE engine was modified to include a learning style parameter, named "felder" (after the learning styles model upon which this is based). This involved a simple modification of an XSLT file to include this as an additional argument in the WHURLE pipeline.

Learning style adaptation was implemented in the lesson plan, where chunks were tagged with metadata relating to the users' learning styles. It was at this point that a pragmatic decision was made, in relation to the granularity of learning style adaptation. It was felt that 5 categories of users (from 2 to -2) were simply too many and provided logistical difficulties in authoring course materials to this level of personalisation. Instead the categories were collapsed from 5 into 3 and re-classed as "visual" (+2), "neutral/no preference" (0) and "verbal" (-2). In this way, authoring was much simplified to provide only 3 paths through the lesson plan. The design of the filter was maintained, however, so that there was some flexibility over the content received by the user. In this way, some chunks were used in more than one path (i.e. across more than one learning style) but the ordering was maintained so that the material seen first was the most appropriate to the user profile.

5.6 User trials of WHURLE-LS

5.6.1 Phase I

5.6.1.1 Introduction

User trials were conducted in May 2005 by the author with a number of undergraduate and taught postgraduate students (n=221) studying for a module offered by the School of Computer Science & IT at the University of Nottingham. They were given the opportunity to use a web-based revision guide as part of the teaching support for the module, introduced to them by the author in a revision lecture. The revision guide was a version of WHURLE that utilised the learning styles filter, as described in Section 5.4 above, that took into account the students' visual/verbal learning styles and placed them randomly into either a matched, neutral or mismatched group. This version of WHURLE has been named WHURLE-LS so that it is clear which filter is being utilised.

In this study, matched students were given content that matched their particular style, whilst mismatched students were given content that was contrary to their learning style (e.g. a visual learner would be given verbal content). Neutral students were those students whose learning styles were not matched to the environment, but interacted with learning materials only just outside of their preference, which were not the bipolar opposite of their learning style preferences. Table 5.4 below makes clear these groupings as categorised in the user trial:

TABLE 5.4: Groupings of pupils in WHURLE-LS user trials

		Learning environment:		
		Visual	**No preference**	**Verbal**
Learning style:	**Visual**	Matched	Neutral	Mismatched
	No preference (bimodal)	Neutral	Matched	Neutral
	Verbal	Mismatched	Neutral	Matched

Screenshots from the system can be seen in Figures 5.6 and 5.7, showing examples of differently represented information, which could be matched and mismatched respectively, for a visual learner.

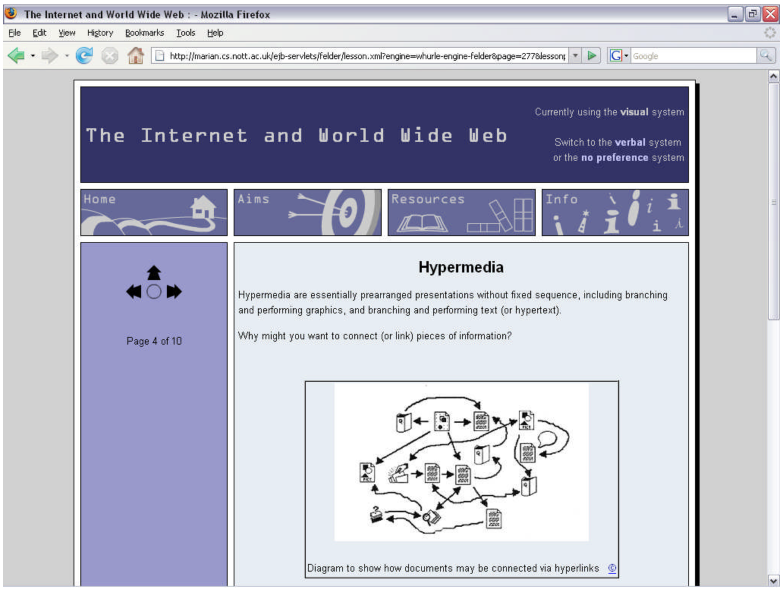

FIGURE 5.6: Screenshot of the revision guide, showing a matched environment for a visual learner (since the content is represented visually)

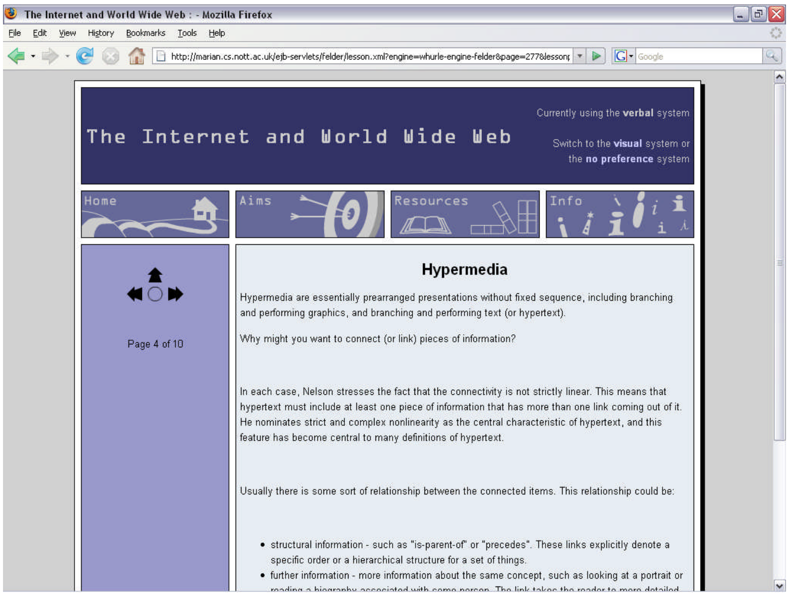

FIGURE 5.7: Screenshot of the same section of the revision guide, but in a mismatched environment for a visual learner (i.e. a verbal representation of content)

Assessment and tracking of the students was carried out using a variety of methods. Access logs of all the pages in the revision guide were collected (giving information about which pages/units were visited by each student), and also data relating to academic performance.

Students' marks for module coursework, exam and overall module mark were collected, together with the mark gained from a Multiple-Choice Quiz (MCQ) that formed part of the revision guide

5.6.1.2 Hypotheses under investigation

A thorough analysis of the data was carried out to explore whether there was sufficient evidence to support any of the following hypotheses:

H_0 – there will be no difference in the learning experience between matched, neutral and non-matched users

H_1 – students who learn in a matched environment will learn significantly better than those who are in mismatched or neutral environment

H_2 – students who learn in a mismatched environment will learn significantly worse than those who learn in a matched or neutral environment

H_3 – one particular type of learning style is better for students in terms of performance

H_4 – one particular type of learning environment is better for students in terms of performance

The initial hypotheses of H_1 and H_2 were expanded somewhat into the next two hypotheses; it was felt that a thorough investigation should explore the possibility of a significant effect of either a particular learning style or particular type of learning environment (i.e. how the material was presented).

5.6.1.3 Experimental results

Extensive data were collected over a 2-week period during which students had full, 24-hour access to the web-based revision guide. Using SPSS, statistical analyses of the data were carried out to see whether there were any significant differences relating to each hypothesis. Academic performance was measured by module exam mark and the score achieved by the student if they chose to answer a 20-question Multiple-Choice Quiz used in the revision guide.

Out of 234 students taking the module, 221 decided to log into the system at least once and consequently had their learning style assessed and recorded. Out of those, 105 were assessed as visual, 105 had no preference (also referred to as 'bimodal') and only 11 were classed as verbal. This small number of verbal learners compared to visual learners is consistent with findings of other studies carried out with electrical engineering students and those studying for other scientific degree programmes [95]. Although 3-way group analyses were intended to be carried out, due to the extremely small and uneven group sizes, these verbal users have had to be excluded from the statistical analysis (this was taken on advice from a quantitative researcher in psychology). Hence the following results are based on those users who were either visual or bimodal. In addition, students who had not appeared to use the system very much were also excluded, since they may have contributed some erroneous data to this quasi-experimental situation. "Use" of the system was defined as those students who had viewed 6 or more separate pages from the system since this was the number of pages in the smallest topic of study.

Each of the following hypotheses is now studied in turn, with accompanying statistical data.

H_1 – students who learn in a matched environment will learn significantly better than those who are in mismatched or neutral environments

This hypothesis investigated the module exam mark awarded to students who were placed in matched, mismatched or neutral groups. A one-way between-groups multivariate analysis of variance (MANOVA) was carried out to study the significance of any difference between performances of these groups. Two dependent variables were used: module exam mark and revision guide MCQ score. The independent variable was group type (match, mismatched or neutral).

The information contained in Tables 5.5 and 5.6 shows mean scores from each of the groups for each dependent variable. Statistical analysis indicates that there was no significant difference between the groups: $F(4,210)=0.66$, $p=0.62$, Wilks' Lambda=0.98, partial eta squared=0.1.

Thus it can be concluded that matched students did not perform any better than students from the mismatched or neutral groups in either the exam performance or in the revision guide MCQ. Thus there is no evidence to support hypothesis 1, and it can be rejected.

TABLE 5.5: Details of mean exam mark for students in matched, mismatched and neutral groups

Student type	N	Mean exam mark (%)	Standard deviation
Matched	101	60.06	13.588
Mismatched	24	59.33	17.591
Neutral	28	62.0	10.364
Total:	*153*	*60.3*	*13.715*

TABLE 5.6: Details of mean MCQ mark for students in matched, mismatched and neutral groups

Student type	N	Mean MCQ mark (%)	Standard deviation
Matched	74	62.3	16.201
Mismatched	14	67.5	11.561
Neutral	21	66.9	16.461
Total:	*109*	*63.85*	*15.239*

H_2 – students who learn in a mismatched environment will learn significantly worse than those who learn in a matched or neutral environment

In this analysis, students were likewise assessed as per the previous hypothesis. This time, mismatched students were compared with students who were not mismatched (i.e. those placed in neutral or matched environment): the scores are presented in Tables 5.5 and 5.6 as before.

The academic performances of mismatched students were very similar to those who were matched or in the neutral environment. With the same statistical values as for hypothesis 1, it is clear that this hypothesis must likewise be rejected since there is no evidence to support it.

H_3 – one particular type of learning style is better for students in terms of performance

The idea behind this hypothesis was to explore the main effect of learning style: was there any benefit to having one particular learning style over another? If so, predictions could be made that certain student types would do better than others, regardless of the type of presentation that they were given.

Analysis was carried out again using a one-way MANOVA. The dependent variables were the same as for the previous hypotheses (i.e. exam score and MCQ score) but the independent variable was learning style (visual vs bimodal). The mean exam and MCQ scores are shown in Tables 5.7 and 5.8.

TABLE 5.7: Details of mean exam mark for students categorised visual or bimodal

Student type	N	Mean exam mark (%)	Standard deviation
Visual	72	60.03	13.837
Bimodal	81	60.54	13.687
Total	*153*	*60.3*	*13.715*

TABLE 5.8: Details of mean MCQ mark for students categorised visual or bimodal

Student type	N	Mean MCQ mark (%)	Standard deviation
Visual	53	64.72	13.778
Bimodal	56	63.04	16.588
Total	*109*	*63.85*	*15.239*

From this analysis, it seems that there was no significant difference between students using different learning styles and their exam or MCQ scores: $F(2,106)=0.46$, $p=0.63$, Wilks' Lambda=0.99, partial eta squared=0.01.

It can be concluded from these results that there is no evidence to suggest that one learning style is better than others for in terms of academic performance, and thus the H_3 hypothesis can be rejected.

H_4 – one particular type of learning environment is better for students in terms of performance

Instead of investigating if one learning style might lead to better academic results over another learning style, this hypothesis tested the environment that the student was presented with. This was to investigate whether a particular type of multimedia representation resulted in a better academic performance, regardless of the students' learning styles.

Data relating to this hypothesis are shown in Tables 5.9 and 5.10. Independent variables used for this MANOVA were environment type: visual, neutral or verbal. Dependent variables were exam score and MCQ score, as used previously.

TABLE 5.9: Details of mean exam mark for students using visual, neutral or verbal environments

Environment type	N	Mean exam mark (%)	Standard deviation
Visual	18	57.89	13.936
Neutral	77	61.55	12.953
Verbal	14	62.93	18.574
Total	*109*	*61.12*	*13.873*

TABLE 5.10: Details of mean MCQ mark for students using visual, neutral or verbal environments

Environment type	N	Mean MCQ mark (%)	Standard deviation
Visual	18	60.0	15.146
Neutral	77	64.09	15.806
Verbal	14	67.5	11.561
Total	*109*	*63.85*	*15.239*

Whilst some of the mean scores shown in Tables 5.9 and 5.10 suggest that there are differences between groups, these were not shown to be statistically significant: $F(4,210)=0.59$, $p=0.67$, Wilks' Lambda=0.98, partial eta squared=0.01.

It can therefore be concluded that the type of multimedia representations made to the students does not have an effect on their academic performance, and the H_4 hypothesis can be rejected.

Two further hypotheses were also investigated, relating to the use of the revision guide:

H_5 – students who use the revision guide will do significantly better than those who do not use it

H_6 – the more that students use the revision guide, the better they will do

H_5 – students who use the revision guide will do significantly better than those who do not use it

In this analysis, the exam scores and MCQ scores were compared between students who used the system (i.e. viewed 6 or more pages) and those who did not (less than 6 page views). There did not seem to be any significant correlation for either of the academic markers and use of the system (for exam scores: r=-0.091, n=210, p=0.189; for MCQ scores: r=0.025, n=114, p=0.792).

Thus, there cannot be said to be a difference between users and non-users, nor indeed any particular benefit to using this personalised system (regardless of matching or mismatching) over normal behaviours of revising.

H_6 – the more that students use the revision guide, the better they will do

Both the exam scores and the MCQ scores were correlated to the number of pages accessed by students that used the system, but they were not statistically significant (for exam scores: r=0.000, n=210, p=0.997; for MCQ scores: r=0.142, n=114, p=0.131).

The statistics presented here show that there is no significant correlation between the number of pages accessed by a student and their resulting academic performance; put another way, prolonged usage of the revision guide does not result in better marks.

The evidence produced from this study overall indicates no support for the alternate hypotheses and thus the H_0 hypothesis is proved (that there will be no difference in the learning experience between matched, neutral and non-matched users). However it is important to note that the verbal learner sub-group could not be included in the statistical testing, and it cannot be assumed that these conclusions are necessarily true for those particular students.

5.6.1.4 Qualitative findings

Qualitative data was also collected from the Phase I study, that comprised feedback from students, in the form of questionnaires (n=122) and one-to-one interviews (n=10) (see Appendix B for a copy of the interview questions).

All the students who were interviewed said that they enjoyed revising using the system more than other, more traditional methods of revising. However, when analysing questionnaire data, this view was supported by only 44% of respondents, with 19% in disagreement (comments were made stating that they liked to use the system in combination with other methods). The interviewed students also said they would like to have used such a system in other modules, and would recommend it to their friends and fellow students. This was supported by questionnaire data, where 61% of students said they would have liked to use a similar application in other modules. Interestingly enough, none of the students who were interviewed seemed to see much difference between what they saw on their own screens, and what their friends saw. When asked about who should control the adaptation, most said that they wanted to have ultimate control over what they saw (70% of interviewees). Only a few students were happy to have a computer take complete control of their content (30% of interviewees). However, all interviewees thought that using an adaptive, personalised system was preferable to a ‘one size fits all’ approach.

Most students found the system easy to use and understood the idea of learning styles to personalise content (71% of questionnaire respondents). A similar number of students said they would be happy to recommend the system to their friends (69% of questionnaire respondents).

Aspects of the system that were most well-liked by the students were a multiple-choice quiz that was integrated into the revision guide as an additional study support tool (2% of respondents); also the ability to look up their coursework marks from the module from the initial welcome page on the system (11%). This ability to check coursework marks was provided as an incentive to students to use the system and seemingly used by the vast majority of students on the course. It is no particular surprise that students appreciated being able to see assessment results online since this has been an important function of web-based educational systems for some time.

Aspects of the system that were least liked by the students were the content itself (10% of respondents) although this was not linked to whether the students were matched or not. It is probable that this result is partially a consequence of students feeling under pressure to revise and do well in the subject; it is also fair to assume that not all students will enjoy all the subjects that they study and this may be reflected in these answers. However, only 6% of respondents said that they did not enjoy using the revision guide itself, whilst a small majority (52%) stated that they liked using the revision guide, and the remainder stating a neutral opinion (42%).

5.6.1.5 System log data

It is also worth investigating how students used the system, in terms of pages served and what they thought of the system in general. There were 48 pages of revision information, spread over 6 topics, and this equates to the average number of pages viewed per student (also 48). There were some students who far exceeded this average though, with one student logging 185 page requests during the study. The log files did not suggest any differences between the number of pages viewed on average between the matched, neutral and mismatched groups, and so a differential dropout did not occur – it seems that students either did not mind too much what kind of material they were viewing or else managed to tolerate it. This is in contrast to what some researchers have found [87, 94].

User evaluations from the aforementioned questionnaires suggest that the students found that the appearance of the interface and page layout was of a high standard (62% of respondents) and consistent (87%). The system was easy to navigate (73%) and easy to use (73%).

5.6.1.6 Summary of findings

From the extensive data collected in these Phase I user trials, it seems as though the use of a visual-verbal learning style model to provide matched or mismatched content to university students is unlikely to enhance learning in a statistically significant way. It did not seem to matter whether a student was a visual or bimodal learner, nor if they were presented with visual, verbal or mixed representations of data. However, there were many variables present in this study that could not be controlled for, which may have had an impact on the results (such as students' prior academic performances – although there was a positive correlation between performance measured in the study when compared with previous academic performance of the same students). It is also possible that, if there was any significant difference to be found, they were so small so as to be obscured by the coarse-grained measures used to assess academic performance in this study. The low scores for partial eta squared suggest that effect size might be an issue and in this, in combination with these coarse-grained measures of academic performance, might explain why the results failed to reach statistical significance: the user trial was simply not fine-tuned enough to be able to detect any significant outcomes.

There are many possible reasons why these negative results were obtained from this study, and the fact that they were negative does not necessarily show that visual-verbal learning styles are not important (or even that learning styles themselves are not important per se).

The qualitative results however indicate that many students preferred this kind of revision aid over other, more traditional means of revision, or appreciate being able to use an application like this alongside their more usual revision techniques. Ensuring that the system was easy and enjoyable to use, along with an added motivational tool of being able to check their coursework marks, meant that a large number of students logged on to use the system. The data shows that 64% of students used the revision guide regularly and 94% logged on at least once.

This research also showed that students like to have their individual needs recognised and catered for. It is this kind of information that is not often highlighted by empirical studies, yet it is an essential part of any system evaluation. Interview data suggests that the majority of students would like to have control over any adaptation mechanism of an AEH although this engenders further debate about the efficacy of providing such functionality. Can students really know what their own preferences are? How well can we know ourselves, and is it even a good idea to always have matched content? Would students even decide to view matched content all the time or would they choose to deliberately mismatch? Would students need to have their learning styles determined prior to using such a system, and would they need or want to be told what their preferred learning style had been categorised as? And if learning styles are not static, how often should the system be assessing the student (if at all)?

5.6.1.7 Impact on future work

It is clear that this study has created many more questions than answers. It has, however, provided a clear example of how learning styles can be integrated into an adaptive hypermedia system, and showed promising results in terms of student motivation, even though academic performance was not in itself affected.

Those students who were interviewed seemed to think that the visual-verbal learning style preference seemed to be a sensible categorisation although a small number of them thought that there might be other ways to assess learning style too. This study has engendered much debate about the use of visual and verbal learning styles, in particular the way in which these representations of information can be authored. It is not without its problems, not least of all the lack of existing visual representations and the possible emergence of subjective bias from authors who might be creating such representations. Indeed, without professional guidance from a cognitive scientist, who can judge what is truly, a wholly visual representation? And what level of granularity should be applied to an image in terms of its visual semantics?

In the qualitative evaluation of the user trial, one of the criticisms made by the users was the lack of personal control over the mode used to present the content – nearly all those who responded to a feedback questionnaire stated that they wished to have overall control, rather than the system [38]. User control has long been an important aspect of human-computer interaction and so this viewpoint came as no surprise.

As a result of this evaluation, a new user trial was planned, that would investigate the effect of user control over the presentational mode.

5.6.2 Phase II

5.6.2.1 Introduction

In this next study, it was decided to assess how users would interact with WHURLE-LS if they could choose the mode of information presentation. The content of the system was kept the same. However, the original Phase 1 interface was modified slightly to include links to different presentation modes, so that the mode of a page could be switched at will between three possibilities: visual, verbal, and neutral. This was a distinct change from the previous user trial, where users had no control over the mode of information presented to them. Individual user tracking would not be a feature of these user trials; rather, users would be briefed on the system and the different modes, and then given completely free access without having to log in every time. This was done to encourage usage of the system, and also to reassure students that they could engage with the system in complete anonymity. The content was kept the same as for the Phase 1 user trials, i.e. 6 topics each consisting of between 6 and 10 pages.

Academic performance was not the factor under investigation this time; rather, it was decided to investigate how users would interact with an adaptive system – if there would emerge a preferred mode, or if users switched modes, and if so, what kind of switching did they do? The mode choice and mode switching of the users reveal much about how they interacted with the system, and also give implicit information about their perceptions of learning style modes as a means of personalisation.

The rest of this chapter presents the Phase 2 user trial in more detail, examining the data gathered and discussing what the results might signify.

5.6.2.2 Observational design

The user trial was conducted by the author in May 2006, with 144 undergraduate and postgraduate students studying for the same taught module as used in Phase I (albeit with a different cohort of users). They were given the opportunity to use the same revision guide as their predecessors and were introduced to it in a similar manner, i.e. a demonstration of the system in a revision lecture, followed by an email containing a URL link to the system. However, the students were not tracked individually and the mode of information presentation in the revision guide could be changed at any time by the user. Students were given an introduction to the revision guide by the researcher and told about the different modes of presentation and the way in which they were to be used. The different learning styles were explained in detail, with users being prompted to choose the learning environment that best matched their preferred learning style at the time of accessing the material. They were also told that they could switch between different modes at will, to a different presentational style. Students were able to interact with the system at any time, either from on or off campus.

The decision not to track users was an important one, and a particular strength of this study since it shows a pioneering technique that could be used to analyse most web log data, and indeed other forms of click-stream data. This is only possible *because* identity is not tracked; in addition, such information often isn't available in real world scenarios (and even if it is available, may be sometimes unreliable). This kind of data is much more 'real' than that gleaned from artificial/experimental situations, and could even be said to mimic naturally-occurring populations.

The user trial was carried out over a period of 2 weeks, leading up to the module exam. Over this time period, web log data were collected. Each log entry shows the page in the system accessed by the user, and its mode (visual, neutral or verbal). The entries were sorted into sessions to enable analysis of user interactions (see Appendix C for a sample of the log data). Log entries belonged to a single session if the IP address was the same for a specific time frame:

separate entries occurring within an hour of each other. Although this procedure may have generated some slippage in the identification of single-user browsing sessions, it seems reasonable and was applied consistently throughout.

For each session, the log thus consists of the sequence of pages accessed and the mode in which each was accessed. During a session a single page can have been accessed several times – with or without change of presentation mode – and each of these occasions is logged.

Towards the end of the study, users were again offered the chance to participate in a multiple-choice quiz, which was marked automatically and gave instant feedback. Users taking part in the quiz were also asked to give feedback about the system via a separate set of questions at the end of the quiz.

The nature of the data does not give a complete picture of the users' activities during each browsing session. They could have been using other applications in between pages loading (such as checking email or using instant messaging); or printing off each page of information without reading it; or they could have been chatting to friends nearby. Hence it is extremely difficult to ascertain how much of the browsing session was actually spent reading or interacting with information on screen. Because of this limitation, techniques such as time series analyses could not be employed, nor could investigations into precise analysis of time spent on specific activities. This kind of information could only be gained through a different kind of design, with users being observed in a laboratory situation, or at the very least, having browsing behaviour recorded with screen capture software. Moreover, because of the absence of user tracking it is impossible to trace user behaviour across a series of sessions; it is not possible to ascertain whether a session is the first session of a given user, or his/her second or later session.

5.6.2.3 User browsing behaviour

There are certain things that are known about common behaviours of people who browse the web. In many cases they tend to be working towards some goal - for example, booking a flight or finding out some new information. Such people usually want to achieve their goal as quickly as possible, and in the most effective manner. In a very general fashion, these are the foundational tenets of rational choice theory (see below). How can these assumptions be used to predict how typical students would interact with the revision guide, when they were allowed free rein with the mode of information presentation? What kinds of browsing behaviour would be expected and why? Rational choice theory (a dominant theoretical paradigm in microeconomics) is now used as the basis for suggesting how users could be expected to interact with the revision guide, and as a framework for theorising what kinds of choices they would make.

5.6.2.4 Rational choice theory

Rational choice theory states that individuals behave in an optimal fashion, according to their preferences/goals and set of actions available to them [1]. Utility maximisation is at the core of this, where the individual chooses actions that will yield the greatest output [187].

However, according to Simon [188], "*rationality fixes attention on particular goals, usually until these are satisfied, but shifts attention to other goals when they become more pressing… So rationality is not just a cognitive function, but depends on motivation and emotion to control attention*".

So, it seems as though individuals will not always make rational choices; people will be limited by other factors such as time and cognitive capability. Individuals will also have their own schemas – their own mental models about how the world works. With these factors in mind, it seems better to look at bounded rationality as a more precise theoretical framework to underpin expectations of user behaviour.

In bounded rationality, rational choice is influenced by the processes leading up to it [188]. The two major causes of bounded rationality are the limitations of the human mind, and the structure within which the mind operates [186]. From this, we have a guided paradigm of expectations, where user behaviour can be triggered and explained by certain events.

5.6.2.5 Expected browsing behaviour

From first principles, several different kinds of mode choice behaviour were expected amongst users. These expectations are detailed below:

- Choice of mode is driven by user characteristics: people have different learning style preferences, i.e., different preferences for presentational modes. The cost of briefly experimenting with each of the three modes is low, hence the differences in benefit will be immediately apparent and users will soon settle into their preferred mode. In the absence of identity tracking, this possibility would manifest itself in a preponderance of sessions in which a single mode is used exclusively.
- Choice of mode is driven by content or page characteristics; for example, some topics lend themselves better to a visual mode, whilst others are more effective in a verbal one. Alternatively, the quality of implementation of the various modes may vary across pages, which will also generate page-related mode choices. This would manifest itself in different profiles of modes chosen when accessing different pages.
- Choice of mode is driven by 'completism': users may not want to run the risk of missing anything at all (in rational choice terms, this is a 'minimum regret' strategy) and will therefore access each page in all modes available.

- Choice of mode can be driven by a chance process, unconnected to characteristics of users or content. If so, mode choice and switching would be expected to be independent of such characteristics.

5.6.2.6 Data analysis

The data is semi-hierarchical (individual accesses of pages being nested in sessions), allowing different views in terms of units of analysis, of which two will be focussed on: **sessions** and **page types**. Lack of individual user tracking has the consequent problem that some interpretations cannot be tested comprehensively, but what can be assessed is the extent that the implications of certain interpretations agree with the observed data.

The main purpose of this user trial was to find out what propels users to choose a mode and to switch modes; they have a choice over which mode to use, so what makes them switch? According to rational choice theory, there is effort involved in switching since the user must invest some time or thought in considering the benefits of switching. There are obviously a number of factors that could be contributing to switching behaviour and the remainder of this chapter infer what these might be and discusses their importance to users.

5.6.2.7 System usage

Overall, 162 sessions were analysed, with an average of 28.7 pages accessed per session (equating to an average of 1.13 sessions per student, assuming 100% participation rate). There were some additional sessions that were excluded from the analysis: those consisting of 5 or fewer distinct pages were not counted since it was not felt that users properly interacted with the system (the smallest topic was 6 pages long). This set of criteria for excluding data is consistent with that used in the Phase 1 user trials.

Of the 162 sessions, 79 did not exhibit any switching between presentational modes but the remaining 83 showed at least one mode switch during the session. Of the 83 “switching” sessions, the average number of mode switches was 4 (S.D. 11.5). The average length of time of a browsing session was 57 minutes, although information with respect to duration is difficult to interpret, as it is unknown for how much of this time people actually interacted with the system, rather than engaged in other activities.

The study was carried out over a period of 15 days; however usage of the system was not at the same level throughout this time. The first third of the browsing sessions occurred over the first 10-11 days; the second third occurred over the next 3-4 days; and the final third took place over the last 12 hours. This increase in usage is not surprising since the period of study finished directly before the exam for this module. As a revision guide, students would be expected to make more use of it as they revise, which is typically done immediately before an exam (otherwise known as “cramming”).

In the analyses below, the timing of the session was taken into consideration as a co-variant. Each session was classified into a time period (first, second or final third) and this was modelled as part of the data analysis. Data was analysed in SPSS, using a combination of ANOVA (Analysis of Variance), t-tests, Chi-square tests, correlations and regressions.

5.6.2.8 Perspective of the individual session

The analyses commence from the perspective of sessions, each of which can be characterised by a number of factors. Examples of these include: the number of different pages accessed (and the identity of those pages); the distribution of modes of presentation chosen by the user; and related to this, the number of mode switches. The first finding from this analysis is that the average number of pages accessed is considerably higher in the third period than in the first two (see Table 5.11), a difference that is significant at the level of $p<0.10$ ($F=2.82$, $df=1$).

TABLE 5.11: Average number of pages per session and proportions of page modes across the three time periods

Time period	No. of pages	Of non-switching sessions, proportion in		
		visual mode	neutral mode	verbal mode
1 Mean N=55	23.4	0.427	0.331	0.241
2 Mean N=54	27.2	0.328	0.383	0.289
3 Mean N=53	35.7	0.326	0.443	0.231
Total mean N=162	28.7	0.361	0.38	0.254

As far as the non-switching sessions are concerned, the proportion of pages accessed in visual mode declines after the first time period. Conversely, the proportion of pages accessed in the neutral mode increases over time. Although these differences do not reach statistical significance (partly as a consequence of the limited number of cases in this perspective), they fit in with other findings that all suggest a small, but distinct, shift in usage patterns in the different time periods. There is a slight fluctuation in the proportion of verbal pages.

Individual pages were grouped in the system into substantive topics. From page usage, it can thus be derived which topics were accessed. Across all sessions, users accessed the later topics progressively less often than the earlier ones (see Table 5.12). The proportion of all sessions in which topics were accessed was highest for topic 1 (0.91), whilst decreasing further down the topics to 0.40 for topic 6. The differences between these proportions for topic 1 versus topic 2 versus topics 3-6 are significant at the level of $p<0.01$ ($t=6.78$ for the first of these contrasts, and 3.91 for the second; $df=161$ in both cases).

This progressive tailing-off of accessed topics suggests that users followed the order of topic presentation in their browsing, while either running out of time at the end (thus not browsing all topics) or using a strategic and satisficing approach to browsing (whereby users think they have mastered enough material in order to pass the exam and hence do not need to study the remaining topics).

In either case, the pattern displayed in Table 5.12 demonstrates the strength of order of presentation on behaviour, even if such an effect is actually not intended.

TABLE 5.12: Proportion of sessions in which topics were accessed

Topic:	**Frequency:**
1	0.91
2	0.60
3	0.42
4	0.42
5	0.40
6	0.40

As indicated above, no mode-switching occurred in 79 sessions, while such switches occurred once or more in the remaining 83 sessions. What is it that drives this difference and that also accounts for the variation in the number of mode-switches that may occur? One possibility could be user characteristics: users with a strong preference for a particular mode (i.e. learning style) only use that mode, while the observed switches have to be accounted for by users without a strong preference for a learning style. As individual users cannot be identified, this possibility must be tested for in a different manner. It can be examined by contrasting it with a different possibility, namely that switching is driven by an unchanging probability, unrelated to user preferences for learning styles. The latter proposition would suggest that the number of switches is linearly related to the number of pages accessed during a session, whereas the former (the learning-style interpretation) should show no relationship between number of pages accessed and number of mode switches.

The relationship between number of pages accessed and number of mode switches is illustrated in the scatterplot displayed in Figure 5.8. This shows a statistically significant linear correlation ($r=0.865$, $n=162$, $p<0.01$). This correlation is even stronger if the two outlying cases in the bottom right-hand corner of the graph are removed (although, since the two outliers do not appear to be erroneous and removing them would not alter the statistical significance of the correlation, there was no need to delete these cases from the analysis). This finding contradicts the implication that mode-switching would be driven by learning styles.

It was also revealed that the number of switches during a session significantly increases with the number of different topics that are accessed during that session (r=0.345, n=162, p<0.01). The average number of topics accessed per session was 3.15 (across all sessions); in switched sessions it was 3.5 and in non-switched sessions it was 2.8.

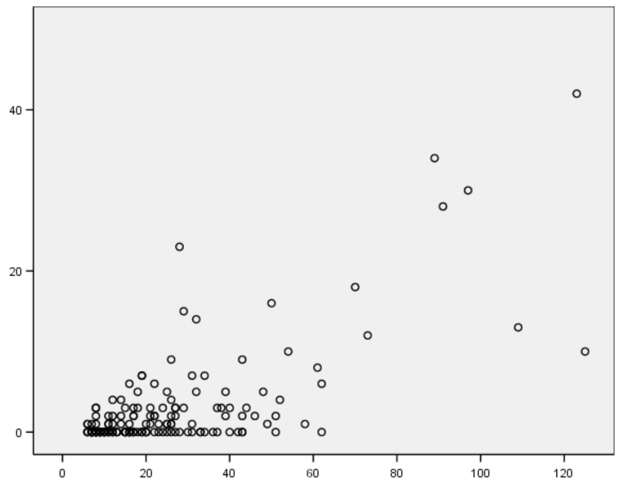

FIGURE 5.8: Scatterplot of number of pages accessed (horizontal axis) and number of mode-switches (vertical axis)

Multiple regression analyses were then used, in order to assess to what extent the effects of number of pages and number of topics were complementary, or overlapping. Additionally, regression enables the investigation of any additional factors that might affect mode-switching. It is possible that particular topics might lend themselves better (or worse) to particular modes of presentation, thus it was also crucial to examine whether the access of any particular topics was significantly related to the number of mode-switches during a session.

From a series of different regression analyses, it was discovered that the specific topics accessed in a session were irrelevant. Rather, it was the number of different topics and the total number of pages accessed that had a significant effect on the number of mode-switches. The latter of these two independent variables had a much stronger effect than the former (and embodies almost 5 times the explanatory power of the number of topics). This simple explanation is very powerful, however, and accounts for 77% of the variation in the dependent variable (number of mode-switches); these results are summarised in Table 5.13.

Table 5.13 also shows that the regression coefficient of number of topics is negative, which indicates that the positive correlation with number of mode switches referred to earlier is spurious, and generated by a positive correlation (r=0.556, p<0.0005) between total number of pages accessed and the number of topics accessed. When controlling for the total number of pages, however, the independent effect of the number of topics is negative. This could be the results of users who have relatively little time available to browse the entire content of the system, and who, in order to do this as effectively as possible, stick to a single mode. The luxury of switching may be beyond the means of those who have very little time available, although this cannot be definitively tested in the absence of tracked user identities.

TABLE 5.13: Multiple regression analysis of number of mode-switches in a session

	Unstandardized coefficients		Standardized coefficients	t	Significance
	B	S.E.	Beta		
No. of pages	0.301	0.014	0.974	21.513	<0.0005
No. of topics	-1.394	0.321	-0.197	-4.348	<0.0005

Adjusted $R^2 = 0.77$

The most interesting result of the regression analyses, however, is the very strong impact of the number of pages accessed on the number of switches. This suggests – in combination with the non-significance of a number of other variables that were tested – that the probability of switching is constant and independent of user or page characteristics. This could be reflecting a process of relieving boredom after having browsed for some time (or for a certain number of pages) in a single specific mode.

5.6.2.9 Perspective of the page type

Pages within the WHURLE-LS system were categorised according to their structural typology, into hubs; start pages; sequence pages and terminus pages. A hub is a page that is universally accessible from any page in the system, such as those in the horizontal navigation bar; these did not form part of the content of the system. Start, sequence and terminus pages are content pages that form the first page of the topic, a middle page, or an end page respectively. A second typology was created that categorised pages according to which of the 6 substantive topics they were in.

These two typologies were then used to ascertain whether they were related, and could thus help to explain differences in users' choice of mode. These analyses hence explore whether it is something about the character of the content that is presented, that drives choice of presentational mode.

In typology 1 (hub/start/sequence/terminus), there were no significant differences whatsoever in terms of how often they were accessed in one mode or another.

In typology 2 (different topics), there were some significant, although relatively minor, differences. Table 5.14 displays how often sessions in which these topics were accessed were single-presentation mode sessions (and if so, which mode) or mixed-mode sessions. Visual only mode was least often chosen for topics 3-6, whilst being most popular for topics 1 and 2. Verbal mode was most often chosen for topic 6, then 5 and 4, then 3, then 2 and 1 (see Table 5.14 for details).

TABLE 5.14: Proportion of pages accessed in different modes across different topics

Topic:	Of all sessions in which this topic was accessed, proportion of:			
	visual only mode used	neutral only mode used	verbal only mode used	mixed only mode used
1	0.15	0.20	0.06	0.59
2	0.14	0.22	0.06	0.58
3	0.08	0.26	0.08	0.57
4	0.10	0.20	0.11	0.59
5	0.08	0.18	0.10	0.63
6	0.09	0.23	0.13	0.55

There are at least 2 potential explanations for this:

- There is something about the contents of these topics that makes verbal or visual modes more or less attractive to users. Thus, mode choice is related to page contents or other page characteristics. Yet this interpretation is not compatible with the findings in the regression analyses, that none of the topics had a significant effect on mode-switching (as reported in the previous section).
- The frequency of use of both the verbal and visual modes is strongly – but oppositely – related to the order of presentation of topics in the system (Table 5.14). Earlier, there was distinct difference found in the frequency of accessing different topics (Table 5.12). In combination, these findings suggest that the verbal mode is used in the first instance, and thus most often if a topic is not revisited. Subsequent accesses, which result in higher number of accesses, are used to experiment with other modes – mainly the visual one.

These findings suggest that users typically start with the first topic and probably in a verbal mode (the large visual proportion is actually an artefact of the data, once the relatively large frequency of access of earlier topics is taken into account). This would be the rational choice to make, since users are preparing for a verbal task (namely, the exam that they have to take). They need to be able to transfer learned concepts to written answers. The fact that a smaller proportion of pages seemed to be accessed in verbal mode for topics 1 and 2 is likely a dilution effect; the longer a user spends accessing pages in the system, the more switching is likely to occur and the more pages are explored in different modes. This dilution effect is evidenced by the preferential drop-off shown by users in Table 5.12. The high proportion of pages accessed in the visual mode for topics 1 and 2 indicates a relatively long session time, when users look at these pages in more than one mode. If a user is looking a small number of topics, the main determinant behind switching is the relatively large number of pages (as discussed in section 5.5.2.8) and hence this overrides the small negative effect shown in the regression coefficients for number of topics, in Table 5.13.

The reason behind this switching is unlikely to be found in learning style preference, as discussed above. There are two other possible interpretations. One reason is that switches reflect attempts to escape from boredom; the other could be a tendency to be as complete as possible in perusing all available material to the extent that available time allows one to do so. In view of the regression findings reported in Table 5.13, it seems that the first of these interpretations is the most plausible one.

5.6.2.10 Perspective of individual page accesses

Finally, the data set was examined from a single-access perspective, i.e. units of analysis are thus the separate accesses of all pages, across all sessions (n=4535).

There seemed to be a slight preference for visual and neutral pages over verbal ones, but this was not very strong (see Table 5.15).

TABLE 5.15: Percentage of pages accessed in different modes

Mode:	Percentage of pages accessed (%):
Visual	36.6
Neutral	37.2
Verbal	26.1

However, Chi-square testing revealed a highly significant difference in the mode choice between different topics (χ^2=45.4, p<0.000, df=12), with visual pages becoming less popular in later topics and verbal ones becoming more popular (see Table 5.16).

This is consistent with the findings discussed in Section 5.5.2.9. There is nothing to suggest that earlier topics are more suited to visual representation than later ones, although these findings could suggest that visual data takes longer to process, or scan, and are hence accessed less when students are running short of time (which is more often the case when they access the last couple of topics).

TABLE 5.16: Percentage of pages accessed in different modes across each topic

Topic:	Percentages of pages (%) in each mode:		
	visual mode	neutral mode	verbal mode
1	38.3	36.1	25.6
2	37.3	39.1	23.5
3	33.6	42.5	23.9
4	34.2	37.1	28.6
5	35.9	32.7	31.4
6	29.7	38.8	31.5

There were no significant correlations between mode choice and whether a page is accessed early or later in a session (the sequence number), or whether it is accessed for the first time or in a repeat access during a session (correlations are r=0.04 and r=0.01 respectively, too weak to be of any importance).

Thus the analyses from this last perspective confirm the findings of previous analyses and failed to produce new insights, although it is important to appreciate that this last view could have yielded new relationships that had not yet been seen. It also reinforces the inference that mode choice and mode switching are not motivated by learning styles, but that the hidden rationality behind mode switching is alleviation of boredom.

5.6.2.11 Qualitative findings

As in the Phase I study, users were asked to provide feedback in return for being able to use a multiple-choice quiz that tested them on their knowledge of the subject and gave them instant feedback. The score from the MCQ again did not form any part of the assessment for the module; rather it was another revision tool used to support the teaching of the module.

Users were asked several questions about their usage of the system and their perceptions of learning styles and personalised learning systems. 63 students chose to participate in the questionnaire and their answers are now discussed.

Most of the respondents (76.2%) had revised using at least one of the units, with the majority of students (81%) using the system between 1 and 3 times. Opinion was divided as to whether students preferred this kind of revision over more traditional forms of revision, although it is clear that students in this study perceived personalised learning to be a good idea (66.7%) and that most of them thought learning styles were a satisfactory personalisation mechanism (69.8%). Around two-thirds of users said they would be happy to use an e-learning system that used learning styles for personalisation (66.7%) although a higher number of students were unsure about this (14.3%) than in previous questions. Interestingly enough, there was some division about who should decide on the personalised content on-screen, with only half the students deciding that the user should have control over this (52.4%). Nearly a third of the students said that the lecturer/course instructor should be in charge of the learning style adaptation (31.7%), whilst only 14.3% of respondents thought the system should have decide this.

Answers relating to students' own learning styles were very interesting: around two-thirds of respondents stated that they knew what their preferred learning style was, for some (44.4%) or all (22.2%) of the time but the remaining third said that they did not know what their preferred learning style was most of the time. This is possibly due to caution, confusion over what learning styles are, or a lack of self-knowing. Linked to this was the question relating to what type of learner (visual/verbal/no preference) students thought they were; interestingly, around half of them thought that they were visual learners. This corresponds to the actual ratio of visual learners in the cohort from the Phase I trials and in the absence of any evidence to the contrary, we can assume that the students from the Phase II study are comparable to this earlier cohort. Thus we would also expect roughly half of them to be assessed as "visual", had they answered the same visual/verbal learning styles questionnaire that was taken by students in Phase I. However, only a third of respondents considered themselves to have no learning style preference; this is a much lower proportion of actual "no preference" students from the Phase I study, which was around 48%. Consequently there was a higher ratio of self-assessed "verbal" students in the Phase II study (17%) than were recorded in the Phase I study (5%). Of course, it is difficult to say with any certainty if the students' self-categorisations would match that recorded by a learning styles questionnaire, or not – or even if they indeed should be compared to the cohort from Phase I. However, it seems reasonable to judge one cohort against the other, since neither the module nor the types of students taking the module altered during the research phase. Bearing all these factors in mind, it is possible that students have categorised themselves wrongly, with a greater number of students thinking that they were verbal learners when in fact they should really be labelled as "no preference".

Following on from the evaluation of student learning style preferences is an examination of the way in which these students then interacted with the system. The majority of students stated that they thought that personalised education using learning styles adaptation was a good thing, however this is not borne out by some of the respondents answers. Given that most students thought that they were visual learners (49%), it seems surprising that the mode of presentation that students said they chose the most was “no preference” environment (41%) (although this is closely followed by the “visual” environment (39.3%)). These figures do not take into account mode-switching. However, they do suggest that students are either unwilling to commit to an untried adaptation mechanism (they say one thing and do another) or do not trust that information equivalence exists in different presentational modes. It is also possible that they themselves have a scepticism over visual and verbal preferences and would prefer a different kind of learning style to be employed.

Respondents were also given the chance to make open-ended comments about the system. Only 10 such comments were received. 2 users criticised the linear nature of the vertical navigation system, whilst 3 users stated that they felt the need to browse material in all 3 different modes in order to get all the information from the system (which corresponds to the suggestion made in the paragraph above). It was clear that these users did not perceive the information to be equivalently represented throughout the different modes, despite this being the main concern of the original content author and even though the students were told that the information was the same in all 3 modes. One student stated that they felt that too much visual information led to cognitive overload, and they preferred to use the text (i.e. verbal) presentational mode because of this. The remaining comments have not been included here since they were not directly relevant to the study.

5.6.2.12 Summary of findings

From the quantitative and qualitative evidence gathered in this user trial, there is little evidence of mode choice and switching being driven by preferences for learning styles or by user characteristics. There is equally little evidence for page characteristics being influential in choice of mode or in switching between modes of presentation.

However, there are some suggestions that mode switching is driven by a probabilistic process that operates uniformly across sessions, topics, pages and periods of time and that such switching might function as an escape from boredom. There is also some evidence that initial usage of the system might be done in verbal mode – conceivably related to the fact that the subsequent test is a verbally structured task – and that other modes are used if sufficient time is available to access pages repeatedly.

5.6.2.13 Conclusions

This Phase II study has investigated the mode-switching behaviour of users when they are given ultimate control over the presentational style of information in an adaptive learning system. It has also shown how generic web log data can be processed statistically to reveal the hidden rationality of such behaviours. This is potentially a powerful approach for exposing patterns in data sets.

The data is also not prejudiced by the Hawthorne effect, a phenomenon whereby the very act of observing something alters its behaviour [177]. Since users are not explicitly observed, they are not aware of any "special treatment" and hence the data is far more likely to be impartial than if they were specifically named as participants in an experimental situation. In addition, although it was possible that users experienced a slight "novelty" effect if they were unused to online revision materials and their use, this was not thought to have much impact since it was used in conjunction with other online resources as part of the undergraduate module and hence unlikely to contribute variance in this respect.

However, the decision taken not to track users was a major limitation of the study, since it meant that it was impossible to carry out further qualitative investigations into the exact nature of users' behaviour. Were this study to be repeated, user tracking should be included so that different sessions can be linked to specific users and provide the basis of further enquiries.

5.7 Conclusions from user trials

This chapter has introduced the concept of using visual and verbal learning styles as a user model for an AEH system and has also presented the findings of two user trials that investigated how university students interacted with a system that implemented this adaptation mechanism. The conclusions of this study – namely that using matched or mismatched visual/verbal learning materials did not significantly benefit nor disadvantage the students taking part – now throw into doubt the extent of their effectiveness in a learning situation[16]. This is especially true when considering the likely reasons behind mode-switching behaviour, as shown in the Phase II trials; it seems that, even when students can make the choice of which presentational mode to use, they do not necessarily choose the mode that seems to match their preferred learning style. This means that mode-switching is likely related to boredom, or a mechanism by which to relieve it.

There are several possible reasons why this work produced negative results. It could be that the students used in the study have already been unintentionally pre-selected on the basis of their academic ability: they are all studying in higher education for a degree. This being the case, it is not unreasonable to assume that these students can already learn effectively, even when presented with less-optimal opportunities (i.e. a mismatched environment). Hence, providing personalised learning would not benefit these kinds of learners very much,

[16] assuming that the visual and verbal representations were adequately designed and truly corresponded to different learning style preferences.

particularly when compared with, for example, younger learners or students with specific learning difficulties. It is also possible that users simply want to access the course content, regardless of any decisions taken as a result of the adaptation mechanism.

It may be that, since learning styles do not seem to be static [207], simply assessing learning preferences once, when students first use the system, is not sufficient. A variable that is susceptible to change should thus be catered for in a truly adaptive system. The Phase I user trial investigated an adapted system that did not support changes in the user model and was thus not as functional as it might have been. The resultant lack of adaptability might have resulted in both the system and the user model being overly simplistic. The Phase II user trials did allow for dynamic changes in a user's learning preferences to be reflected in the system, but detailed analyses of this study does not imply that the mode switches could be directly attributable to such variations.

It is possible that the visual and verbal representations may have been inaccurately constructed; even if they were suitable for use in this system, the ways in which multiple representations affect learning have still not been fully explored [5]. Paivio's dual coding theory states that human cognition deals with visual and verbal processing simultaneously [161], which suggests that AEH systems should provide for both of these types of representation if learning is to be effective.

Another factor to take into account was the way in which students' visual and verbal learning styles were assessed, using a subset of the ILS questionnaire that related to only one axis, rather than the four dimensions in the original instrument. Though necessary in the context of this work, this modification may not have been appropriate, since each axis is actually a component of the model and not the whole instrument. This could have had an impact on the reliability and validity of the questionnaire, which had both been previously reported to be good [95, 132, 236]. It is thus possible that students were not assessed as effectively as they might have been for the Phase I trial. On a related note, it is also possible that students do not in fact know what their preferred visual/verbal learning style is, when asked, hence it is impossible to find out from the Phase II study if students were truly matching their preference to the mode of presentation or not. Self-knowing, or meta-cognition, is not something that has been explored in great detail in this research but this could be another important variable in the pursuit of effective user modelling.

However, just because the results of these user trials did not show any benefits to using learning styles as means of adaptation in an AEH system does not imply that they are totally without merit. The preferences studied in this phase of research were constrained to visual and verbal perspectives; other learning style models incorporate many other aspects of cognition and behaviour and these have not been yet investigated to the same extent. For example, a study by Bajraktarevic *et al* [15] showed some interesting results when matching and mismatching learners with global or sequential preferences. They demonstrated that matched students achieved significantly higher post-test scores than non-matched. It is possible that global/sequential adaptation is more appropriate for hypermedia systems than visual/verbal adaptation, certainly when taking into account the variability in browsing habits of web users (as mentioned in Chapters 3 and 7). There is some published evidence to suggest that systems such as these may be effective under certain conditions, but they do not seem to have been tested with enough users, or with sufficient scientific rigour.

It is also clear that, without sufficient qualitative evidence, it is impossible to accurately state the reasons behind the mode-switching behaviours seen in the Phase II user trials. It is strongly advised that any further work in this area should incorporate qualitative data collection as part of the experimental methodology to help determine this information.

5.8 The next user study

The two main problems with this episode of work have been to do with the type of users and the learning style that was modelled in the adaptation mechanism.

Firstly, it seems highly likely that students in higher education would not benefit from a personalised learning system like the one utilised here, since they already know how to learn effectively from a range of educational resources. They have already been pre-selected for their ability to gain knowledge and thus do not reflect the wider variation of social, cognitive and behavioural traits shown by other types of learner.

Secondly, the notion of visual/verbal learning style preferences is problematic. It begins with the difficulty of modelling certain concepts in a pictorial manner, but related to this much more complex issue of just how “visual” a visual representation is. In addition, how much agreement can be fostered relating to this granularity? A piece of conceptual information could be represented graphically in several different ways by several different people – who can be said to be most correct in their particular visualisation? This is clearly a very subjective issue and until some guidelines or standards can be produced to clarify these issues, they remain highly complex and difficult to resolve.

It seems that the final phase of this research must address these two issues. As stated in Section 5.3, most learning style models refer either implicitly or otherwise, to the ideas of visual/verbal and sequential/global dimensions (this latter axis is sometimes referred to as analytic/wholist [or holist]). It seems obvious that, having investigated visual/verbal preferences in detail, the next user trial should explore the sequential/global learning style.

Upon consultation with colleagues from the Learning Sciences Research Institute at the University of Nottingham, it was decided that the target users for this next study should be primary school children. Such participants would provide greater diversity in learner characteristics when compared to university students and would be representative of a much larger number of potential users. Due to their youth and relatively short time in formal education, primary school pupils would not be expected to know how to learn effectively yet and so a personalised learning system could reasonably be assumed to have a beneficial effect for such users. Advice was taken from staff at the school about the existing ICT skill level of such pupils but it was felt that such pupils would be able to cope with the tasks required of them in a satisfactory manner.

The next chapter details the subsequent user trial carried out with 9-11 year old pupils at a school in Nottingham. It describes the user model, its implementation, the experimental design and detailed statistical analyses, together with the findings resulting from the study.

CHAPTER 6:
DEUS

6.1 Introduction

In the preceding chapter, the two user trials carried out with the WHURLE-LS system were analysed in detail, and the findings presented therein. In Phase I, there were several criticisms made of WHURLE-LS, related to both the user model (visual/verbal learning styles) and the performance and design of the system itself. From Phase II, it was apparent that when users were given control over the mode of presentation, choices in mode seemed determined by factors other than visual/verbal learning style. These criticisms led to the decision to create a new e-learning system to explore other, related user models in further user trials.

This new system has been named DEUS: Digital Environment Utilising Styles. This chapter explains the rationale behind the design of DEUS, its new user model and how it was used by primary school children to help them learn science at Key Stage 2. It utilises not only a different learning style model from that used in WHURLE-LS, but also a uniquely different group of users to most other adaptive educational hypermedia systems: 9-11 year old children.

The author was solely responsible for the conceptual design, system architecture and coding of DEUS. She programmed the system in PHP (Hypertext Preprocessor) and XHTML (Extensible HyperText Markup Language), which was linked to an SQL database to store information relating to user profiles that was subsequently retrieved as part of the personalisation mechanism.

The author also found an appropriate group of school children to participate in user trials for the system, via an existing contact in a local school. She then liaised closely with staff from this school, in particular the head teacher and the Year 5/6 co-ordinator, to determine the topic most suitable to be taught via the system and also to work through the logistics of the user trials. The lesson plans and content for the system were created entirely by the author, with advice and guidance given by staff from the school. As with WHURLE-LS, the author designed and carried out the user trials and collected quantitative data, which were then subjected to statistical analysis.

6.2 The rationale behind DEUS

After the WHURLE-LS user trials, a number of conclusions could be drawn about the system and its limitations. A major problem seemed to be concerned with the learning style being utilised by the system, namely the visual-verbal dimension of the Felder-Silverman ILS. Since most students showed either visual or no preference, this had major implications for whether an adaptive system should really cater for this tiny minority of verbal students; certainly it cannot be justified in a cost-benefit analysis, since the amount of time taken to author 3 different lesson plans and associated content is fairly substantial. This issue, combined with the fact that either matching or mismatching users did not seem to make any statistically significant differences to academic performance, indicated that this particular learning style was probably not worth pursuing further.

As an alternative, it was decided to utilise one of the other Felder-Silverman ILS dimensions, namely that of the global-sequential axis. This learning style seems a logical choice to use within a hypermedia system, since it concerns preferences for the presentation of information in either a linear (sequential) structure or a more holistic (global) structure; this architecture is easily modelled by hypermedia and forms a favourable comparison to different types of browsing styles. To ensure that the potential user population was normally distributed for this variable, initial data were collected about a cohort of children in a primary school in Nottingham, ahead of the proposed new user trials. This data is presented in more detail later in this chapter, although the main finding was that the frequency of pupil preferences was normally distributed for sequential-global learning style. It was this data that proved the main factor in deciding to use this learning style for the new user trials, due to its distribution curve. Had the distribution been skewed (as in the visual-verbal dimension), this would have demonstrated the limited benefit of providing for users at each end of the scale. It also provides for an interesting comparison with Bajraktarevic’s work [15], which also utilised the sequential/global dimension from the Felder-Silverman model. The distribution of pupils’ sequential/global preferences in Bajraktarevic’s study is similar to this, although slightly skewed to the sequential end (this could be an artefact due to the nature of the small sample size used, however).

The other problem from WHURLE-LS was the overall design of the system and its performance. The system tended to perform somewhat slowly (or “lag”), as the XML pipeline was processed by the server; this meant that users often had to wait several seconds in order for a page to be rendered to them. This was seen as undesirable, but not something that was easily remedied. There was also some instability in the Tomcat Cocoon process (which renders the XML pipeline), resulting in irregular system downtime. This was fixed by Cron scheduling to stop and restart Tomcat once a day, which resulted in no downtime at all;

however this is not an ideal solution. There were also some features of WHURLE that were not required in WHURLE-LS: for example, the ability to swap in different skins for different topics or user models and also the main linkbase feature. Taking into account all these issues, it was decided that a simpler, quicker system was needed in order to carry out subsequent user trials. The new system would need to be adaptive, to incorporate different user models, but also possess a simple, intuitive interface for users and allow relative ease of authoring, both in terms of the lesson plan and of the content itself.

Since WebCT, Blackboard, Moodle and other extant e-learning platforms had already been evaluated and found to be unsuitable for use with this research (see Chapter 2), a new system would need to be created from the ground up. It was decided to create a small, simple system that would allow for adaptive presentation based on user information, would be quickly rendered, as stable as possible and easily expandable in the future. This was the conception of DEUS.

6.3 The DEUS system

DEUS was written in PHP (Hypertext Preprocessor) and XHTML (Extensible HyperText Markup Language). It uses a mySQL database to store user information and provide a personalised login. (This personalisation also allowed user browsing behaviour to be tracked via web log analysis.)

The design of DEUS was intentionally very simple, and only requires knowledge of XHTML in order to author content or alternatively, familiarity with a WYSIWYG editor that outputs XHTML. The navigation system is third-party software called XHawk phpNav[17], which converts a text file into a hyperlinked navigation system (see Appendix D). The content is written in XHTML and linked to the navigation system via the phpNav text file. This design parallels that of the WHURLE-LS framework, and the components of DEUS have conceptual equivalence to WHURLE-LS chunks (the XHTML files in DEUS) and the WHURLE-LS lesson plan (phpNav text file). In this way, the same flexibility is employed over re-purposing of content. It is interesting to note that, due to the new user model employed in this system, a different filter design (discussed at length in Section 5.4) is utilised. In WHURLE-LS, the filter design consisted of flexible, ordered content; however, because of the nature of the learning styles adaptation, some content was excluded from users in the Phase I trials. One distinct advantage of using a sequential/global user model is that none of the content need be excluded; it is merely the ordering that is modified (akin to

[17] http://xhawk.net/

Option 5, see Section 5.4.1.5 for details). This is much more desirable from the perspective of the user, since nothing is hidden and there are none of the problems encountered in the studies with WHURLE-LS relating to informational equivalence across different modes of presentation.

Lesson plans are stored slightly differently in DEUS than in WHURLE-LS. In WHURLE-LS, a single XML lesson plan is created, that contains the path through the learning materials for each type of user (visual/verbal etc). In DEUS, a separate lesson plan is created for each user type (sequential/global). Figure 6.1 shows the framework for the interface. It consists of three main parts: a header bar at the top (containing the system logo and user's name); a navigation system on the left-hand side; and a large window to the right of the navigation bar, that displays the content to the user.

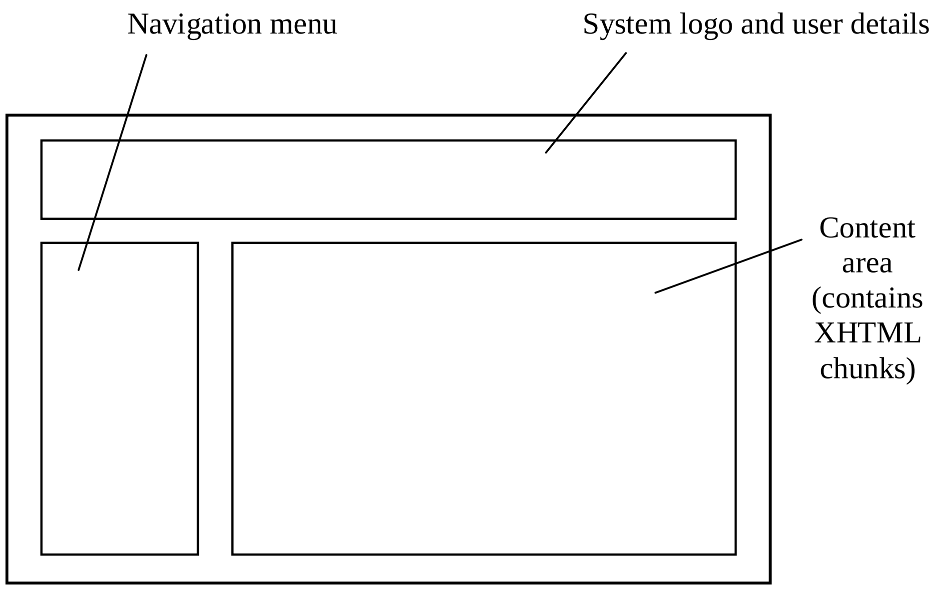

FIGURE 6.1: DEUS main interface

When a user first logs on to DEUS, the system checks to see if some initial user parameters have been set, namely their learning style and also a quiz score indicating their existing knowledge (see Figure 6.2 for a screenshot of the DEUS login screen). If either of these parameters is missing, the user is directed towards a learning styles questionnaire and then, if necessary, a quiz to determine their existing knowledge of the subject (henceforth referred to the user's pre-test score).

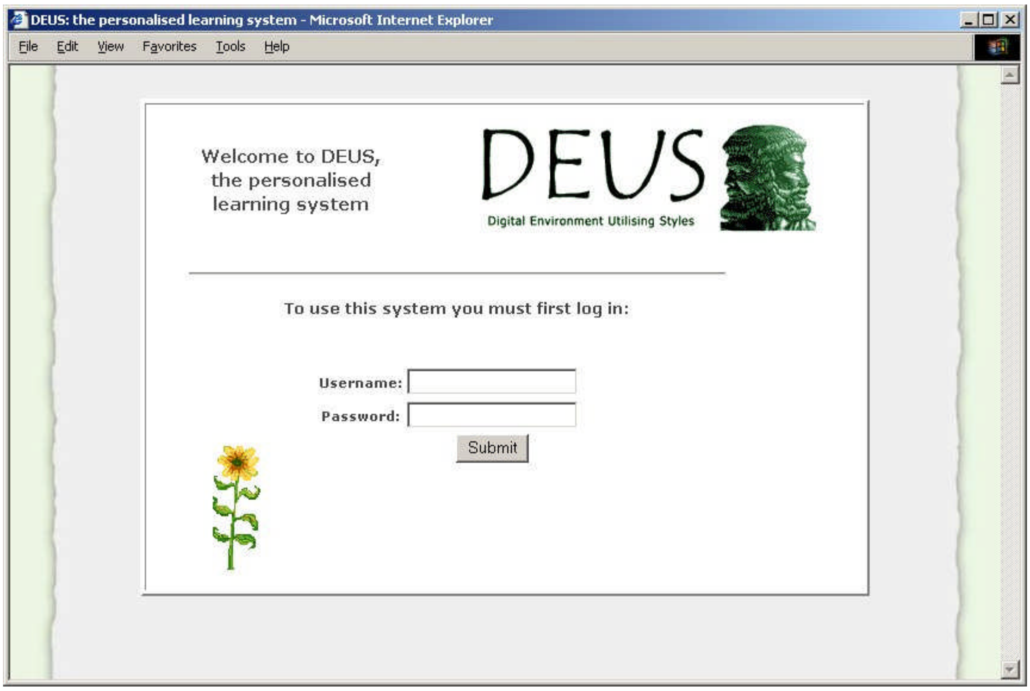

FIGURE 6.2: DEUS login screen

Once these parameters are known to the system, the user is then assigned to either a matched or mismatched group and can then interact with the system. In these user trials, pupils were manually assigned to experimental groups, but this could easily be automated, as in WHURLE-LS. When a user has been assessed for their learning style and pre-test score, and then placed in a matched or mismatched group, they can log onto DEUS and browse the system.

Upon logging on, users are assigned a sessionID that persists for the length of that session. Information relating to each user is also retrieved from their stored profile in the database; for example, the user's name, which is then displayed at the top of the screen. The sessionID (and thus the user) is tracked through parameters in the URL of each page. The sessionID is also passed into the phpNav system, allowing the user profile data to be perpetuated throughout the navigational links.

When the user has finished browsing the system, they should log out or close down the browser. This destroys the sessionID and allows another user to create a new session.

6.4 User trials

The user trials for DEUS were carried out with year 5 & 6 pupils at Glapton Primary School in Clifton, Nottingham. Glapton School is a community school, taking pupils aged 3-11 years old. According to the most recent Ofsted inspection in November 2006, there are around 300 pupils on roll, of mixed gender and from mostly white British backgrounds. The number of pupils there with specific learning difficulties or disabilities is close to the national average. Ofsted has awarded the school a Grade 2 (“Good”) in terms of overall effectiveness; this grade was also carried across to achievement and standards, quality of provision, and leadership and management. The Local Authority that has overall responsibility for the school is the City of Nottingham.

The age group of the pupils for the user trials was discussed in consultation with a colleague from the University of Nottingham’s Learning Sciences Research Institute (LSRI) and also the headteacher of Glapton School. The pupils involved in the study would need proficiency in computer skills and also be able to self-evaluate based on cognitive factors; this latter ability was considered to be a somewhat higher-order skill that would be more likely to be found among the older children in the school.

6.4.1 Pilot study

A pilot study was carried out with target users in July 2006. The objective of this study was to acquire some preliminary data related to the users’ learning styles. Data were gathered for both the visual-verbal and sequential-global dimensions of the Felder-Silverman ILS model, on 2 separate occasions (a time period of 10 days between visits). There were several reasons for this methodology:

- To compare visual-verbal distributions of these school pupils with the students from the WHURLE-LS user trials.
- To see if pupils’ answers to a learning styles questionnaire would be the same on each occasion.
- To investigate the distribution of both learning style dimensions in primary school children (of which there is a paucity of published data).
- To provide evidence to justify whether further adaptive hypermedia user trials should utilise a sequential-global user model or not (based on pupil distribution for this factor).

The pupils were assessed via a 22-item modified questionnaire based on the Felder-Soloman Inventory of Learning Styles 44-item questionnaire (see Appendix E for details). Changes were made for several reasons:

- To reduce the number of questions to include only those assessing the two learning styles under investigation (the original questionnaire also assesses 2 other learning styles, as referred to in Chapter 4).

- To modify the language so that the pupils could understand the questions. The original questionnaire (aimed at post-16 learners) was not suitable for use with children and had to be re-written.
- To ask the questions in a slightly different way, to make it easier for the pupils to understand. The original questionnaire consisted of a series of statements, in which were phrased implicit questions relating to learning preferences. These were transformed into explicit questions, considered easier for children to answer.

Around 50 pupils from years 5 and 6 were assessed although some were absent from school on one or both occasions – their data was not included in the analysis. Pupils were instructed how to fill in the paper-based questionnaire and each question was read out in turn, allowing time for the pupils to circle the appropriate responses. This was a standard approach that was used with each class of children.

The subsequent bar charts show an analysis of questionnaire data from the two visits. The results were initially amalgamated from class and year groups to give an overall distribution of learning style preferences for the entire cohort of years 5 and 6. The data were then plotted as bar graphs (see Figures 6.3 and 6.4). However, when the data were analysed separately by year and by gender, there were no meaningful differences in the patterns of learning style distribution and so these have not been included.

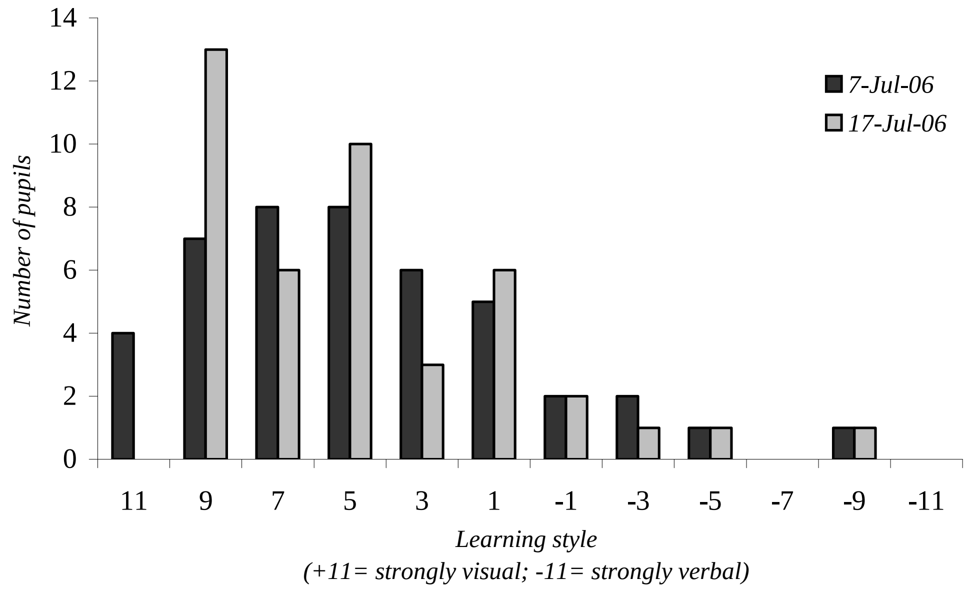

FIGURE 6.3: Visual-verbal preference in 10-11 year old children

To interpret the results of the bar charts correctly, it is important to recall how the scoring works. On each dimension, a score of -3 to 3 indicates no or little preference; 5 to 7 or -5 to -7 indicates a moderate preference; and 9 to 11 or -9 to -11 indicates a strong preference.

From Figure 6.3, it is clearly seen that most pupils were shown to be visual learners to a greater or lesser extent, with hardly any of them scoring in the verbal aspect. This is clearly a fairly skewed distribution, although somewhat consistent with other research findings that indicate that a significant proportion of people are visual learners [93]; it also parallels the user data from the WHURLE-LS user trials.

There is a markedly different distribution for the sequential-global learning style (Figure 6.4). Pupils assessed for this preference show a more normal pattern of distribution, although still slightly skewed to the left-hand side (the sequential aspect).

It is interesting to see that, although learning style has changed slightly between the two visits, the overall distributions are not that dissimilar. From these results, it seems as if there might be some merit in designing a digital learning environment to cater for the sequential-global style, although probably not one for the visual-verbal learning environment. This is because the distribution of visual-verbal learning style in these users is skewed towards the visual dimension, whilst the distribution in the sequential-global learning style is more normally apportioned. Hence there is value in catering for pupils at either end of the normal distribution, whose preferred learning styles might deviate from the preferred teaching approach and hence place them at a disadvantage.

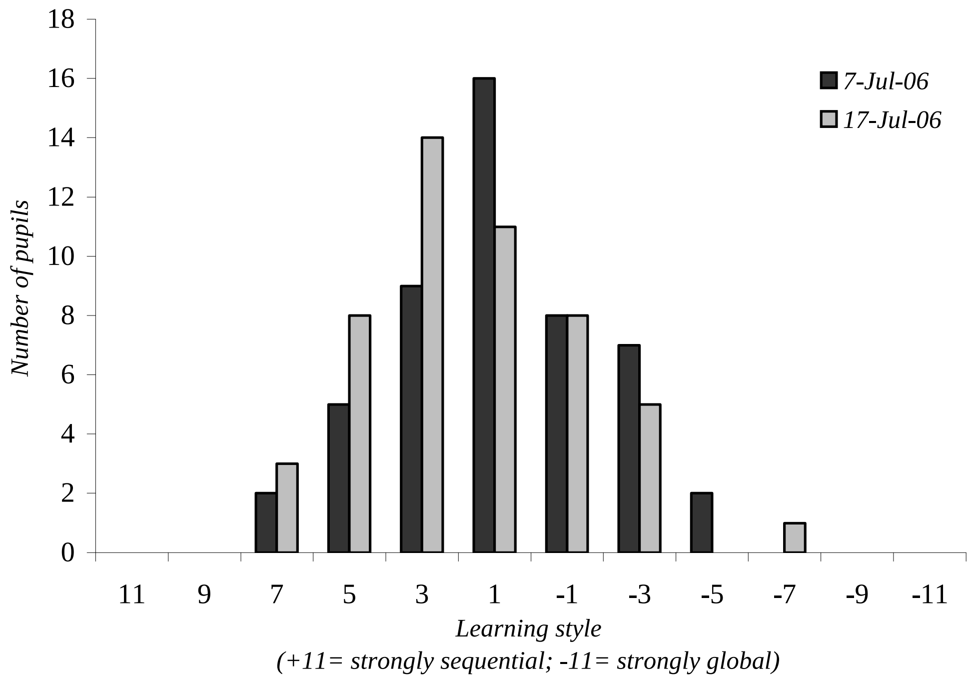

FIGURE 6.4: Sequential-global preference in 10-11 year old children

The notion of self-evaluating is likewise fascinating. From informal observation at the time of the data collection, pupils seemed able to answer most of the questions with little assistance. On occasion, an example was used to illustrate a particular question; these were especially useful when provided by the class teacher, since they usually related to a recent learning situation experienced by the pupils. Most children were happy to keep pace with the investigator as she read out each question. The exception to this was the bottom set, several of whom shouted out that they were finished when only half the questionnaire had been read out. It is worth noting that this was the middle of a Friday afternoon however, with all the behaviour management issues that are involved therein. Although these responses from these pupils might be less reliable than those from the other pupils, there was no real way to identify these pupils and, from looking at their responses, hardly any pupils just circled all "a" or all "b" answers (which a bored or disinterested pupil might have done), indicating that they might well have independently read and understood the questions.

Several children wanted to answer "both" for some of the questions, although a limitation of the questionnaire (and others like it) is that respondents **must** choose one response over another; either "a" OR "b", but not both. They were told that they must choose the answer that was most like them, most of the time. However, some pupils still wrote "both" on their questionnaires, or circled both answers. Where this happened, or if they had missed out a question, or their response was unclear, a score of 0 was entered into the data sheet (otherwise a response would be scored as either -1 or 1, depending on which aspect was being assessed). From meta-analysis of the responses from the children, this seemed to happen more frequently with the visual-verbal questions than the sequential-global questions: 6 pupils during the first visit either left a question blank or circled both answers for at least one of the visual-verbal questions, and 7 pupils likewise on the subsequent visit. On the first visit, the number of pupils answering ambiguously for sequential-global questions was only 1; this decreased to 0 on the subsequent visit. These data suggest that pupils either find it difficult to self-assess themselves on the visual-verbal dimension or simply cannot choose a preference between the two dimensions. This adds weight to the suggestion that the visual-verbal learning style is rather limited in its use with school pupils like these and possibly other types of learner too.

6.4.2 Experimental design

6.4.2.1 Overview

Since the WHURLE-LS trials showed no statistically significant differences between groups, it seems that if there *were* any difference to be found, this would be very small. In order to create the best possible scenario in which to discern these differences, it was decided to categorise pupils into either sequential or global learning style preference, and dispense with the no preference/neutral group. In this manner, the learning style environment would also be bipolar: either sequentially-presented or globally-presented learning material.

The distribution of pupil learning style assessed for the main study (in November-December 2006) is shown in Figure 6.5:

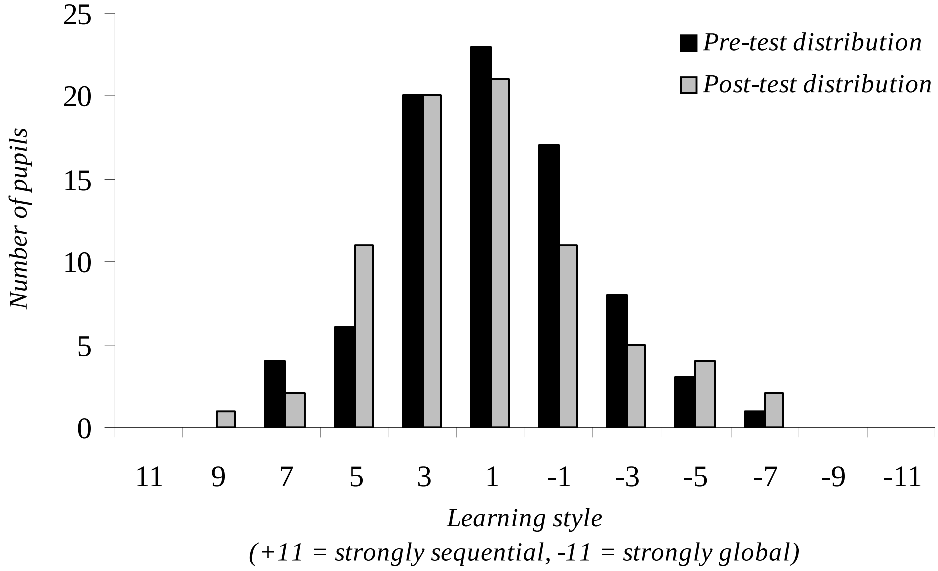

FIGURE 6.5: Pre and post-test distributions of pupils' learning style

From Figure 6.5, it can be seen that a normal distribution was found for sequential-global learning style in the pupils involved in this user trial, in keeping with the earlier pilot studies (see Figure 6.4). However, pupils were allocated into either an overall "sequential" (1 to 11 on the learning style axis) or global (-1 to -11) preference, in keeping with the experimental design. In doing so, it is clear that many pupils who would otherwise have been classed as "neutral" or "no preference" (3 to -3) had a higher weighting attached to their preference so that, if they showed even a slight shift towards the sequential axis (i.e. scored 1 or 3), they were grouped with those scoring more highly (5, 7, 9 or 11); this was likewise done for those scoring -1 or -3, so that they were grouped with other pupils showing a preference for global learning style (-5, -7, -9 or -11). In assigning these stereotypes, it is thus possible that the accuracy of the findings from this study is somewhat flawed and that the experimental design is less than ideal. However, under the classical Felder-Soloman grouping, the majority of these users show no particular bias for either learning style and hence the removal of their data from the overall data set would result in insufficient sample sizes for statistical analysis. It is a pragmatic approach for an imperfect situation although this limitation must be considered in light of the conclusions drawn from this study. It is also reassuring to note that further statistical investigation using ANOVA testing showed that the removal of these traditionally “neutral/no preference” pupils from the overall data set (so that only the data from participants showing a marked learning style were analysed), still did not result in any statistically significant difference (see end part of section 6.4.4 for details).

The same overall design was employed as for the Phase I user trials with WHURLE-LS, where users were arranged into deliberately matched or mismatched groups. A matched group would be presented with the same kind of learning environment as their preferred learning style, whilst a mismatched group would be presented with an environment containing information in a supposedly sub-optimal (opposite) learning style. This resulted in the DEUS user trials design of 2 matched and 2 mismatched groups of pupils from each learning style dimension (see Table 6.1):

TABLE 6.1: Groupings of pupils in DEUS user trials

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="2">Learning environment:</td></tr>
<tr><td>Sequential</td><td>Global</td></tr>
<tr><td rowspan="2">Learning style:</td><td>Sequential</td><td>Matched
(group code MS)</td><td>Mismatched
(group code MMS)</td></tr>
<tr><td>Global</td><td>Mismatched
(group code MMG)</td><td>Matched
(group code MG)</td></tr>
</table>

6.4.2.2 Details of user trial

The user trials were conducted from November-December 2006. An initial visit was made in late October to assess the pupils’ learning styles and pre-test knowledge. The time frame between the initial and subsequent visits allowed for the manual assignment of pupils into experimental groups, ensuring better homogeneity of age, gender and academic ability (based on school data) in each category than if the grouping had been automated.

During the user trials, pupils were given a booklet to work through, to accompany the on-screen material. The booklets were created in both sequential and global versions that corresponded to the learning environment being experienced by the user (i.e. a mismatched global user would encounter a sequential learning environment and sequential booklet). The questions in the workbooks were the same for both but the order in which they are presented varies, in keeping with the course material presented in each environment. The questions in the workbook were meaningless unless used in combination with the AEH system, and meant that pupils were given short, task-oriented activities designed to maintain concentration. Pupils were instructed to fill in the answers to the booklet on their own, at their own pace. They were not allowed to interact with other pupils.

They were told that they could complete the booklet in any order, and that they did not have to start at the beginning if they did not want to. This was reiterated several times throughout the study, to remind pupils that they did not have to choose the default path.

The user trial was designed so that each pupil would work on the booklet for half an hour at a time, until the booklet was completed. Once this was done, pupils were then prompted to fill in a post-test quiz, designed to test their knowledge of the concepts presented to them via DEUS. They were also re-assessed on their learning style, to see if this had changed during the course of the user trials.

Pupils were told at the start of their involvement with the system that they were going to use a new learning system that presented information differently to different people. They were told that they would be tested again when they finished using the system and prizes would be awarded for the people who got the best marks, and also those who had improved the most between their first score (the pre-test) and the second score (the post-test). In this manner, it was hoped that motivation was kept high throughout so that pupils would be keen to learn as much as possible.

6.4.2.3 Choice of content

The unit chosen for the pupils to study was decided upon in conjunction with the teaching staff at the school. “Life cycles” was chosen since most pupils would not have studied the topic before and so it would be new to many of them. In addition, it was a topic that all pupils would study later in the year, and so by exposing them to the concepts in this study first, it was hoped that the information would be retained and then reinforced more effectively later on.

This National Curriculum Key Stage 2 topic essentially teaches pupils about reproduction in flowering plants; reproduction in humans (at a very basic level); the concepts of extinction and the consequences of not reproducing.

The school governors gave permission for the study to go ahead; this was especially important due to the delicate nature of some of the subject matter. Parents/guardians were informed of their child’s participation in the user trial ahead of the study, and were given the opportunity to withdraw from the user trial, although none did.

6.4.2.4 Main hypotheses under investigation

The key focus of the study was to find out whether there was any benefit (or disadvantage) to matching or mismatching users’ learning style preferences to their environment. The other aspects under investigation was to see if one learning style or learning environment was better than another in terms of the knowledge gained.

- H_0 – there will be no statistically significant difference in knowledge gained between users from different experimental groups
- H_1 – students who learn in a matched environment will learn significantly better than those who are in mismatched environment
- H_2 – students who learn in a mismatched environment will learn significantly worse than those who learn in a matched environment
- H_3 – one particular type of learning style provides more effective learning than another
- H_4 – one particular type of learning environment provides more effective learning than another.

The measure used to assess knowledge gained was the post-test quiz score minus the pre-test quiz score (both scored out of 30). The data related to these hypotheses were all analysed using univariate Analysis of Variance (ANOVA); the results from these statistical tests are presented in the following section.

6.4.3 Data analysis

User data from each experimental group were processed statistically to find evidence to support or reject the hypotheses noted in the previous section. Data from those pupils who did not complete the booklet were excluded from the analysis, since this indicates that they did not interact with all the content presented in the DEUS system. These pupils also did not complete a post-test quiz, so the difference between the pre-test and post-test scores could not be observed.

The sample sizes of each group are presented in Table 6.2, after the excluded data were taken into account:

TABLE 6.2: Number of participants per group (total = 82)

		Learning environment:	
		Sequential	**Global**
Learning style:	**Sequential**	24	28
	Global	15	15

Table 6.3 shows the average difference in knowledge gained between matched and mismatched users.

TABLE 6.3: Difference in knowledge gained between matched and mismatched groups

Group type	N	Avg. knowledge gained (points)	Standard deviation
Matched	39	1.23	3.29
Mismatched	43	1.98	3.65

Matched users were those who learning styles were matched with the lesson plan e.g. sequential users with a sequential lesson plan. Mismatched participants used a lesson plan that was not matched to their learning style, e.g. sequential users with a global lesson plan. The two matched and two mismatched sub-groups were aggregated into 2 larger groups respectively.

Statistical testing was carried out using SPSS, to determine if there was any significant difference in knowledge gained. Initial conjecture suggests that the mismatched group actually performed better than the matched group. However, the difference between the two groups was not significant ($F(1,80)=0.939$, $p=0.34$, partial eta squared = 0.012) and hence hypotheses 1 and 2 can be rejected.

When taking into account learning style and learning environment type as separate factors, there did also not seem to be any significant differences between groups (see Tables 6.4 and 6.5). Since there was no statistically significant difference between pupils from different learning style groups in terms of knowledge gained ($F(1,80)=0.122$, $p=0.73$, partial eta squared = 0.002), there is clearly no educational benefit to possessing one learning style over another, in terms of academic performance.

TABLE 6.4: Difference in knowledge gained between pupils using different learning styles

Learning style	N	Avg. knowledge gained (points increase)	Standard deviation
Sequential	52	1.52	3.25
Global	30	1.80	3.9

TABLE 6.5: Difference in knowledge gained between pupils using different learning environments

Learning environment	N	Avg. knowledge gained (points increase)	Standard deviation
Sequential	39	1.33	3.25
Global	43	1.88	3.7

In addition, there did not seem to be any benefit to using a particular type of learning environment, since the differences between groups was also not significant ($F(1,80)=0.51$, $p=0.48$, partial eta squared = 0.006). Hence hypotheses 3 and 4 can also be rejected.

Another aspect of the study was to investigate any differences in knowledge gained between pupils with Special Education Needs (SEN) and those who did not have Special Educational Needs, in case this created complications in any of the sub-groups that might have had a disproportionately higher number of SEN pupils. This was formally represented in an additional hypothesis:

- H_5 – SEN pupils had different levels of academic achievement from non-SEN pupils.

From the data in Table 6.6, it can be seen that although there was some difference in knowledge gained between the two groups, this difference was not statistically significant ($F(1,80)=1.62$, $p=0.21$, partial eta squared = 0.02). Hence the proportion of SEN pupils to non-SEN pupils within different experimental groups would not have had any covariant effect on any of the previous data analyses.

TABLE 6.6: Difference in knowledge gained between SEN and non-SEN pupils

Type of pupil	N	Avg. knowledge gained (points increase)	Standard deviation
SEN	35	1.06	3.13
Non-SEN	47	2.04	3.7

6.4.4 Summary of main findings

From the statistical analysis carried out of the main hypotheses, it seems that there is no evidence to support the theory that matching users' global and sequential learning styles to their environment has any impact the efficacy of learning. Nor does possessing a particular learning style (regardless of environment) make any difference – pupils with global learning styles seem to perform the same as pupils with sequential learning styles. When taking into account the learning environment, regardless of learning style, there is still no difference between groups. We therefore reject hypotheses 1-4 and instead revert to the null hypothesis, which is supported by these findings, namely that there is no statistically significant difference in knowledge gained between matched and mismatched users.

However, these findings assume that the initial assessments of learning style were valid and also, that the differentiated learning environments did indeed cater to the supposed differences in learning style of the users.

In addition to the average knowledge gained (post-test score minus pre-test score), the post-test quiz score was also examined independently, in relation to all of the above hypotheses, but the difference between groups still failed to reach significance for any of them[18].

It was possible that these results were a direct consequence of the strong normal distribution seen in Figure 6.5 and that there were not enough users exhibiting strong preferences (seen at each end of the distribution curve), so that even if the adaptation led to an observable effect, this was overshadowed by a negative effect shown by the large remainder of the pupils (as discussed in Chapter 7). This was investigated with further univariate ANOVA testing with a filtered data set[19] whereby pupils with an original score of 3 to -3 (“neutral/no preference”) were excluded, so that any significant effect contained within each end of the distribution curve (scores of 11/9/7/5 and -5/-7/-9/-11) would not be affected by those in the middle. The statistical results from the filtered data set were not markedly different from the unfiltered data set and did not display any significant differences for any of the hypotheses mentioned in this chapter (e.g. for hypothesis 1 in section 6.4.2.4, the results were $F(1,12)=0.166$, $p=0.69$, partial eta squared = 0.014). From these results, it can be surmised that the unfiltered data set was representative of the all the participants, including those at each end of the distribution curve. Thus the experimental approach taken with these user trials with respect to assignation of neutral/no preference participants to global or sequential groupings, although not ideal (refer back to Section 6.4.2.1), can nevertheless be justified in this situation.

[18] This was done in order to provide a comparison with the approach used by Bajraktarevic [15], who used post-test scores in her statistical analyses.
[19] It is worth noting that although the sample size used for this filtered data set is low (n=14), the ANOVA test is sufficiently robust to be able to handle this and takes the small participant number into account.

6.4.5 Additional findings

In keeping with previous studies [15, 102], it was also decided to investigate different amounts of time taken to browse the system, since this could be used as a marker of how effective the system is to learn from, e.g. if someone can learn the same amount in a shorter time then this is possibly more efficient than someone who spends longer on it for the same academic gain.

Several hypotheses were examined, and the data were analysed with univariate ANOVA tests. The hypotheses are as follows:

- H_0 – there will be no statistically significant difference in amount of browsing time between users from different experimental groups
- H_1 – browsing times are different in matched versus mismatched users
- H_2 – browsing times are different for different learning styles
- H_3 – browsing times are different for different learning environments
- H_4 – browsing times are different for SEN pupils compared to non-SEN pupils

Browsing time was recorded implicitly by the number of sessions required by users to complete the workbook task. The number of sessions varied between 2 and 6, but averaged at nearly 4 per user. This equates to approximately 2 hours of intervention time (30 minutes per session).

Based on the findings of the study so far, no differences were expected between any of the groups. This was certainly the case for the hypotheses 1 and 2: there was no statistical significance between matched or mismatched groups ($F(1,80)=0.61$, $p=0.44$), nor between users of different learning styles ($F(1,80)=1.097$, $p=0.298$). This supports the findings of Bajraktarevic *et al* [15].

However, a statistically significant difference was found between users of different learning environments ($F(1,80)=4.522$, $p<0.05$). Table 6.7 shows details of the average number of sessions attended by users from each experimental group.

TABLE 6.7: Difference in number of sessions in users from different learning environments

Environmental type	**N**	**Average number of sessions**	**Standard deviation**
Sequential	40	4.08	1.085
Global	42	3.56	1.119

The data in Table 6.7 show that pupils studying in the sequential learning environment took slightly longer to browse the system than those using the global learning environment. Since the amount of content contained in each environment is the same, merely ordered differently, this variation cannot be explained by suggesting there is more content.

The final additional hypothesis examined differences in browsing times between SEN and non-SEN pupils; however, no statistically significant differences were found ($F(1,80)=1.339$, $p=0.25$).

From these additional hypotheses, it can be seen that there is partial support for hypothesis 3, so the null hypothesis can be rejected. Hypotheses 1, 2 and 4 can also be rejected since they are not supported by the data.

6.4.6 Correlations

Lastly, the data was examined for any expected correlations, using Pearson product-moment coefficients. There were no correlations between knowledge gain and browsing time ($r=0.05$, $n=82$, $p=0.65$) meaning that pupils did not learn more if they spent more time browsing the system.

However, there was a significant negative correlation between post-test score and browsing time ($r=-0.364$, $n=82$, $p<0.001$). This indicated that the longer the user spent browsing the system (and completing the workbook), the lower the post-test score. It is postulated that this could be attributed to a motivation effect: that the pupils taking longer to finish the workbook were getting de-motivated and bored, and this had a negative effect on aspects of learning. It is also possible that these were less able pupils that usually take longer to complete a task.

There was also a significant (positive) correlation between the number of pages visited and the number of browsing sessions ($r=0.555$, $n=82$, $p=<0.001$); this is to be expected since the more time spent browsing, the more pages will usually be visited. This may at least indicate that pupils were browsing the pages for information to answer the questions in the workbook rather than making up the answers or copying them from the participant next to them. This is useful information in itself – it suggests that pupils were on-task for much of the time, and engaged by the system rather than being distracted by external events.

6.5 Conclusions from user trials

6.5.1 Overview

From these experimental trials, there does not seem to be any clear evidence to suggest that using global and sequential learning styles as a means of personalisation in AEH has any obvious educational benefit to users. The participants in the study were what could be termed “real users”: a varied group of children who were not pre-selected for the study on any criteria. There was a mix of ages, abilities, backgrounds and gender. This was, in every sense of the phrase, “real world research” and it is fair to assume that the findings of this study could reasonably expect to be mirrored elsewhere, excepting intervention by random factors.

The only statistically significant result seemed to be that pupils using the global environment seemed to complete the workbook more quickly than those using the sequential environment. This might be seen to be important, when taking into account the correlation of time spent using the system versus the achievement of pupils (the longer pupils spent on the system, the lower their achievement – see section 6.4.6). Combining these two phenomena could suggest that a global environment is more beneficial than a sequential one, since pupils using the sequential environment might achieve less because they end up spending more time with it. However, this suggestion is tested formally in Hypothesis 4 (see section 6.4.2.4), where the difference in achievement between pupils using different learning environments is examined. Although there is a difference in achievement (1.33 points gained in sequential environments vs. 1.88 points gained in global environments), this is not proved to be statistically significant. Hence there might be some benefit to the teacher or pupils in that they seem to get through the material in the system more quickly when using the global environment; however this translates to a difference of approximately 15 minutes (4 hours compared to 3¾ hours) and might only be of limited value. There is also the danger that this is an overly-simplistic view since it does not take account of the ability levels of individuals that might be contributing to this effect (again, a potential artefact as a result of analysing groups as a whole compared to data from individuals).

Following on from this, it seems reassuring that the pupils were not disadvantaged in any way, and that, irrespective of the learning environment that was used, achievement was not affected. Although this is not a preferred outcome in terms of searching for an effective personalisation mechanism, it at least means that all pupils had the same end result.

In addition, if pupil achievement was not affected by the learning environment, or the learning style, then the falling level of achievement that is correlated to a longer amount of time spent using the system must, by definition, be caused by some other factor.

6.5.2 Limitations

One of the main problems encountered was how to assess the learning styles of 9-11 year old children, since there are no freely-available tools to do this. The resulting questionnaire produced for this study, although based on an existing document, was not tested for internal validity and reliability and hence some slight variance was introduced at the start of the study. The modified questionnaire was created in consultation with an HCI specialist at the University of Nottingham, so that the new questions were as equivalent to the original ones; however this still introduces a possible source of error into the study.

It is also possible that this study suffered from one of the same problems as WHURLE-LS, whereby using just one of the dimensions of the Felder-Silverman ILS in isolation from the others results in the instrument becoming too "blunt" and cannot then integrate the interaction of the other axes (see Chapter 5 for details). However, as previously discussed, the complexity of modelling all four learning style dimensions is beyond the current scope of this work and so this remains an unresolved issue.

In addition, although the pilot study shows that sequential-global learning style can be fairly changeable, this dynamic nature of user preferences was not catered for by the system. However, the post-test learning style assessment indicated that 62% of pupils had the same learning style at the end of the study as at the start; it is not known if this changed in the period in-between though.

Lastly, as with the statistics generated by WHURLE-LS Phase I trials, the estimated effect size seems to be very small as indicated by the low partial eta squared scores; this is discussed in more detail in Section 7.4.

6.5.3 Implications for future work

From this study, it seems that using global and sequential learning styles as a personalisation mechanism for AEH systems is of very limited value. Although there is not much additional overhead in the authoring process (excepting the creation of separate lesson plans), given that there is no clear benefit to the users, it seems that this method of personalisation cannot be recommended to developers or tutors involved in the creation of AEH to support teaching. It is recommended that further studies of comparable users should be carried out, in order to contribute further evidence to support or refute these findings. This is especially important since they are at odds with some of the positive results shown by other AEH studies.

CHAPTER 7:
DISCUSSION

7.1 Introduction

This final chapter revisits the main aims and objectives of the work as stated in Chapter 1 and discusses the findings of the user trials conducted in the course of this research and the resulting implications for the negative results shown by the work.

There is also some deliberation over the limitations of the work and the difficulties that are encountered when conducting educational research. Lastly, there are some suggestions of how the work could progress further.

7.2 Research objectives re-visited

The research objectives stated originally in Section 1.2 were:

a) to investigate how learning styles can be used to provide personalisation for students in computer-based learning.

b) to conduct user trials amongst groups of learners who engage with e-learning systems that employ learning styles as the main adaptation mechanism.

b) to utilise a strong quantitative approach in the experimental design and statistical processing of data from the user trials.

The first objective has been achieved by an extensive literature review into the fields of learning styles research and also that of adaptive educational hypermedia (AEH). In particular, a great amount of detail has been shown to those AEH systems that have used learning style, or aspects of learning style, to provide tailored e-learning to users. This has included a survey of the state of the art in evaluation of AEH systems, also related to the third objective.

The second objective has been realised through the development and testing of two AEH systems: WHURLE-LS (see Chapter 5) and DEUS (see Chapter 6). The WHURLE-LS system used an existing AEH framework and added to it a learning style adaptation filter, so that content could be conditionally transcluded to selectively present visual, verbal or no preference/neutral representations. DEUS was created as a brand new system, almost as the next evolution of the WHURLE framework; certainly it shared a common conceptual structure of lesson plan and chunks. DEUS was used to investigate sequential and global learning style and participants in the user trials were primary school children, as opposed to the university students who had interacted with WHURLE-LS.

The third and final objective was a key feature of this research throughout; it was embedded in the literature review (Section 3.10) and was a focal point of the user trials with both WHURLE-LS and DEUS; it can thus said to be achieved fairly successfully. Whilst there were some limitations from the user trials (as discussed previously in Sections 5.7 and 6.5.2), these did not alter the key findings of the studies nor did they invalidate the methodological approaches taken.

7.3 Contributions to the field

As specified in Section 1.3, there was one major contribution arising from this research and one minor contribution. In addition to the work presented in this thesis, a number of publications have resulted from this research (see Appendix F).

The major contribution of this work relates to the experimental approach and data analysis, which states that for certain groups of users, some types of learning style do not seem to provide an effective way of providing personalised learning. In particular, this research focuses on the use of visual/verbal learning style amongst university students and sequential/global learning style amongst 9-11 year old children. The evidence for these conclusions is quantitative in nature and uses participants' test scores as the basis for testing with several statistical techniques including ANOVA, Chi-square (χ^2) tests, Pearson correlations and multiple regressions.

The minor contribution addresses the issue of objective user evaluation, concentrating on a quantitative methodological perspective. It is clear from a survey of existing research (see Section 3.10) that empirical evaluations are either not widely practiced or are not conducted to an appropriately high quality yet it seems to be the best way to quantifiably test the effect of a particular intervention. Whilst it is true that quantitative methods do not give us all the information that might be gleaned from a user trial, they are a useful and scientifically-accepted measure of success. Qualitative methods are also helpful but they tend to give different information, such as why something has happened, not if it has happened in the first place. A decision was made at the start of this research to discover if learning style personalisation had a significant effect; if this were to be the case, follow-on studies would have employed qualitative methods to investigate further. However, the focal point in the first instance was the quantitative approach, for reasons mentioned previously.

Two systems were utilised for these studies (WHURLE-LS and DEUS) in which different user groups and different learning styles were considered. With respect to the methodology, a scientific approach was taken so that formal hypotheses could be tested with empirical data and subsequent statistical analyses. Whilst the results of these trials were largely negative, it is important to realise how crucial it was to take this quantitative approach and also to attempt to control for as many compounding factors as possible – something that many published studies have not done previously. It is of great concern that the vast majority of prior work, presented and discussed in Chapters 3 and 4, do not provide adequate intervention or satisfactory sample sizes, nor do they utilise naïve users in their user trials. The overarching theme of this research is that it needs to be completely objective and its findings governed by tightly-controlled evidence-based studies, regardless of what those findings might be (whether positive or negative). The controversies relating to learning styles that were uncovered in the course of the work have been openly presented and discussed rather than ignored; where possible, the problems arising from this have been addressed in the research.

However, it must also be noted that these outcomes were produced from only small studies that were not repeated and so it is not known if the results would be replicated in other studies. There were a number of additional limitations that are discussed in Section 7.4.

It must also be realised that the systems presented in this research were *adapted* rather *adaptive*. This was a fundamental aspect of the work; it was felt that before a system could be made adaptive to the user, the benefit of doing so should first be tested by a fixed intervention (hence the system was adapted to a particular user model under specific experimental conditions). Had this intervention shown positive results, the scale of the work could have been increased to accommodate an adaptive functionality. However, since there did not seem to be any measurable improvement seen in matched students (or conversely, any disadvantage seen in mismatched students) it did not seem prudent to consider this an effective adaptation mechanism and hence was not utilised for a truly adaptive system. This and other constraints are now discussed in more detail.

7.4 Limitations of the work

WHURLE-LS and DEUS were the two AEH systems used in this research to investigate the effect of using learning style as a means of personalisation. Despite three successful user trials, there were several limitations of the work that warrant some consideration. These can be sub-divided into criticisms of the user trials themselves and also aspects of the research from a broader perspective.

7.4.1 Issues with the user trials

The studies that were carried out were satisfactory from the perspective of sample size and amount of intervention, as discussed in Chapter 3. However, in two of the studies (with DEUS and Phase I of WHURLE-LS), the Hawthorne effect could not be controlled for and thus any positive results would have required careful *post-hoc* analysis and possibly additional experimentation, in order to determine what had caused this beneficial effect. This did not prove to be an obstacle though, since the methodology employed in these two user trials would still have allowed for comparison between groups because the interventions were carried out under uniform conditions and with similar group compositions. However, it is useful to consider this issue here in greater detail, so that this potential problem might be resolved for future studies. In order to control for the Hawthorne effect, participants in the study cannot realise that they are part of a study where they might be being given special treatment. This is not always possible to do, and so the best way to deal with this is to use a control group, or have a crossover design (where all participants experience the different interventions, at different phases of the study). The Hawthorne effect tends to be more problematic when positive results are observed, since it is easy to attribute causality to the intervention rather than to the effect of being observed, resulting in a Type 1 error, otherwise referred to as "over-optimism" [162].

Another potential issue with the user trials was that the group compositions themselves might have proved problematic in terms of the granularity of the research, as mentioned in Chapter 6. The way in which learning style itself was used could have been far too generalised: users were categorised into broad overarching groups reflecting the learning style under investigation, i.e. visual or verbal; sequential or global. For those who were actually in the "middle ground" of "little/no preference", this was possibly not an ideal way to categorise them. With particular respect to DEUS, where a large number of pupils were in the central region of a normal distribution, it might be expected that they would not have benefited from any kind of adaptation. Thus, any positive results might have been obscured by a larger number of the negative effects as a consequence of this course-grained categorisation of users (although this seems unlikely in this particular study, as discussed in Section 6.4.4). In addition, because the main factor under investigation was learning styles, other aspects of users were not considered as co-variants. The groups tested in the user trials were as homogeneous as possible, so that the mix of gender, age and generalised measures of intelligence were equivalent between groups. If the effect of learning style is a small one, this could easily have been masked by variance between these individual characteristics in the group as a whole. Hence the homogeneity of groups could have contributed to the negative results and so further trials should be carried out with much stricter controls applied to the make-up of user characteristics within groups. However, it should be noted that these group compositions were grounded in typical "real world" situations and thus provided truly authentic conditions for user testing. Given that schools in the real world rarely contain large groups of pupils that are exactly alike, the consequences resulting from the user trials can thus be applied to schools and other educational institutions in general and reflect the highly variable assortment of learners seen in such situations.

Another factor to take into account was the way in which students were assessed, using the Felder-Soloman ILS model that was simplified down to a single axis (visual/verbal for the WHURLE-LS user trials and sequential/global in the DEUS study). Though necessary in the context of this work, it may not have been appropriate, since that axis is actually a component of the model and not the whole instrument. It is thus possible that students were not assessed as effectively as they might have been but this is beyond the scope of this work and would require input from additional detailed studies from an HCI/psychological perspective. In any case, the approach taken here is in keeping with previous studies that have also only used certain aspects of learning style and so the conclusions can be said to be comparable with those works.

7.4.2 Issues related to the broader research area

There seem to be two main problems that arise from using learning styles for user personalisation. The first problem is concerned with learning style theory and its subsequent application, whilst the second addresses the complexity of learning as a process.

7.4.2.1 Learning styles

The value of learning styles is a contentious issue with many psychologists and neuroscientists, who have questioned the scientific basis of learning styles and the theories upon which the models are based [62, 109]. The work of Coffield *et al* [62, 63] suggested that many learning style models do not in fact measure what they are intended to, and have low internal reliability and validity. The Coffield reports still do not seem to have had the international recognition that they deserve (although perhaps this is understandable from some parts of the world, where the report could be damaging to certain vested interests). As a result, it seems that many AEH researchers are still naively using learning styles as user models for their studies, which are often flawed in their experimental design in some way. Thus, when positive results are found, it is easy to think that learning styles have a significant impact on learning, whereas in fact, the real reasons for the positive results may be almost impossible to determine.

There is also some controversy over the temporal stability of learning styles. It has yet to be established whether (and how often) learning styles change [67, 143, 166] , hence any valid method of personalisation that utilises learning style may need to accommodate a flexible, dynamic model of user preferences rather than a fixed, static measurement.

There are some additional issues with respect to the particular learning style models employed in this research. The concept of visual and verbal preference is itself highly complex and very much more sophisticated than has been suggested by this work. For example, Paivio's dual coding theory states that human cognition deals with visual and verbal processing simultaneously [161], which suggests that AEH systems should provide for both of these types of representation if learning is to be effective [152, 167]. Kozhevnikov *et al* [124] state that although "verbalisers" tend to be a fairly uniform group, "visualisers" can be further categorised into those of high and low spatial ability. They found that these two groupings (the "spatial" type and "iconic" type, respectively) interpreted visual representations differently and this suggests that a further source of variance could have been introduced in the studies conducted with WHURLE-LS. There is also the issue of author bias: the representations may not have been suitably constructed for this wide range of visual and verbal users; even if they were appropriate for use in this system, the ways in which multiple representations affect learning have still not been fully explored [5, 182].

There is also the notion of *visual literacy*, a related but different concept to that of visual learning style. Visual literacy, a term first attributed by Debes [78] in 1968, is the "*ability to construct meaning from visual images*"[101] although subtly different definitions exist across different disciplines. It may be that learners with a strong visual learning preference are highly visually literate although there do not seem to be any published correlations between the two measures. *Linguistic literacy*, where meaning is derived from written or spoken language, is possibly related to verbal learning preference. However, researchers such as Kress [125] state that the integration of visual and linguistic literacies is essential to help students construct meaning, advocating a mixed media approach rather than dichotomous learning, reflecting the ideas of Paivio.

One of the overwhelming and insurmountable problems regarding learning style is that it is only one characteristic of the learner, as mentioned in relation to the problems using groups in the user trials (Section 7.4.1). Melis and Monthienvichienchai refer to eight other aspects such as motivation, working memory capacity and personality traits, amongst others [143]. Plass *et al* suggest that there might be a link between learning styles and other features of the user, such as behaviour or culture [167], whilst Germanakos *et al* [98] refer to models of adaptation that involve emotional parameters. Thus, in addition to these factors impacting upon the learning experience as already discussed, it seems likely that they could – and should – make an important contribution to user models. Learning is clearly affected by a number of determinants and further work into these aforementioned aspects of users might provide crucial insights into what is effective in terms of providing personalisation.

Another factor to take into account is the estimated effect size of learning styles. The low partial eta squared scores for the WHURLE-LS Phase I and DEUS user trials suggest that effect size of learning style in these experiments was very small and this, in combination with numerous other variables (such as the limited gains in knowledge shown by pupils engaging with DEUS) would anticipate it being very difficult to find any results approaching statistical significance. The power of a particular phenomenon will determine what range of sample sizes and the extent of the intervention needed to be able to find any statistically significant differences. Whilst the sample sizes were adequate in these experiments, it is likely that the amount of learning that took place and the time frames involved in both studies were not large enough to reveal any significant difference, if the effect size for learning styles is indeed so small.

Lastly, it is worth noting that learning style theory is not suggested as a replacement for user modelling based on knowledge, but as a complementary improvement to these existing user models. In addition, it is not suggested that any one particular learning style/preference is better than any other (regardless of the typology used), nor that learners should learn only in their preferred style. Indeed, it may be beneficial to a learner to study in a non-preferred learning style for some of the time, since they will develop compensatory skills from this non-optimal situation.

7.4.2.2 Learning as a process

The second problem is that which is common to educational research: the development of learning. Learning and the factors that affect it are extremely complex; there are many different influences that together or separately affect how people learn. Issues such as overall IQ (itself influenced by several factors); motivation; socio-economic background; time; effort; health; other distractions related to personal and social activities or commitments – these all contribute to how, when and under what circumstances somebody learns [153, 174]. A phenomenon commonly seen in schools is the effect of the weather on pupil behaviour. Many experienced teachers correctly predict that their pupils will become more badly-behaved when there is a sudden change in the weather (e.g. to rain or wind), as evidenced by Badger and O'Hare [13].

The nature of learning is obviously very complex, with a large interplay of factors. Learning (and the study of it) can therefore be said to be a "wicked problem", a phrase coined by Rittel and Webber [175] to describe problems that are incomplete and contradictory, that often have changing constraints and resources. Solutions to wicked problems are often difficult to realise because of complex interdependencies, and cannot be considered finite: they tend to be "good or bad" rather than "true or false". Although initially used by Rittel and Webber in the context of social planning, it seems to be a fitting terminology to use with studies of how people learn. Additionally, because of the complex nature of learning, it can be difficult to predict the outcome of certain interventions; even when the same intervention is carried out with in an identical study, a different result may occur.

Somewhat related to "wicked problems" is the compounding phenomenon of the "butterfly effect". This is an aspect of chaos theory that provides a metaphor for sensitive dependence on initial conditions; the name refers to the idea that the movement of a butterfly's wings might create a slight disturbance in the atmosphere and indirectly cause a tornado to appear (or conversely, prevent one from occurring) [111]. It is possible that projects involving educational research might well suffer from the butterfly effect, where similar starting conditions with very minor adjustments might result in widely differing outcomes. Complexity theory provides a more formal integration of the butterfly effect into educational research, where it has been used to study the adaptation of schools to their environment (i.e. the resources available, strategies employed, limitations imposed by the government or other educational bodies etc) [153]. Complexity theory, when applied to personalisation for computer-based learning, suggests that user modelling is only one small component when taking into account the wider factors that might help provide for a more effective learning experience, such as making computer-based resources more widely available or examining the effect of computers in the classroom on pupil motivation, for example.

With these two overarching problems, what then can be done from a pragmatic perspective to ensure future quality-assured studies?

It is clear that there is a need for high-quality AEH research, with well-designed experiments based on theoretically sound models. Fortunately, this is not difficult to do provided that the researchers involved are aware of these requirements. It is not expected that all researchers will necessarily have the pre-requisite knowledge to design the experiments, or know to what extent the intervention needs to happen (or for how long), since this information can be gleaned from colleagues or existing literature. Many areas of computer science, including AEH, seem to blur into that of social science since much work is done with people – the users of our systems. An extremely useful guide to this kind of research is provided by Robson [176], who discusses the different kinds of experimental designs, including those that cannot be carried out in a closed laboratory setting. He states that the “gold standard” of applied research is the randomised controlled trial (RCT), where there is a control group and random assignment of users to either the control group or experimental group. He also discusses aspects of experimental design, such as sample sizes; data collection; interviews and questionnaires; and analysis of data.

Another aspect of high-quality research is to realise the limitations or controversies surrounding any part of the study, including the theoretical model upon which it is based. The learning styles model used as the basis for the studies discussed in Chapters 5 and 6 has been tested for reliability and validity, and found to have relatively high scores for both [132, 236] – hence its use in this research can be justified[20]. However, learning styles researchers should be aware of the problems that might be related to their particular choice of learning styles model so that all potential sources of bias are brought out into the open [176].

Researchers should also think carefully as to whom they should be testing their system on. Obviously, if a system is created for a specific cohort of the population then they should be the target participants of any study. However, if a researcher were looking to generalise their findings to a wider perspective, they would do well to factor out any compounding variables, and think carefully whether the participants might have been non-randomly selected. In other

[20] Although the modified questionnaire used in the DEUS user trials is open to valid criticism.

words, are these "real people" that are being used, or just those that are convenient (such as university students)?

Finally it is suggested that another aspect of statistical analysis is considered, namely that of effect size. Effect size was estimated for both WHURLE-LS Phase I and the DEUS user trials but is not often mentioned in the published literature and it is possible that its exclusion from these papers is detrimental to those studies. This is because, even when genuine positive results are found, it is difficult to ascertain the level of importance of those results. By calculating effect size, a more realistic viewpoint can be taken, since different interventions will have a common unit of comparison. In this way, phenomena that have a large positive effect size can be recognised as having greater benefit than those having a small positive effect.

7.5 Further work

There are several aspects of this research that merit further investigation, building on the studies carried out thus far and also introducing new ideas for consideration.

Firstly, it seems sensible that before learning styles can be judged as inadequate for effective personalised learning, further studies should be carried out with them to examine how they affect groups of truly homogeneous users. The findings from this research are somewhat limited due to the simplicity of the user trials; it could be argued that this was a very narrow, "snapshot" view of what is a very broad and complex field. Future research should control for as many factors as possible, thus reducing the variance of initial conditions and lessening the "butterfly effect", or the chance of a Type 2 error, where scientists are too cautious in their methodology or analysis and present negative findings when they should actually have been positive [162]. It is envisaged that age, gender, measures of intelligence/personality type and motivation should all be as uniform as possible within a specific cultural group. This might cause practical problems where the number of potential test subjects is small although it does allow for much stricter management of controlled variables.

Secondly, leading on from the methodology employed for the Phase II WHURLE-LS user trials, it is suggested that further work be carried out with data analysis of web log files in order to determine useful browsing patterns. This builds upon work carried out by researchers who have elicited information for the user model from such browsing behaviour: Hynecosum deduces the user's experience level from their browsing patterns and HYPERCASE uses similar information to infer the user's didactic goal [40, 147]. However, the information resulting from the amount of time spent on a node or the number of visits to that node is somewhat limited and does not yield reliable conclusions about the user's intentions since there is no guarantee that the user has actively engaged with the content in each node [40]. Thus, the proposal is not to use this data to feed back into the user model, but rather to compare the patterns of navigation of one user to that of another and use commonly-traversed paths as "recommended" routes for others, if guidance is requested by the user. In this way, no explicit user model is required and no causality is inferred as to which aspects of users might affect how the adaptivity evolves. It is a very simple idea that caters for the complexity of factors that contribute to the learning process without having to specifically state which of them is being addressed. It also removes the issue of asking the user for explicit information about their preferences (which might change at short notice and across different domains) and hence does not require continual updating. It is possible that this approach could be used to investigate which aspects of the user model result in certain navigational patterns, if this information were readily available. However, this would only establish correlations, which would then require further, more formal user trials to ascertain the relative benefits of using these user characteristics as models for adaptation. Nevertheless, this is potentially a very powerful method of providing adaptation for computer-based learning, once some established or suggested paths have been constructed. Brusilovsky suggests that these "non-symbolic" approaches, that include case-based reasoning and neural networks, may help in providing adaptation decisions where no particular rules are available [42].

Similar recommender systems have been used already for providing personalisation, typically seen in e-commerce situations such as Amazon.com [183], where users are shown lists of other products bought by people who have just purchased the same item as them. Users might also be guided towards other products by the same author/musician or a best-seller in the same category of that product. It would be intriguing to investigate how recommender systems could be used to collect and analyse implicit data [159] to provide adaptation for educational content. Some interesting work has already been carried out by Plua and Jameson [168], Fok and Ip [97] and Wang *et al* [211] and these studies could prove a valuable starting point for future research.

Thirdly, in this era of evolving technology and expanding networking capabilities, it seems logical to pursue the concept of device-based adaptation. Thus, users interacting with mobile devices such as laptops and "palmtops" or mobile phones would be expected to have different requirements and preferences from those interacting with materials on a desktop computer or a device with a bigger screen. Usability is already an important aspect of designing for small screens and it is possible that some of the modality (visual/verbal) or structure-based (sequential/global) aspects of learning style might influence the thinking behind the user interfaces for educational content displayed on such devices. The work by Dagger *et al* [70] provides a fascinating introduction to this kind of adaptation and demonstrates its integration into the APeLS (Adaptive Personalised eLearning Service) system [65].

Fourthly, a new framework is suggested to address an aspect of learning that has so far been largely neglected by AEH systems. The omission of social interaction in adaptive systems is possibly a critical one, since interpersonal relationships contribute a vital part of the learning process [82, 180]. Using the example of social networking websites (which have augmented and enhanced communication and help construct distributed communities) it seems likely that similar techniques could be integrated into an AEH system, providing the social interaction that so many computer-based learning systems currently lack. Adaptation could then include interpersonal aspects, whereby users could prefer to interact with a small number of individuals or as part of a larger group, depending on their preferences.

7.6 Conclusion

It is clear that the field of learning style application in AEH is a highly complex and somewhat controversial area of research and one that has no quick answers. There does not seem to be any particular evidence to invalidate this area of research and any work carried out by others should not be dismissed out of hand; however it does seem that personalisation to show a statistically significant benefit in educational systems is much harder to create than first envisaged. A crucial aspect of this research was to exemplify a quality-assured, rigorous and strongly scientific approach in the field of adaptive hypermedia so that the findings would be based on sound evidence gleaned from carefully-controlled user trials and taking into account the many issues surrounding user variability and learning style theory. From this perspective, the work has been a considerable success, inspiring debate amongst academics and practitioners and seeking to readdress the issue of learning styles for computer-based learning and whether in fact they should be used for effective personalisation.

However, until more evidence is acquired (for example, from more extensive user trials and/or user models), it is difficult to draw firm conclusions about the efficacy and validity of using learning styles as means of adaptation for computer-based learning. The lack of any kind of correlation seen in these user trials might be a particular characteristic of the study, although it is possible (maybe even probable) that it is indicative of a universal pattern.

The issues raised in Section 7.5, along with many others, remain unanswered for the time being. It is evident though, that whatever future research is done, there is a clear and pressing need to produce quality-assured studies with as much quantitative and qualitative evidence as possible, in order to help us answer at least some of these questions.

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APPENDIX A:

VISUAL/VERBAL QUESTIONNAIRE USED IN WHURLE-LS USER TRIALS

Learning Preferences Assessment Page
Please answer the following questions so we can find out what your learning preferences are. For each of the 11 questions below select either "a" or "b" to indicate your answer. Please choose only one answer for each question.

If both "a" and "b" seem to apply to you, choose the one that applies more frequently. When you have finished, click the submit button at the end of the form.

When I think about what I did yesterday, I am most likely to get
a) a picture
b) words

I prefer to get new information in
a) written directions or verbal information
b) pictures, diagrams, graphs, or maps

In a book with lots of pictures and charts, I am likely to
a) look over the pictures and charts carefully
b) focus on the written text

I like teachers/lecturers
a) who spend a lot of time explaining
b) who put a lot of diagrams on the board

I remember best
a) what I see
b) what I hear

When I get directions to a new place, I prefer
a) written instructions
b) a map

When I see a diagram or sketch in class, I am most likely to remember
a) the picture
b) what the instructor said about it

When someone is showing me data, I prefer
a) text summarizing the results
b) charts or graphs

When I meet people at a party, I am more likely to remember
a) what they looked like
b) what they said about themselves

For entertainment, I would rather
a) read a book
b) watch television

I tend to picture places I have been
a) easily and fairly accurately
b) with difficulty and without much detail

APPENDIX B:

INTERVIEW QUESTIONS

(WHURLE-LS PHASE I USER TRIALS)

DIGITAL REVISION GUIDE: User evaluation

1. Did you like using the system?
2. How often did you use the system?
3. Would you like to have been able to use it for other modules?
4. How useful do you think this kind of system is?
5. Did you look at anyone else's display – and if so, did you notice any differences?
6. What did you think of the way the information was organised?
7. What are your preconceptions of adaptive or adapted systems?
   (are they a good thing or not?)
8. Was there anything you really liked or disliked?

APPENDIX C:

EXAMPLE OF LOG FILE FROM WHURLE-LS PHASE II USER TRIALS

tracking	ID number	IP address	Date	page	node no	felder	f-number	user	envtype
4	542	10.3.50.231	11/May/2006:18:11:11			felder	0	user	neutral
4	543	10.3.50.231	11/May/2006:18:11:59	page	obj	felder	0	user	neutral
4	544	10.3.50.231	11/May/2006:18:12:00	page	res	felder	0	user	neutral
4	545	10.3.50.231	11/May/2006:18:12:01	page	cred	felder	0	user	neutral
4	546	10.3.50.231	11/May/2006:18:13:03	page	33	felder	0	user	neutral
4	547	10.3.50.231	11/May/2006:18:15:00	page	41	felder	0	user	neutral
4	548	10.3.50.231	11/May/2006:18:16:05	page	51	felder	0	user	neutral
4	549	10.3.50.231	11/May/2006:18:16:26	page	56	felder	0	user	neutral
4	550	10.3.50.231	11/May/2006:18:17:31	page	68	felder	0	user	neutral
4	551	10.3.50.231	11/May/2006:18:18:14	page	68	felder	2	user	visual
4	552	10.3.50.231	11/May/2006:18:18:34	page	68	felder	-2	user	verbal
4	553	10.3.50.231	11/May/2006:18:19:14	page	81	felder	2	user	visual
4	554	10.3.50.231	11/May/2006:18:19:32	page	81	felder	0	user	neutral
4	555	10.3.50.231	11/May/2006:18:21:03	page	91	felder	2	user	visual
4	556	10.3.50.231	11/May/2006:18:22:09	page	91	felder	0	user	neutral
4	557	10.3.50.231	11/May/2006:18:22:48	page	91	felder	-2	user	verbal
4	558	10.3.50.231	11/May/2006:18:23:41	page	33	felder	-2	user	verbal
4	559	10.3.50.231	11/May/2006:18:43:29	page	102	felder	-2	user	verbal
4	560	10.3.50.231	11/May/2006:18:43:36	page	102	felder	2	user	visual
4	562	10.3.50.231	11/May/2006:18:43:52	page	102	felder	0	user	neutral
4	563	10.3.50.231	11/May/2006:18:45:06	page	115	felder	0	user	neutral
4	564	10.3.50.231	11/May/2006:18:47:26	page	127	felder	0	user	neutral
4	568	10.3.50.231	11/May/2006:18:59:28	page	139	felder	0	user	neutral
4	571	10.3.50.231	11/May/2006:19:00:16	page	147	felder	0	user	neutral
4	572	10.3.50.231	11/May/2006:19:01:53	page	155	felder	0	user	neutral
4	573	10.3.50.231	11/May/2006:19:03:09	page	165	felder	0	user	neutral
5	3876	10.3.50.77	25/May/2006:19:24:30			felder	0	user	neutral
5	3877	10.3.50.77	25/May/2006:19:24:44	page	33	felder	0	user	neutral

5	3878	10.3.50.77	25/May/2006:19:24:54	page	33	felder	0	user	neutral
5	3879	10.3.50.77	25/May/2006:19:25:05	page	356	felder	0	user	neutral
5	3880	10.3.50.77	25/May/2006:19:25:20	page	367	felder	0	user	neutral
5	3884	10.3.50.77	25/May/2006:19:26:20	page	377	felder	0	user	neutral
5	3894	10.3.50.77	25/May/2006:19:31:17	page	383	felder	0	user	neutral
5	3895	10.3.50.77	25/May/2006:19:31:37	page	397	felder	0	user	neutral
5	3896	10.3.50.77	25/May/2006:19:32:05	page	405	felder	0	user	neutral
5	3897	10.3.50.77	25/May/2006:19:32:14	page	413	felder	0	user	neutral
6	2797	10.3.59.108	24/May/2006:22:49:20			felder	2	user	visual
6	2798	10.3.59.108	24/May/2006:22:49:49	page	33	felder	2	user	visual
6	2799	10.3.59.108	24/May/2006:22:51:09	page	41	felder	2	user	visual
6	2802	10.3.59.108	24/May/2006:22:51:59	page	51	felder	2	user	visual
6	2804	10.3.59.108	24/May/2006:22:52:55	page	51	felder	-2	user	verbal
6	2805	10.3.59.108	24/May/2006:22:53:07	page	51	felder	0	user	neutral
6	2806	10.3.59.108	24/May/2006:22:53:12	page	56	felder	0	user	neutral
6	2808	10.3.59.108	24/May/2006:22:53:19	page	56	felder	2	user	visual
6	2809	10.3.59.108	24/May/2006:22:53:52	page	56	felder	-2	user	verbal
6	2810	10.3.59.108	24/May/2006:22:54:23	page	68	felder	2	user	visual
6	2811	10.3.59.108	24/May/2006:22:55:01	page	68	felder	-2	user	verbal
6	2812	10.3.59.108	24/May/2006:22:55:26	page	33	felder	-2	user	verbal
6	2813	10.3.59.108	24/May/2006:22:55:43	page	obj	felder	-2	user	verbal
6	2814	10.3.59.108	24/May/2006:22:55:47	page	res	felder	-2	user	verbal
6	2815	10.3.59.108	24/May/2006:22:56:00	page	cred	felder	-2	user	verbal
6	2816	10.3.59.108	24/May/2006:22:56:18	page	obj	felder	-2	user	verbal
6	2817	10.3.59.108	24/May/2006:22:56:23			felder	-2	user	verbal
6	2827	10.3.59.108	24/May/2006:23:07:19	page	41	felder	-2	user	verbal
6	2828	10.3.59.108	24/May/2006:23:25:59	page	81	felder	2	user	visual
7	3170	10.3.59.108	25/May/2006:13:03:39	page	91	felder	2	user	visual
7	3222	10.3.59.108	25/May/2006:14:06:14			felder	2	user	visual

7	3223	10.3.59.108	25/May/2006:14:06:22	page	102	felder	2	user	visual
7	3225	10.3.59.108	25/May/2006:14:06:47	page	115	felder	2	user	visual
7	3794	10.3.59.108	25/May/2006:18:31:11	page	127	felder	2	user	visual
7	3795	10.3.59.108	25/May/2006:18:33:16	page	139	felder	2	user	visual
7	3796	10.3.59.108	25/May/2006:18:33:44	page	147	felder	2	user	visual
7	3996	10.3.59.108	25/May/2006:21:04:46			felder	2	user	visual
7	4079	10.3.59.108	25/May/2006:21:42:49			felder	2	user	visual
8	4313	10.3.59.108	26/May/2006:01:05:05	page	139	felder	-2	user	verbal
8	4314	10.3.59.108	26/May/2006:01:05:31	page	147	felder	-2	user	verbal
8	4315	10.3.59.108	26/May/2006:01:05:33	page	127	felder	-2	user	verbal
8	4316	10.3.59.108	26/May/2006:01:05:33	page	127	felder	-2	user	verbal
8	4317	10.3.59.108	26/May/2006:01:05:38	page	115	felder	-2	user	verbal
8	4318	10.3.59.108	26/May/2006:01:05:43	page	102	felder	-2	user	verbal
9	1926	10.3.61.215	23/May/2006:21:59:55			felder	-2	user	verbal
9	1927	10.3.61.215	23/May/2006:22:00:30	page	33	felder	-2	user	verbal
9	1928	10.3.61.215	23/May/2006:22:01:28	page	41	felder	-2	user	verbal
9	1929	10.3.61.215	23/May/2006:22:01:42	page	51	felder	-2	user	verbal
9	1930	10.3.61.215	23/May/2006:22:01:50	page	56	felder	-2	user	verbal
9	1931	10.3.61.215	23/May/2006:22:01:55	page	68	felder	-2	user	verbal
9	1932	10.3.61.215	23/May/2006:22:01:57	page	81	felder	-2	user	verbal
9	1933	10.3.61.215	23/May/2006:22:02:10	page	81	felder	2	user	visual
9	1934	10.3.61.215	23/May/2006:22:02:22	page	91	felder	2	user	visual
9	1935	10.3.61.215	23/May/2006:22:02:35	page	res	felder	2	user	visual
9	1936	10.3.61.215	23/May/2006:22:02:41			felder	2	user	visual
9	1937	10.3.61.215	23/May/2006:22:02:50	page	cred	felder	2	user	visual
9	1938	10.3.61.215	23/May/2006:22:02:53	page	33	felder	2	user	visual
9	1939	10.3.61.215	23/May/2006:22:03:03	page	33	felder	2	user	visual
9	1940	10.3.61.215	23/May/2006:22:03:14	page	418	felder	2	user	visual
9	1941	10.3.61.215	23/May/2006:22:03:58	page	428	felder	2	user	visual

9	1942	10.3.61.215	23/May/2006:22:04:21	page	428	felder	-2	user	verbal
9	1950	10.3.61.215	23/May/2006:23:34:07	page	102	felder	-2	user	verbal
9	1951	10.3.61.215	23/May/2006:23:34:18	page	102	felder	2	user	visual
9	1952	10.3.61.215	23/May/2006:23:35:41	page	115	felder	-2	user	verbal
9	1953	10.3.61.215	23/May/2006:23:37:46	page	127	felder	-2	user	verbal
9	1954	10.3.61.215	23/May/2006:23:39:44	page	139	felder	-2	user	verbal
9	1955	10.3.61.215	23/May/2006:23:40:45	page	147	felder	-2	user	verbal
9	1956	10.3.61.215	23/May/2006:23:43:32	page	155	felder	-2	user	verbal
9	1957	10.3.61.215	23/May/2006:23:44:33	page	165	felder	-2	user	verbal
9	1958	10.3.61.215	23/May/2006:23:45:57	page	179	felder	-2	user	verbal
9	1959	10.3.61.215	23/May/2006:23:46:42	page	191	felder	-2	user	verbal
9	1960	10.3.61.215	23/May/2006:23:47:59	page	202	felder	-2	user	verbal
9	1961	10.3.61.215	23/May/2006:23:50:08	page	215	felder	-2	user	verbal
9	1962	10.3.61.215	23/May/2006:23:50:56	page	226	felder	-2	user	verbal
9	1963	10.3.61.215	23/May/2006:23:52:01	page	237	felder	-2	user	verbal
9	1964	10.3.61.215	23/May/2006:23:53:30	page	254	felder	-2	user	verbal
9	1965	10.3.61.215	23/May/2006:23:53:39	page	266	felder	-2	user	verbal
9	1966	10.3.61.215	23/May/2006:23:54:00	page	277	felder	-2	user	verbal
9	1967	10.3.61.215	23/May/2006:23:55:01	page	290	felder	-2	user	verbal
9	1968	10.3.61.215	23/May/2006:23:56:03	page	303	felder	-2	user	verbal
9	1969	10.3.61.215	23/May/2006:23:56:35	page	313	felder	-2	user	verbal
9	1970	10.3.61.215	23/May/2006:23:57:22	page	321	felder	-2	user	verbal
9	1971	10.3.61.215	23/May/2006:23:57:35	page	335	felder	-2	user	verbal
9	1972	10.3.61.215	23/May/2006:23:57:42	page	344	felder	-2	user	verbal
9	1973	10.3.61.215	23/May/2006:23:57:56	page	356	felder	-2	user	verbal
9	1974	10.3.61.215	23/May/2006:23:58:21	page	367	felder	-2	user	verbal
9	1975	10.3.61.215	23/May/2006:23:59:02	page	367	felder	2	user	visual
9	1976	10.3.61.215	23/May/2006:23:59:34	page	367	felder	0	user	neutral
9	1977	10.3.61.215	23/May/2006:23:59:45	page	377	felder	0	user	neutral

9	1979	10.3.61.215	24/May/2006:00:00:21	page	377	felder	-2	user	verbal
9	1980	10.3.61.215	24/May/2006:00:00:36	page	383	felder	-2	user	verbal
9	1981	10.3.61.215	24/May/2006:00:00:46	page	383	felder	0	user	neutral
9	1982	10.3.61.215	24/May/2006:00:01:16	page	383	felder	2	user	visual
9	1983	10.3.61.215	24/May/2006:00:02:16	page	397	felder	-2	user	verbal
9	1984	10.3.61.215	24/May/2006:00:03:11	page	405	felder	-2	user	verbal
9	1985	10.3.61.215	24/May/2006:00:03:39	page	413	felder	-2	user	verbal
9	1986	10.3.61.215	24/May/2006:00:04:10	page	cred	felder	-2	user	verbal
9	1987	10.3.61.215	24/May/2006:00:05:00	page	obj	felder	-2	user	verbal
10	2456	10.3.61.215	24/May/2006:16:59:06			felder	-2	user	verbal
10	2457	10.3.61.215	24/May/2006:16:59:21	page	33	felder	-2	user	verbal
10	2464	10.3.61.215	24/May/2006:17:00:59	page	179	felder	-2	user	verbal
10	2466	10.3.61.215	24/May/2006:17:01:24	page	237	felder	-2	user	verbal
10	2517	10.3.61.215	24/May/2006:17:30:00	page	191	felder	-2	user	verbal
10	2518	10.3.61.215	24/May/2006:17:30:02	page	191	felder	-2	user	verbal
10	2535	10.3.61.215	24/May/2006:17:39:35	page	202	felder	-2	user	verbal
10	2541	10.3.61.215	24/May/2006:17:48:20	page	215	felder	-2	user	verbal
10	2542	10.3.61.215	24/May/2006:17:50:47	page	226	felder	-2	user	verbal
11	2648	10.3.61.215	24/May/2006:20:15:01	page	254	felder	-2	user	verbal
11	2654	10.3.61.215	24/May/2006:20:26:55	page	266	felder	-2	user	verbal
11	2655	10.3.61.215	24/May/2006:20:30:59	page	277	felder	-2	user	verbal
11	2656	10.3.61.215	24/May/2006:20:38:31	page	290	felder	-2	user	verbal

APPENDIX D:

EXAMPLE OF XHAWK PHPNAV TEXT FILE USED IN DEUS

```
#
# PHP Nav Sample Database
#
# blank lines and commented lines are ignored
# comments are : and #
# fields are: path	page_name	parent_name
# path and page name are (should be) primary keys
# fields are delimited by one or more tabs

# Top level links
/~ejb/cgi-bin/DEUS/index.php?page=introduction		1. Introduction		.
/~ejb/cgi-bin/DEUS/index.php?page=plants	2. Plants	.
/~ejb/cgi-bin/DEUS/index.php?page=humans	3. Humans	.
/~ejb/cgi-bin/DEUS/index.php?page=global_why 4. Why reproduce?	.

# 1. Life cycles: introduction links
/~ejb/cgi-bin/DEUS/index.php?page=global_intro		1.1 Life cycles		1. Introduction
/~ejb/cgi-bin/DEUS/index.php?page=global_plants		1.2 Life cycles in plants	1. Introduction
/~ejb/cgi-bin/DEUS/index.php?page=global_humans		1.3 Life cycles in humans	1. Introduction
/~ejb/cgi-bin/DEUS/index.php?page=global_other		1.4 Life cycles in other animals	1. Introduction


# 2. Plants links
/~ejb/cgi-bin/DEUS/index.php?page=global1_1  2.1 Parts of a flower  2. Plants
/~ejb/cgi-bin/DEUS/index.php?page=global1_2  2.2 Pollination	2. Plants
/~ejb/cgi-bin/DEUS/index.php?page=global1_3  2.3 Fertilisation	2. Plants
/~ejb/cgi-bin/DEUS/index.php?page=global1_4  2.4 Fruit and seed production 2. Plants
/~ejb/cgi-bin/DEUS/index.php?page=global1_5  2.5 Seed dispersal	2. Plants
/~ejb/cgi-bin/DEUS/index.php?page=global1_6  2.6 Germination	2. Plants
/~ejb/cgi-bin/DEUS/index.php?page=global1_7  2.7 Growth of seeds	2. Plants


# 3. Humans links
/~ejb/cgi-bin/DEUS/index.php?page=global2_1  3.1 Stages in our lives	3. Humans
/~ejb/cgi-bin/DEUS/index.php?page=global2_2  3.2 Differences in other animals	3. Humans


# 4. Why reproduce? links
/~ejb/cgi-bin/DEUS/index.php?page=global3_1  4.1 Introduction	4. Why reproduce?
/~ejb/cgi-bin/DEUS/index.php?page=global3_2  4.2 Animal SOS!	4. Why reproduce?
/~ejb/cgi-bin/DEUS/index.php?page=global3_3  4.3 What if...?	4. Why reproduce?
```

APPENDIX E:

MODIFIED FELDER-SOLOMAN INVENTORY OF LEARNING STYLES QUESTIONNAIRE

Visual/verbal and sequential/global axes: rewritten for 9-11 year old children (modified text shown in red)

Visual-verbal questions:

Q. no.	*To be used in class:*	*Based on original question:*
1	When I think about what I did yesterday, I am most likely to get a) a picture b) words	*When I think about what I did yesterday, I am most likely to get* *a) a picture.* *b) words.*
2	I prefer to get new information in a) pictures, drawings or photos b) words	*I prefer to get new information in* *a) pictures, diagrams, graphs, or maps.* *b) written directions or verbal information.*
3	In a book with lots of pictures and charts, I am likely to a) look over the pictures and charts carefully b) focus on the words	*In a book with lots of pictures and charts, I am likely to* *a) look over the pictures and charts carefully.* *b) focus on the written text.*
4	I like teachers a) who put a lot of pictures or drawings on the board b) who spend a lot of time explaining	*I like teachers* *a) who put a lot of diagrams on the board.* *b) who spend a lot of time explaining.*
5	I remember best a) what I see b) what I hear	*I remember best* *a) what I see.* *b) what I hear.*
6	If I am going to make something that I haven't done before, I prefer a) written instructions b) drawings or pictures to show me what to do	*When I get directions to a new place, I prefer* *a) a map.* *b) written instructions.*
7	When I see a picture or drawing in class, I am most likely to remember a) the picture b) what the teacher said about it	*When I see a diagram or sketch in class, I am most likely to remember* *a) the picture.* *b) what the instructor said about it.*

8	When someone is showing me some information, I prefer a) graphs or pictures describing it b) words describing it	*When someone is showing me data, I prefer* *a) charts or graphs.* *b) text summarizing the results.*
9	If I see new people on TV, I am more likely to remember a) what they looked like b) what they were talking about	*When I meet people at a party, I am more likely to remember* *a) what they looked like.* *b) what they said about themselves.*
10	For entertainment, I would rather a) watch television b) read a book	*For entertainment, I would rather* *a) watch television.* *b) read a book.*
11	When I’ve been somewhere, I can a) easily remember how the place looked b) have problems remembering how the place looked	*I tend to picture places I have been* *a) easily and fairly accurately.* *b) with difficulty and without much detail.*

Global-sequential questions:

Q. no.	*To be used in class:*	*Original question:*
12	I am usually able to a) understand details of a topic but may be a bit fuzzy about its overall structure b) understand the overall structure but may be fuzzy about details of a topic	*I tend to a) understand details of a subject but may be fuzzy about its overall structure. b) understand the overall structure but may be fuzzy about details.*
13	Once I understand a) all the parts of an idea, I understand the whole thing b) the whole thing, I see how the parts of an idea fit together	*Once I understand a) all the parts, I understand the whole thing. b) the whole thing, I see how the parts fit.*
14	When I solve maths problems a) I usually work my way to the solutions one step at a time. b) I often just see the solutions but then have to struggle to figure out the steps to get to them.	*When I solve math problems a) I usually work my way to the solutions one step at a time. b) I often just see the solutions but then have to struggle to figure out the steps to get to them.*
15	When I'm studying a story or a book a) I think of the things that happen and try to put them together to figure out the main stories b) I just know what the main stories are when I finish reading and then I have to go back and find the things that happen to show these stories	*When I'm analyzing a story or a novel a) I think of the incidents and try to put them together to figure out the themes. b) I just know what the themes are when I finish reading and then I have to go back and find the incidents that demonstrate them.*
16	It is more important to me that a teacher a) lays out the material in clear ordered steps b) give me an overall picture of the topic and relates the topic to other subjects	*It is more important to me that an instructor a) lay out the material in clear sequential steps. b) give me an overall picture and relate the material to other subjects.*

17	I learn a) at a fairly regular pace. If I study hard, I'll "get it" b) in fits and starts. I'll be totally confused and then suddenly it all "clicks"	*I learn* *a) at a fairly regular pace. If I study hard, I'll "get it."* *b) in fits and starts. I'll be totally confused and then suddenly it all "clicks."*
18	When considering a piece of information, I am more likely to a) think about the details and miss the main idea b) try to understand the main idea before getting into the details	*When considering a body of information, I am more likely to* *a) focus on details and miss the big picture.* *b) try to understand the big picture before getting into the details.*
19	When writing a story, I am more likely to a) think about or write the start of the story and progress forward. b) think about or write different parts of the story and then put them in order	*When writing a paper, I am more likely to* *a) work on (think about or write) the beginning of the paper and progress forward.* *b) work on (think about or write) different parts of the paper and then order them.*
20	When I am learning a new topic, I prefer to a) concentrate on that topic, learning as much about it as I can b) try to make connections between that topic and related topics	*When I am learning a new subject, I prefer to* *a) stay focused on that subject, learning as much about it as I can.* *b) try to make connections between that subject and related subjects.*
21	Some teachers start their lessons with an outline of what they will cover. Such outlines are a) a bit helpful to me. b) very helpful to me.	*Some teachers start their lectures with an outline of what they will cover. Such outlines are* *a) somewhat helpful to me.* *b) very helpful to me.*
22	When solving problems in a group, I would be more likely to a) think of the steps to get to the answer b) think what sorts of things might happen because of how the problem is solved	*When solving problems in a group, I would be more likely to* *a) think of the steps in the solution process.* *b) think of possible consequences or applications of the solution in a wide range of areas.*

APPENDIX F:

LIST OF PUBLICATIONS

Brown, E., T. Fisher and T. Brailsford (2007) Real users, real results: examining the limitations of learning styles within AEH. *Proceedings of the Eighteenth ACM Conference on Hypertext and Hypermedia (Hypertext 2007)*, Manchester, UK, 10-12 Sept 2007.
****Awarded Theodore Holm Nelson Prize for Best Newcomer Paper****

Brown, E., T. Brailsford, T. Fisher and C. van der Eijk (2007) Revealing the hidden rationality of user browsing behaviour. *Proceedings of the Eighteenth ACM Conference on Hypertext and Hypermedia (Hypertext 2007)*, Manchester, UK, 10-12 Sept 2007.

Brown, E., T. Brailsford, T. Fisher, A. Moore and H. Ashman (2006) Reappraising cognitive styles in adaptive web applications. *Proceedings of the 15th International World Wide Web Conference (WWW2006)*, Edinburgh, UK, 22-26 May 2006.

Brown, E., C. Stewart and T. Brailsford (2006) Adapting for visual and verbal learning styles in AEH. *Proceedings of the IEEE International Conference on Advanced Learning Technologies (ICALT 2006)*, Kerkrade, The Netherlands, 5-7 July 2006.
****Awarded Best Paper in the Adaptive Web-Based Education and Learning Styles (AWELS) workshop****

Brown, E., A. Cristea, C. Stewart and T. Brailsford (2005) Patterns in Authoring of Adaptive Educational Hypermedia: A Taxonomy of Learning Styles. *Educational Technology & Society (Special Issue)* **8** (3): 77-90.

Brown, E. J. and T. Brailsford (2004) Integration of learning style theory in an adaptive educational hypermedia (AEH) system. *Proceedings of the 11th International Conference of the Association for Learning Technology (ALT-C 2004)*, Exeter, UK, 14-16 September 2004.