Construction of an Adaptive E-learning Environment to Address Learning Styles and an Investigation of the Effect of Media Choice

Christian Wolf

Diplom-Informatiker (FH) Digitale Medien

(equivalent to BCompSc(Hons) Digital Media)

This exegesis is submitted with the durable record of the project materials on DVD in fulfilment of the requirements for the degree Doctor of Philosophy.

School of Education

Design and Social Context Portfolio

RMIT University

January 2007

Certification

I hereby state that

a. except where due acknowledgement has been made, the work has been carried out by myself alone;

b. the work has not been submitted previously, in whole or in part, to qualify for any other academic award;

c. the content of the exegesis is the result of work which has been carried out since the official commencement date of the approved research program; and

d. any editorial work, paid or unpaid, carried out by a third party is acknowledged.

e. ethics procedures and guidelines have been followed.

Christian Wolf Melbourne, January 2007

Acknowledgements

This PhD by project was partially funded by a scholarship from the German Academic Exchange Service and a grant from the Telematics Course Development Fund Trust.

Thanks to my supervisors Tony Owens, Andrew Seaton, Nicola Yelland, and Robyn Blake for their comments on my work and on earlier versions of this exegesis. Additional thanks for helpful comments on the statistics sections go to John Izard, Cliff DaCosta and Boyka Bratanova.

I would also like to express my gratitude to the 63 multimedia students from RMIT University (TAFE division), who participated in the evaluation of iWeaver, as well as to all the ADoM staff members for their support and cooperation.

A big "thank you" goes to all my friends. You were my social network that kept me out of the dark holes of doing a PhD. It was always rewarding and enlightening to socialise with all of you and you kept me sane. Special thanks to Stefan G. and Stefan K., who both helped me greatly with practical and emotional support. Similarly, I would like to express my gratitude to Tess and Floyd for their thorough proof-reads and insights.

Additional cheers must go to my housemates (for putting up with me), to Apples (for encouragement and constructive criticism), to Ben and Rosalba (for asking the right questions), to Sampo and Lil (for many great discussions), to Anna (for the spoken components), to Jeremy Parker (for his invaluable support during the recording sessions) and to everyone who provided feedback on preliminary versions of iWeaver.

Thanks to my parents who supported me and believed in me. Thank you both for never losing faith that I would complete this PhD. You were always there for me and I always felt safe and supported.

This work is dedicated to my family and friends.

Christian Wolf

Related Publications

Parts of the background and method chapter of this exegesis have been published before in conference proceedings.

Wolf, C. (2002). *iWeaver: Towards an Interactive Web-Based Adaptive Learning Environment to Address Individual Learning Styles.* Paper presented at the Interactive Computer Aided Learning Workshop (ICL2002), Villach, Austria.

http://www.adaptive-learning.net/media/pdf/2002_ICL_Paper.pdf

Wolf, C. (2003). iWeaver: Towards 'Learning Style'-based E-learning in Computer Science Education. In T. Greening & R. Lister (Eds.), *Conferences in Research and Practice in Information Technology* (Vol. 20, pp. 273-279). Adelaide, Australia: Australian Computer Society.

http://www.adaptive-learning.net/media/pdf/2003_ACE_Paper.pdf

Table of Contents

List of Tables

List of Figures

Abstract

This study attempted to combine the benefits of multimedia learning, adaptive interfaces, and learning style theory by constructing a novel e-learning environment. The environment was designed to accommodate individual learning styles while students progressed through an introductory course on computer programming.

The accommodation of learning styles with different forms of instruction has been shown to improve learning gain and learner attitudes in several classroom-based studies. In a classroom environment, one instructor usually teaches many learners simultaneously and as such, individualised instruction can be tedious and time-consuming. In comparison, an e-learning environment can respond to every learner and his or her needs individually with a timely and precise adaptation of learning materials.

Despite these benefits and a growing worldwide e-learning market, there is a paucity of guidance on how to effectively accommodate learning styles in an online environment. Several existing learning-style adaptive environments base their behaviour on an initial assessment of the learner's profile, which is then assumed to remain stable. Consequently, these environments rarely offer the learner choices between different versions of content. However, these choices could cater for flexible learning styles, promote cognitive flexibility and increase learner control.

The first research question underlying the project asked how learning styles could be accommodated in an adaptive e-learning environment. The second question asked whether a dynamically adaptive environment that provides the learner with a choice of media experiences is more beneficial than a statically adapted environment.

To answer these questions, an adaptive e-learning environment named "iWeaver" was created and experimentally evaluated. iWeaver was based on an introductory course in Java programming and offered learning content as style-specific media experiences, assisted by additional learning tools. These experiences and tools were based on the perceptual and information processing dimension of an adapted version of the Dunn and Dunn learning styles model.

An experimental evaluation of iWeaver was conducted with 63 multimedia students. The analysis investigated the effect of having a choice of multiple media experiences (compared to having just one static media experience) on learning gain, enjoyment, perceived progress, and motivation. In addition to these quantitative measurements, learners provided qualitative feedback at the end of each lesson.

Data from 27 participants were sufficiently complete to be analysed. The initial analysis revealed no significant differences between the two conditions. However, a small negative effect on learning gain was observed for the choice condition. To further investigate this unexpected effect, participants were divided into two groups of high and low interest in programming and Java, then into two groups of high and low experience with computers and the Internet. Both group comparisons revealed statistically significant differences for the effect of choice. Having a choice of media experiences proved beneficial for learners with low experience but detrimental for learners with high experience or interest. An analysis of the contextualised qualitative feedback from participants moderately supported the quantitative findings.

These findings suggest that the relationship between media choice and the dependent variables is not as trivial as equating more choice with a comprehensive benefit for the learner. Conversely, the effect of choice appears to be strongly influenced by the learner's background. Thus, it seems only worthwhile to provide low experience learners with a choice of media experiences. It is hypothesised that encouraging a more active learner role in educational systems would expand the positive influence of choice to a wider range of learners.

The study has contributed some weight to the argument that for certain groups of learners, it is constructive to view learning style as a flexible, rather than a stable construct. As a practical implication, it seems advisable to collect data on prior experience, interest, as well as the initial learning style distribution of the target audience before developing environments comparable to iWeaver.

1 INTRODUCTION

1.1 Overview

This chapter provides the context and motivation of this study. It starts with a definition of key terms, which include e-learning, learning style, multimedia and adaptive educational hypermedia. Next, the motivation of this project is presented, subdivided into five interrelated aspects. Main motivational aspects include that individualised approaches are still uncommon in e-learning environments and that several existing environments view style as a static, rather than a dynamic construct. The resulting research questions were investigated by creating and experimentally evaluating an adaptive e-learning environment named “iWeaver”. This chapter concludes with a summary of the contributions, scope and limitations of this study and an outline of the structure of this exegesis.

1.2 Components of this PhD

In accordance with RMIT University guidelines (RMIT University, 2002), the outcome of this project consisted of two parts. The first part is the exegesis, this document, which describes the purpose, context and theoretical background of the project as well as the process of knowledge production. In essence, the exegesis answers the question of how the project has been developed and what has been achieved. Secondly, the submission guidelines request an observable and durable record of the completed project. This durable record is represented by the DVD that accompanies this exegesis. The DVD contains the iWeaver environment, including the source code, all media materials and instructions on how to install and run iWeaver. To demonstrate the features of iWeaver in an easily accessible format, the DVD contains several sample learning sequences as movies (animated “screen captures” or “screen cams”) in Macromedia Flash format.

1.3 Definition of Terms

In order to establish a firm conceptual framework for this exegesis, several key terms that had varying connotations in the reviewed literature needed to be defined.

Broadband

Broadband is defined as an always-on Internet connection with a minimum of 256 Kilobits per second (Kbps) downstream bandwidth and 64 Kbps upstream bandwidth. This represents the most basic ADSL connection available in Australia at the time of writing (Whirlpool Broadband Multimedia, 2003).

E-learning

The term “e-learning” was defined in alignment with a definition by Rosenberg (2001). According to Rosenberg, the first and most important feature of e-learning is that it takes place in a networked environment. This means that the computer of the learner is in constant communication with a central server. A second important feature is that e-learning materials are accessible via an Internet browser on a personal computer.

Learning Style

The term “learning style” is used as an umbrella term for the perceptual and the information processing dimension (see next definition). Following the restriction of the term to these two dimensions, a definition by James and Blank (1993, p. 47) was adopted. These authors defined learning style as “the complex manner in which, and the conditions under which, learners most efficiently and most effectively perceive, process, store and recall what they are attempting to learn”.

The expression “learning preference” is used synonymously with “learning style” in this document, because a preference implies more flexible characteristics. This is in line with the assumption, discussed later, that any person’s learning style may fluctuate, depending on the context of a particular task or topic.

Perceptual and Information Processing Dimension

For reasons outlined in the subchapter on learning style theories, this study only focused on the perceptual and psychological dimensions of an adapted version of the Dunn and Dunn model by Rundle and Dunn (2000). To avoid confusion with other psychological constructs, the psychological dimension of this model is referred to as “information processing dimension” in this exegesis. This dimension covers different ways in which people process information and solve problems. It consists of two dichotomous element pairs: global-analytic and impulsive-reflective. According to Rundle and Dunn, global learners prefer to get the big picture first and details later. In comparison, analytic learners prefer to process information sequentially: details first, working towards the big picture. Impulsive learners prefer to try out new material immediately, whereas reflective learners prefer to take time to think about a problem. The perceptual dimension refers to different ways people perceive information with their senses. It consists of several sub-elements, including a preference for visual text, visual pictures, tactile-kinaesthetic and auditory materials.

Multimedia

Multimedia is defined on a semiotic level, which refers to different signs and signals, as suggested by Schnotz and Lowe (2003). Therefore, the multimedia materials in this project encompassed different representational formats including texts, pictures, and sounds. In addition, some materials were interactive.

Interactivity

Interactivity refers to the capability of a computer environment to respond to user activity by providing feedback. As a result, an ongoing “learning dialogue” is established, which has been regarded as beneficial for learning (Gao & Lehman, 2003; O'Neil, 2003, p. 120).

Adaptive Educational Hypermedia

Hypermedia refers to a software system in which various media (e.g., textual, graphical, and/or auditory materials) are linked or presented together and the user can jump between materials. According to Brusilovsky (1996, p. 88), adaptive hypermedia environments are “all hypertext and hypermedia systems which reflect some features of the user in the user model and apply this model to adapt various visible aspects of the system to the user”. The term “adaptive educational hypermedia”, as used in this exegesis, extends the definition by restricting it to systems that facilitate learning. It follows that the model that reflects certain features of the user in the memory of a computer is referred to as the “learner model”.

1.4 Motivation

The argument for building a learning-style adaptive environment such as iWeaver can be subdivided into five aspects:

1. Available bandwidth and connectivity increase, which expands the possibilities of using multimedia materials for e-learning.
2. E-learning is a growing worldwide market, which warrants research on increasing its effectiveness.
3. Adaptive systems can be more efficient, more effective, and/or more user-friendly compared to their non-adaptive counterparts.
4. Adaptive learning approaches have been applied successfully in classroom-based environments, yet such approaches are rare in e-learning environments and possible learner models are subject to much discussion.
5. A potential deficit of most existing learning-style adaptive environments is that they base their learner model on the view that style is a static, rather than a dynamic construct.

These five aspects are elaborated in more detail in the following sections.

1.4.1 Broadband as Facilitator for Media-Rich E-learning

Research suggests that the use of multimedia benefits learning (Paivio, 1986; Mayer, 2001; Vekiri, 2002). In comparison to a single medium, such as text, multimedia materials require more data to be transmitted over a network. In order to accommodate these increased transmission demands and to reduce waiting times for the learner, more bandwidth is required. Therefore, broadband Internet is a facilitator for media-rich e-learning.

An increasing percentage of the Australian population has access to broadband services. According to a report from the Australian Competition and Consumer Commission (ACCC, 2006), the number of broadband subscribers in Australia is steadily increasing. For example, the number of subscribers rose by almost 80% between March 2005 (1.8 million) and March 2006 (3.2 million). Additionally, a growing number of wireless hotspots are available in densely populated inner city suburbs (Maslog-Levis, 2005). In its summary statement, an Ericsson survey (2004) considered the Australian Internet segment as a mature market with high consumer interest, making it a perfect launching pad for media-rich e-learning applications.

1.4.2 Growth of E-learning

As Kay (2001, p. 114) succinctly stated, “there is a general and strong perception that the world is changing quickly.” Rapid change brings with it the need for rapid adjustment and thus the need for life-long learning. E-learning can cater for this need by providing flexibility and just-in-time access to instructional content (Rogers, 2001).

A German study (Bentlage, 2000) predicted that by 2005 every second student would study at a virtual university. Although these predictions were put into perspective by a worldwide downturn in the IT-industry during 2000 and 2001 (OECD, 2002), forecasts from market research companies for the global development of the e-learning market remained optimistic. For example, the International Data Corporation (IDC) (P. Harris, 2003) projected that the worldwide corporate e-learning market would increase from US$6.6 billion in 2002 to US$23.7 billion in 2006. When contemplating these figures, one should bear in mind that the definitions of e-learning vary between reports. Nevertheless, there remains the impression of a large potential for growth in the e-learning market.

In accordance with the global trend, e-learning is also a growing market in Australia. In a specific report on the Asia-Pacific region, IDC projected a volume of US$233 million for the corporate e-learning market for 2005, with a continuing growth of 25% per year (Lim, 2001). The study “Universities online” (Bell, Bush, Nicholson, O’Brien, & Tran, 2002), conducted for the Commonwealth Department of Education, Science and Training (DEST) found that e-learning was widely employed at Australian universities with 54% of the courses containing already some type of web component. As a major trend for Australian universities, the study anticipated that “all university students in future will need to use the Internet as a regular part of their university studies” (p. 30). Exemplifying this trend, RMIT University in Melbourne recently established a “minimum online presence” project (RMIT University, 2006b, p. 7), which aims to achieve an online presence for all RMIT courses by the first semester in 2007.

Despite the growth in the market, the quality of many e-learning environments is still lacking. For example, a web-based survey conducted amongst European training professionals (Massy, 2002) showed that 61% of the respondents rated the overall quality of e-learning courses as “fair” or “poor”. In contrast, only 6% of the courses received the rating “good” or “excellent”. These results suggest that the growing e-learning market is in need of a more solid research base in order to justify development decisions and expenditure to improve e-learning solutions.

1.4.3 Benefits of Adaptivity

Adaptive systems can be more efficient, more effective, and/or more user-friendly compared to their non-adaptive counterparts. For example, adaptive traffic control systems that considered traffic density to dynamically adjust traffic light cycles outperformed static systems (Eghtedari, 2005). In the home entertainment sector, digital video recorders attempt to predict viewing preferences of their owners and record programs of potential interest to them (Zaslow, 2002). Due to the perceived benefits of adaptivity, there is a large trend towards personalisation technologies that adapt to user needs. For this reason, the market research firm Datamonitor predicted that worldwide investments in personalisation technologies would quadruple from US$0.5 billion in 2001 to US$2.1 billion in 2006 (DMReview, 2001).

1.4.4 Adaptive Learning Approaches

This project was based on the assumption that some forms of instruction are more effective for learners with compatible characteristics than for learners with non-compatible characteristics (Cronbach & Snow, 1977; Snow, 1989). Several learner characteristics have been considered as a basis for adapting instructional material, including prior knowledge, instructional goals, experience, and layout preferences (Brusilovsky, 2000).

This study focussed on learning styles, which were (under the name of “cognitive preferences”) part of a proposed standard for learner models (IEEE, 2000). The accommodation of learning styles has been shown to improve learning gain and learner attitudes in several classroom-based studies (Felder & Silverman, 1988; McCarthy, 1990; Riding, 2000; Lefkowitz, 2001; O'Hare, 2004). In a classroom environment, one instructor usually teaches many learners simultaneously and as such, individualised instruction can be tedious and time-consuming. In comparison, an e-learning environment can respond to every learner and his or her needs individually with a timely and precise adaptation of learning materials. However, there is limited research on how to effectively adapt to learning styles in an e-learning environment and a “one size fits all” mentality is still prevalent in many environments. This was illustrated by Mioduser, Nachmias, Lahav, and

Oren (2000), who found after an analysis of 436 educational websites, that very few sites used a learner model and adapted to learners.

One of the first researchers who put forward the idea of individualised computer-based learning was Koumi (1994). He advocated the development of “multi-media intelligent tutoring systems” (p. 54), in which the computer offers individualised control and interactivity, whilst adapting to the learner’s individual needs. More recently, Kemnitz (2003) acknowledged in a report on the LearnTEC conference the need to “tailor the content and context of the learning programmes to the specific needs of the users” (p. 2). Kemnitz also noted that the focus of the LearnTEC shifted in the last years from new technologies towards “the individual as learner and user” (p. 2). Similarly, Greenagel (2002) concurred that tailoring content is one of the key issues that need to be addressed by the e-learning industry in the near future:

> Educational technology has long been seen as promising, but has rarely lived up to the promises. Not because it was not effective, but because it was cumbersome, boring, and did not adapt to the way people wanted to learn. The e-learning industry is in danger of repeating that cycle. (Outlook section, ¶ 2).

There has been some research in building learning-style adaptive environments (e.g., Carver, Richard, & Edward, 1996; Corso et al., 2001; Martinez, 2001; Gilbert & Han, 2002; Kelly & Tangney, 2005). These environments usually generate a model of the learner and correspondingly adapt the navigation and/or content of the environment (Brusilovsky, 1996). However, which parameters should be considered in a learner model and how these parameters can be reliably measured, is still subject to much discussion (Kono, Ikeda, & Mizoguchi, 1994, p. 375).

Exemplifying this problem is contradictory evidence as to whether it is better to match or to mismatch learner preferences. Several studies found matching to be more beneficial (Hodges & Evans, 1983; Martini, 1986; Riding & Douglas, 1993; Butler & Mautz, 1996; A. V. Roberts et al., 2000), whereas other studies found mismatching to be more beneficial (E. McKay, 2000; Dekeyser, 2001; Kelly & Tangney, 2004). This debate is investigated in more detail in the subchapter on learning style theories.

1.4.5 Dynamic Adaptation and Choice

A possible middle-ground to resolve the debate around matching or mismatching could be to offer the learner a choice between matched and mismatched materials. Choice is potentially beneficial, because it empowers learners by giving them control (J. Kay, 2001) and it promotes cognitive flexibility (Spiro, Feltovich, Jacobson, & Coulson, 1992). Nevertheless, with the exception of EDUCE (Kelly, 2005), the impact of choice has not been evaluated in the context of learning-style adaptive e-learning environments.

Even though all learning style models claim to emphasise individuality, most models still stereotype learners (Coffield, Moseley, Hall, & Ecclestone, 2004; Revell, 2005). As a result, several adaptive environments had one single "matching point", usually before the learner entered the environment. This single matching point was believed to be sufficient for an adaptation (e.g., Carver et al., 1996; Laroussi, 2001; Bajraktarevic & Fullick, 2003).

However, there is a trend in the learning style literature to regard learning style as a flexible, rather than a static construct. A recent critical review of learning style models (Coffield et al., 2004) argued that an approach that considers a mixture of influences on style "will prove more fruitful in organisational psychology, education and training than the many existing commercial applications which rely on theories of fixed personality traits" (p. 58). Similarly, Kolb (1984) hypothesised that "styles are not fixed *traits* but stable *states*. … [They are] enduring patterns of human individuality [that] arise from consistent patterns of transaction between the individual and his or her environment" (p. 63, emphasis in original).

This project also viewed learning style as a flexible construct and investigated whether there is a benefit for learning by offering the learner choices and dynamically adapting the learner model on a continual basis.

1.5 Research Objectives

The main goal of this research was to construct and evaluate an e-learning environment, which adapts itself to individual learners. However, during the progression of the literature review, the focus shifted from the matching/mismatching approach to the potential benefits of choice for the learning process. When this project began, no learning-style adaptive environment could be located in the literature that provided learners with a choice of media experiences *and* adapted itself in a continuous fashion. Therefore, the iWeaver learning environment constructed in this project was regarded as an important contribution to educational research. By the completion of this work, Kelly (2005) had investigated the impact of choice under similar conditions in his thesis on the adaptive environment EDUCE. Apart from EDCUE, no other empirical studies could be located that examined the effect of media choice in a learning-style adaptive environment.

In order to carry out this project, two main research questions needed to be answered. The first question concerned the design and technical development of a learning-style adaptive environment, including the rationales for decisions. The second question concerned the effect of choice and whether a dynamically adaptive version of the environment constituted an improvement compared to a statically adapted version.

1. **In what ways can an e-learning environment adapt itself to accommodate individual learning styles?**

To answer this question, it was helpful to divide it into smaller components. Firstly, a decision on a suitable learning style theory needed to be made. Then, a framework for the effective adaptation to styles had to be developed. This framework dictated which media experiences and learning tools can accommodate which styles. Next, it had to be decided which learner behaviour was considered in the adaptation algorithm and which components of the environment were adapted. Finally, the environment needed to be conceptualised, designed and built. This process included the technical programming, the instructional design of the materials, as well as the production of multiple style-specific media experiences and learning tools.

In order to answer the first research question, an adaptive e-learning environment named "iWeaver" was created. iWeaver was based on the first two modules of a computer programming course with the title "An Introduction to Java".

2. **Is it more beneficial for participants to learn with a choice of media experiences, or to learn with only one media experience, matched for their most-preferred learning style?**

To answer this question, the iWeaver environment was experimentally evaluated with 63 multimedia students. Participants were randomly allocated to choice and no choice conditions and crossed over between conditions after each lesson. Benefit was measured objectively by assessing learning gain with pre- and post-tests and subjectively by asking participants about their perceived enjoyment, progress, and motivation on six-point Likert scales. In addition to these quantitative measurements, learners could provide qualitative feedback at the end of each lesson. It was expected that giving learners a choice of media experiences would have a positive effect on all four dependent variables and that this effect would also be prevalent in the qualitative feedback. To test this expectation, data were analysed statistically and qualitatively for differences between the conditions. Following, it was discussed whether the results warrant further investigation of the flexible e-learning approach proposed in this study.

1.5.1 Contributions

The most significant contributions of this study are:

- a theoretical matching framework for perceptual and information processing preferences based on findings of previous studies;
- an application of the matching framework in a prototype environment that consists of custom-designed media experiences and learning tools;
- a substantiated proposal to view learning style as a context-dependent and flexible construct, rather than a stable construct;
- an innovative, dynamic adaptation approach that takes style flexibility into account and provides guided recommendations; and
- the results of an experimental evaluation of the effect of media choice.

These contributions are expected to be of value to researchers and practitioners in the fields of learning styles, adaptive educational hypermedia and multimedia learning. Researchers can take these contributions as a starting point for future projects and practitioners are welcome to use the theoretical framework, as well as the actual iWeaver environment in their curriculum.

1.5.2 Scope and Limitations

There are some limitations to the generalisability of the results of this project. Firstly, the main focus of this project is on just two out of six dimensions of an adapted version of the Dunn and Dunn learning styles model (Rundle & Dunn, 2000). Although iWeaver offered tools and experiences for both dimensions, the adaptive behaviour was limited to the perceptual dimension. As mentioned before, there is an inestimable number of facets to every person's individuality and every learner model is essentially hypothetical (Kono et al., 1994). Therefore, the reader should be aware that there are numerous other dimensions of individual differences that have not been considered in this project, even though they may potentially be important. Similarly, while the importance of computer supported collaborative learning is acknowledged (e.g., McConnell, 2000), an investigation of the benefit of social interaction between learners was not part of this enquiry.

The adaptations that were offered to learners with different styles were limited to the constraints of a computer environment. For example, tactile-kinaesthetic learners were merely offered increased interactivity levels with input devices (e.g., mouse and keyboard), rather than involving their whole body.

iWeaver was teaching basic principles of computer programming using the Java programming language. Within this domain, the learning materials chiefly focused on technical and scholastic knowledge (ASCD, 1999, as cited in Seaton, 2002). Other types of knowledge, for example the ability to identify and solve complex programming problems, most likely require different learning materials, tools and matching approaches.

1.6 Exegesis Outline

In the development of an adaptive environment such as iWeaver, several core issues needed to be addressed and decisions needed to be justified. This exegesis represents the documentation of these issues, the decisions and the project outcome.

Chapter 2 outlines the background of the project by reviewing the literature regarding its five theoretical corner stones: (1) individualisation tendencies in learning paradigms, (2) multimedia learning, (3) e-learning, (4) learning style theories, and (5) adaptive educational hypermedia. The findings in these areas are used to develop a framework for the adaptation of perceptual and information processing preferences in an e-learning environment. Furthermore, existing adaptive environments similar to iWeaver are reviewed and it is explained how iWeaver differs from previous research and fills a research gap in this field.

Chapter 3 describes the methods of the project. The outcome of this chapter was the final prototype of iWeaver, which is considered as an answer to the first research question. First, didactical issues of the learning materials are discussed and the interface design is explained. Then, the low-level design of the environment is discussed by describing its architecture, the learner model, the content model and its adaptive behaviour. Next, the production of media experiences and learning tools is outlined, including the issues that were encountered in the production period and how they were resolved. Following, software and hardware requirements are described. The chapter continues with an explanation of the experimental design, which includes a description of the data collection instruments, the pilot tests and the evaluation procedure. The chapter ends with a report of the actual evaluation and a description of the statistical data analysis.

Chapter 4 presents the results of the experimental evaluation in an initial and an exploratory analysis approach. As such, this chapter provides an answer to the second research question on the effect of media choice. A description and discussion of the quantitative and qualitative data is provided.

Finally, chapter 5 summarises the conclusions of this project, lists its contributions, implications and suggests directions for future research.

As a convention for this exegesis, the first hierarchy level of content is referred to as "chapter", the second level as "subchapter" and the third level as "section". Whenever practical, cross-references between chapters are hyperlinked, which is indicated by the keywords "see section". Cross-references to figures, tables, and different sections can be clicked and followed in the pdf version of this document. To pre-empt a confusion between exegesis chapters and the learning content chapters of iWeaver, the latter are referred to as "lessons", which contradicts the naming in some screenshots.

2 BACKGROUND

2.1 Introduction

This chapter documents the literature review that was carried out to inform the design of the iWeaver learning environment. It establishes the theoretical framework of the project and places it in the context of the existing body of literature. Further, it provides a structured overview of the background research that was used to answer the research question on how an e-learning environment can adapt itself to accommodate individual learning styles. The literature review gave rise to the second research question, which asked, if the static adaptation approach of existing learning-style adaptive environments can be improved by introducing the aspect of choice.

This chapter is divided into five subchapters, each representing one of the five main areas of investigation, namely: learning paradigms, multimedia learning, e-learning, learning style theories and adaptive educational hypermedia.

The subchapter on *individualisation tendencies in learning paradigms* outlines the psychological foundations of this project and how dominant learning paradigms were harnessed to advocate the individualised learning approach of this environment.

The *multimedia learning* subchapter focuses on information processing theories and multimedia design principles as proposed by Mayer’s cognitive theory of multimedia learning (2001).

Next, the *e-learning* subchapter justifies why e-learning was chosen as a platform to implement an environment based on learning styles. In addition, the implications of the “no significant difference” phenomenon for this project are discussed.

Then, the subchapter on *learning style theories* examines the controversial and diverse field of learning style theories. The most influential theories are outlined and the approach taken for this project is justified. Furthermore, previous studies that demonstrate the interaction between multiple media and learning styles are reviewed.

Finally, the *adaptive educational hypermedia* subchapter summarises prior research findings in this field, which were integrated in this project. Existing environments which adapt to learning styles are reviewed and it described how iWeaver differs from previous research and fills a research gap in this field. In doing so, this subchapter investigates some deficits of existing environments and makes suggestions on how they can be addressed.

2.2 Individualisation Tendencies in Learning Paradigms

This subchapter of the literature review outlines the psychological foundations for the iWeaver learning environment. The three dominant learning paradigms: constructivism, cognitivism and behaviourism are analysed to advocate the individualised approach of the iWeaver learning environment. The review begins with a definition of “learning” and proceeds to summarise how the aforementioned learning paradigms influenced the design of the iWeaver learning environment.

2.2.1 A Definition of Learning

Learning is often defined as a potential change in behaviour that results from experience (Learning, 2000, 2004). This definition is of great significance for this project. Following this definition, it can be emphasised that experience is unique to each individual. This uniqueness is particularly acknowledged in constructivism, which holds that learners dynamically construct and reconstruct their knowledge based on their pre-existing knowledge and new experiences. A more detailed examination of constructivist principles follows towards the end of this subchapter. First, the influences of the behaviourist and cognitivist paradigms on this project are outlined. Whilst this study is positioned within a cross-section of the cognitivist and constructivist learning paradigms, some useful perspectives on an improved learning process emphasised in behaviourism (mostly from the programmed instruction approach) are also acknowledged.

This subchapter should be read with the type of knowledge in mind that was mediated by the learning content, the learning experiences and the learning tools of the iWeaver environment. According to the knowledge model suggested by the Association for Supervision and Curriculum Development (ASCD, 1999, as cited in Seaton, 2002), there are four levels of knowledge: surface knowledge, technical or scholastic knowledge, felt meaning and deep meaning. It is noteworthy that the type of content taught by iWeaver and much of the substance and implications of this research project, are limited to the technical/scholastic knowledge level.

2.2.2 Behaviourist Influences

Early behaviourist approaches treated every learner as equal. Lefrançois (2000) qualified this statement by explaining that most behaviourist theories subscribed to the Lockean "tabula rasa" doctrine. This doctrine assumes that the brain is an empty vessel, waiting to be filled with knowledge. As examples, Lefrançois listed Pavlov's classical conditioning theory as well as Thorndike's laws of exercise, effect and readiness.

As its name suggests, behaviourism focused on the study of observable behaviour and outcomes. Researchers were guided by the belief that the optimal learning outcome was achieved when correct responses were reinforced by positive feedback and wrong or unwanted responses resulted in further learning requirements. Learning was generally regarded as a process of stimulus, response, and reinforcement (Skinner, 1969). Consequently, learning was thought to be *reactive* behaviour, with little or no differentiation between individual learners. Learners were regarded as passive and had no influence on the way in which their learning environment was created or manipulated. This view was prominently expressed in a famous quote by the founder of American behaviourism, John Watson:

> Give me a dozen healthy infants well-formed, and my own specified world to bring them up in and I'll guarantee to take any one at random and train him to become any type of specialist I might select—doctor, lawyer, artist, merchant-chief and yes, beggar man and thief, regardless of his talents, penchants, tendencies, abilities, vocations, and race of his ancestors. (1930, p. 104 as cited in Lefrançois, 2000, p. 46)

However, the original stimulus-response model of behaviourism is rather narrow. It is now widely acknowledged that stimulus and response are mediated by an internal reference standard, an aim, purpose, or desired perception (Glasersfeld, 1995; Seaton, 2005). Nevertheless, instructional strategies that were emphasised in behaviourism are still employed today for certain teaching approaches, most saliently for materials that require the acquisition of complex muscle movements. For example, most touch-typing programs use a drill-and-practice approach to learning.

An important observation made in early behaviourist experiments, was the positive influence of rich and interactive environments on the learning process. Watson (1972) described an experiment where three groups of toddlers had different kinds of mobiles installed over their beds: Group A had normal mobiles, which stood still; Group B had mobiles which were moved by a motor in periodic intervals and unrelated to the toddlers' head movements; Group C had pillow-activated mobiles, which translated the head movements of the toddlers into movements of the mobile. The result was that the toddlers in Group C were significantly more lively and active during the day playing with their mobiles, had more frequent happy expressions on their faces (smiling) and they also uttered more sounds (cooing) to express their well-being and amusement.

A major conclusion that can be drawn from the results of this experiment is that parents should provide their children with rich and interactive environments to facilitate learning. This conclusion can be extended to the relationship between the learning environment and the learner: interactive and media-rich learning environments have resulted in superior learning outcomes, compared to less interactive versions (Mayer, 2001; Gao & Lehman, 2003). Hence the integration of interactivity and multimedia played an important role in the development of iWeaver.

It is important to note, that some behaviourist principles are compatible with the succeeding paradigm, cognitivism, and that these principles are still applied in contemporary instructional design. Most notable were principles established in the programmed instruction approach (H. Kay, Dodd, & Sime, 1968). These were summarised by Kentridge (n.d.) as:

- Clearly stated educational objectives, which are the expected, demonstrable outcome of learning.
- Chunking of learning materials into small, testable frames (which is incidentally also a cognitive strategy to support short-term memory (Matlin, 2002)).
- Self-paced learning.
- Immediate feedback to the learner's responses to questions that are integrated into the instructional materials.

Due to the increased focus of these design characteristics on the individual learner, programmed instruction can be regarded as one of the first steps from a content-centred approach to instruction towards a learner-centred approach. As the paradigm shift towards cognitivism became more pronounced, so did the need for an instructional approach that took individual differences into account.

2.2.3 Cognitivist Influences

Cognitivism is a learning paradigm that is based on theories of cognition. Cognition is frequently defined as the process of "acquisition, storage, transformation and use of knowledge" (Matlin, 2002, p. 2). The Bibliotheca Britannica defines cognition as "every mental process that may be described as an experience of knowing (including perceiving, recognizing, conceiving, and reasoning)" (Cognition, 2004). In summary, cognitivism revolves around two main areas of investigation: perception and information processing. Due to the cognitivist-influenced view of learning of this project, these two areas of investigation were an essential criterion for the inclusion of a learning style model with corresponding style dimensions.

In the middle of the 20th century, there was a gradual shift from a behavioural to a mainly cognitive learning paradigm (West, Farmer, & Wolff, 1991). The reason for this shift was that many theorists were unsatisfied with the mechanistic view of behaviourism. It was difficult, if not impossible to explain complex human behaviour with behaviourist concepts alone. For example, the acclaimed linguist Chomsky (1972) highlighted the incompatibility between a behaviourist approach and language acquisition. In addition, the results of experiments undertaken decades earlier by Tolman and Honzik (1930) already showed that behaviour was purposeful and not just the result of a mindless stimulus-response connection: when the shortest (conditioned) path to food was blocked, rats consistently chose the second shortest path, even though this path had not been conditioned. These results led the researchers to hypothesise the existence of cognitive maps or mental representations of the environment.

Cognitivism led to the establishment of cognitive strategies, with the aim to improve the learning process. Cognitive strategies are tools or mental methodologies that can help learners to remember information, develop schemata and refine their problem solving abilities. A selection of these strategies, including advance organisers (Ausubel, 1968, p. 148), chunking and multimodal approaches (Matlin, 2002, p. 173), were incorporated into iWeaver. These strategies are described in more detail in the method chapter (section 3.2, p. 93). To avoid confusion between strategy and style, the subchapter on learning style theories in this literature review defines learning strategies as conscious approaches to new materials and learning style as an unconscious predilection to use one strategy over another.

Cognition implies the existence of metacognition, which is an awareness of one's own cognitive processes. This awareness can help learners to monitor and fine-tune their approaches to studying (Hacker, 1998) and as a result, the process of learning can become more effective and efficient. By extrapolation, it can be postulated that the mere knowledge of one's learning style and associated strategies can have a positive impact on one's overall learning experience.

In contrast to behaviourism, the cognitive approach focuses on the learning process and how knowledge is internally represented by the brain. These internal representations are referred to as "schemata". Schemata can be seen as mental models, scripts or pictures. They represent our generalised knowledge about objects, events or situations. An often quoted study that corroborated the existence of schemata was conducted by Brewer and Treyens (1981). The experimenters asked participants to wait in an alleged office for 35 seconds. Afterwards, each participant was given a surprise test in which they had to remember any objects they had seen in the room. The results showed that participants were highly likely to remember objects associated with the "office schema", for example a desk, a chair, a model of a brain and a skinner box. However, few remembered the existence of the wine bottle or the picnic basket. Surprisingly, some participants remembered objects that fitted the office schema, but were not actually present in the office. Examples for these inferred objects were books, pens and a coffee cup.

An important contribution to schema theory was made by the Swiss psychologist Piaget, who claimed that learning and development are driven by equilibration. Equilibration is the process of elimination perturbations (cognitive dissonance) between experiences and existing cognitive structures, which encompasses two approaches: assimilation and accommodation (Wadsworth, 1989). Assimilation occurs when learners fit their impression of an experience into an existing cognitive structure: new facts and more details are added to an existing schema. Contrarily, accommodation occurs if it is impossible to reconcile a new experience or insight with an existing cognitive structure. The mind then conforms to the demands of the environment and changes the existing schema or generates a new schema. The result is the acquisition of a new and previously unknown concept.

According to Piaget, a balance between assimilation and accommodation is required. If a learner solely assimilates, there is little new learning. On the other hand, if a learner is required to accommodate frequently, learning can become chaotic. One of the implications of Piaget's work for instructional design in general (and for this project in particular) is that the learning materials should provide "optimal difficulty" (Lefrançois, 2000, p. 229).

Piaget emphasised the concepts of assimilation and accommodation, which means learners constantly reconstruct their understanding of the world. As a result of these close parallels between Piaget's concepts and constructivism, he is sometimes credited (e.g., Lefrançois, 2000) as one of the bridging figures between cognitivism and constructivism.

2.2.4 Constructivist Influences

The last of the three learning paradigms discussed in this subchapter is constructivism. Constructivism is often described as an extension or branch of cognitivism with a more specific focus. The central idea is that learning is an active process in which every learner constructs his or her own individual perspective of the world, depending on prior experiences and pre-existing schemata (Bruner, 1968).

An important thinker and early contributor to constructivist literature was the American philosopher John Dewey, who articulated many of the key ideas of constructivism. For example, Dewey (1963/1972) emphasised that knowledge is built upon prior experiences and concluded that learners should be active participants in their learning environment. Dewey's work highlighted the "unique and individual nature of interaction in the learning experience" (Boettcher & Conrad, 1999, p. 21) and was one of the fundamental philosophies taken into account in the design of the iWeaver learning environment.

Cognitive flexibility theory (Spiro et al., 1992) (CFT) is a further prominent theory within the constructivist approach that was harnessed to inform the design of this project. CFT is particularly relevant to the design of learning materials in ill-structured knowledge domains. Ill-structured knowledge domains are characterised by a high interrelation between concepts, making it difficult to teach individual concepts separately. CFT holds that learners spontaneously structure and re-structure knowledge, depending on the demands of a situation. To facilitate this re-structuring process, CFT recommends presenting information from multiple perspectives.

As the domain of computer programming (the exemplary topic taught by iWeaver) is ill-structured, CFT was considered a worthwhile theory to investigate and subsequently use. The CFT idea of presenting information from multiple perspectives was implemented in iWeaver by offering learners different media experiences for the same learning materials.

Consequently, it can be argued that in addition to catering for different learning styles, iWeaver simultaneously had the potential to assist cognitive flexibility by offering multiple perspectives on new concepts.

Some theorists argued that differences in learning are associated with the different maturity levels of learners. A prominent figure in this area is Malcolm Knowles, who proposed the term "andragogy" (the original spelling was "androgogy") as the adult learning complement to "pedagogy" (Knowles, 1968). He formulated five basic assumptions of andragogy, which are consistent with the basic concepts of constructivism (Knowles & Associates, 1984, p. 12):

1. With maturity, a person becomes less dependent and more self-directed. Each person has an independent self-concept.
2. With maturity, a person accumulates a pool of life experiences that can be harnessed as a useful resource for learning.
3. With maturity, a person increasingly situates learning within the context of his or her changing social role.
4. With maturity, a person is increasingly inclined to immediately apply new knowledge. Hence a problem-based approach is useful.
5. With maturity, a person has an increasing internal motivation to learn.

These assumptions were taken into account wherever possible in the development of iWeaver. For example, the first assumption (self-directedness) was acknowledged by the adaptive nature of iWeaver: learners were given multiple opportunities to direct their learning. Furthermore, the third assumption (immediate application of knowledge) was applied in iWeaver's try-it tool. This tool gave learners the opportunity to apply a new concept immediately within the context of a small problem.

Knowles originally asserted that the assumptions of andragogy applied to adult learners only. However, some authors questioned the narrow scope of the theory (Merriam, 2001) and hypothesised that the assumptions apply independent of age. According to Merriam, anecdotal evidence suggested that in some cases the assumptions equally applied to children, whereas in other cases they did not apply to adult learners. For example, some children can be very self-directed and independent learners, whereas some adults need substantial teacher guidance. These observations can be regarded as further support for the existence of individual learning styles, independent of the learner's age and/or maturity levels. Furthermore these observations emphasise the need for continued research on individualisation possibilities in learning environments.

2.2.5 Summary

This subchapter defined learning as a potential change in behaviour that results from experience. This study was positioned within a cross-section of the cognitivist and constructivist learning paradigms, whilst acknowledging useful contributions of behaviourism (programmed instruction). It was noted that the type of knowledge that was mediated by the learning content of iWeaver is of technical/scholastic nature, which limits the generalisability of results.

The behaviourist paradigm treated every student as equal because the brain was regarded as a vessel that needed to be filled. Despite this mechanistic view of learning, behaviourism is still the precursor of valuable instructional design principles. For example, certain principles of the programmed instruction approach, including the stating of objectives and immediate feedback, are still used in contemporary instructional design as well as in this project.

The cognitivist paradigm had four important influences on this project. Firstly, in comparison to behaviourism, the focus shifted from content-centred instruction to learner-centred instruction. This development created the need to take individual differences into account. Secondly, cognitivism revolves around human perception and information processing models. These two areas were used to select a model with adequate learning style dimensions for this project. Thirdly, cognitivism led to the establishment of cognitive strategies, some of which were implemented in this project to facilitate learning. Lastly, the knowledge of one's learning style has a metacognitive effect on the learner, which has the potential to make the learning process more effective and efficient.

Finally, several ideas from the constructivist paradigm were drawn upon in this project. Most importantly, Dewey's insight that the learning process is of a "unique and individual nature" played a formative role in the development process. In addition, the cognitive flexibility theory was applied, which states that it is beneficial for the learning process to offer multiple perspectives on new concepts. Furthermore, Knowles' five assumptions underlying andragogy were taken into account wherever possible, for example by giving learners the opportunity to immediately apply new knowledge via a try-it tool.

2.3 Multimedia Learning

iWeaver used multimedia materials to address perceptual preferences. This subchapter examines the concept of multimedia and the interaction of multimedia materials with the learning process. A definition of the term "multimedia" is provided due to the wide range of interpretations available. Additionally, this subchapter reviews relevant cognitive psychology literature on multimedia learning effects.

2.3.1 A Definition of Multimedia

Although "multimedia" is a commonly and frequently used term, its connotation often varies. The meaning of the word often depends on the context and is therefore easily confused. For example the American Heritage Dictionary of the English Language (Multimedia, 2000) differentiated between three major contexts: (1) in education and entertainment, multimedia can be the "combined use of media, such as movies, music, lighting, CD-ROMs, and the Internet"; (2) in advertising or publicity, multimedia refers to "the combined use of media, such as television, radio, print, and the Internet"; and (3) in computer science, multimedia can mean "an application that can combine text, graphics, full-motion video, and sound into an integrated package".

Schnotz and Lowe (2003) offered a slightly different classification, which consists of three levels. Firstly, media can be seen at a *technical* level as the transporters of signals and symbols (e.g., computers, text books, speakers, and the Internet). Secondly, it can be seen at a *semiotic* level, which refers to different signs and signals, the form of different representational formats including texts, pictures, and sounds. Finally media can be defined on the level of *sensory modalities*, which are the input channels of the body (e.g., the visual, kinaesthetic or auditory modality).

Mayer (2001) defined multimedia also on a semiotic level as "the presentation of material using both words and pictures" (p. 2). He elaborated by adding that *words* encompass both written text and audio material and that *pictures* include static formats (illustrations, photos, graphs, diagrams, charts and maps) and dynamic formats (e.g., animations and videos).

A crucial characteristic of multimedia for the scope of this project was the existence of interactivity. Interactivity refers to the capability of the computer environment to respond to user activity by providing feedback. As a result, an ongoing “learning dialogue” is established, which has been regarded as beneficial for learning (O'Neil, 2003, p. 120).

For the scope of this project, multimedia was defined on a semiotic level (different representational formats) with the added criterion that interactivity must be available.

2.3.2 Information Processing Theories

A number of researchers compared multimedia learning arrangements with single-medium learning arrangements. Paivio, for example, found strong evidence supporting his dual coding theory (Paivio, 1986; J. M. Clark & Paivio, 1991). His theory signifies that the human brain works with (at least) two cognitive subsystems: the first is specialised on the processing of nonverbal objects (e.g., images and graphics) and the second is specialised on dealing with language. According to dual coding theory, instruction is more effective by presenting information in both visual and verbal form.

Sweller (1988) compared the problem solving approaches of experts and novices. Following the results of those experiments, he established a cognitive load theory (CLT), which describes the effect of the complexity of learning material on the act of learning. Cognitive load can be seen as the “mental energy” (Cooper, 1990) that is required to process and comprehend new information. The theory acknowledges that working memory is limited in the number of elements it can contain simultaneously.

Chandler and Sweller (1996) established further evidence for the existence of cognitive load and differentiated between *intrinsic* and *extraneous* (also called *ineffective* or *irrelevant*) load. Intrinsic load is the effect of the intellectual complexity of the learning materials, whereas extraneous load is the effect of the format in which the materials are presented. The higher the interactivity between learning concepts, the higher is the intrinsic load, because more learning concepts need to be perceived and processed concurrently. CLT states that intrinsic load can not be influenced, whereas extraneous load can be reduced through effective instructional design. Learning a new programming language (as required in iWeaver) can bear a high intrinsic load, because multiple new concepts interact with each other and need to be learned concurrently. Following CLT, this learning task required an effective instructional design. Therefore, the work that was carried out to carefully adapt learning materials to individual preferences seemed justified.

According to CLT, effective learning materials should keep the extraneous load for a novice learner at a relatively low level to facilitate the acquisition of new schemata. This can be achieved by avoiding two major sources for cognitive load: the split-attention effect and the redundancy effect (Chandler & Sweller, 1996; Leahy, Chandler, & Sweller, 2003). The split attention effect occurs if sources of related information (e.g., a diagram of a machine and the labels for its components) are presented far away rather than close to each other (examples in Cooper, 1990). The redundancy effect occurs if unnecessary “nice-to-have” information is contained in the learning materials. Both effects were further corroborated in the work of Mayer (2001).

Mayer (2001) integrated the theories of dual coding and cognitive load (which he referred to as “limited capacity”) as the first two assumptions to form a unified cognitive theory of multimedia learning. He also included a third assumption, that learners actively process the learning materials. This means a prerequisite of Mayer’s theory is that learners actively engage with the materials, which includes paying attention to features, creating links with prior knowledge and organising new information.

Mayer’s cognitive theory of multimedia learning was greatly based on his experimental results, which showed that particular combinations of media promoted learning whereas others had a detrimental effect. He summarised his findings in seven multimedia design principles, four of which were applied in the design of this project:

1. The *multimedia principle* states that students learn more deeply from a combination of words and pictures than from words alone.

2. The *spatial contiguity principle* specifies that words should be located near the corresponding pictures, rather than farther away from them.

3. The *redundancy principle* holds that students learn more deeply from animation and narrated text compared with animation, narrated text and additional written text. Again, an overload of the visual perception channel serves as the justification for this principle.

4. Finally, the *coherence principle* states that a detrimental effect on learning occurs if interesting but irrelevant words and pictures are added to the learning materials.

Mayer (2003) later added the *personalisation principle*. This principle was derived from experiments which showed that students learned better by hearing text in an informal, conversational style compared with a formal style.

Mayer’s principles have guided the choice of media and informed decisions on the combination of different media in this project. For example, the learning materials were designed to follow the coherence principle by excluding nice-to-have information. Additionally, spatial contiguity was a priority in the design of the visual learning materials.

One could argue that in accordance with Mayer’s principles, multimedia materials are equally beneficial for every learner. However, Mayer and Sims (1994) acknowledged the role of individual differences in an earlier paper. The researchers conducted two experiments in which computer-generated animations of the mechanics of a bicycle pump and the human respiratory system were shown simultaneous with narration or in succession of narration. The experiments were designed to investigate the interaction of spatial ability with the contiguity effect (students learn more deeply if visual and verbal materials are presented in a coordinated fashion, rather than separately). Results showed that the contiguity effect was strong for high spatial ability students, but weak for low-spatial ability students. Mayer and Sims explained this with cognitive load theory: students with low-spatial ability have to spend more cognitive effort on building visual representations of a system. Consequently, Mayer and Sims recommended that researchers further examine the role of individual differences in multimedia learning.

Mayer’s principles were later complemented by studies of other researchers with a focus on the instructional quality of the learning materials. Schnotz and Bannert (2003) conducted a detailed investigation of interactions between the *external* representations (e.g., text and pictures) and the *internal* representations (often referred to as “mental models”) of learners. They conducted an experiment where students had to solve a circumnavigation and a time zone task by using three different visual representations: (1) the earth projected on a two-dimensional rectangle (2) the earth as a circle diagram seen from the north pole and (3) a text-only description. They found that the multimedia principle (students learn better from a combination of words and pictures) was not applicable in general, but that it was in fact strongly affected by the task-appropriateness of the representation.

Findings by Lowe (2003) on learning with animations went in a similar direction. Lowe found that merely providing a learner with animated pictures does not promote learning per se. In more complex animations the central message was difficult to grasp for learners, especially on a novice level. Lowe concluded that the central message of an animation needs to be clearly depicted. The implication of these findings for instructional design is that animations should be simple and cover only one central idea at a time. The findings of Schnotz, Bannert and Lowe can be generalised to the assertion that the instructional quality, task-appropriateness and coherence of multimedia learning materials are of great importance for learning.

2.3.3 Multimedia as Multiple Representations

A number of researchers have applied the concept that different objects "afford" specific actions (Norman, 1990, p. 9) from the real-world to different media in the computer world. Concluding from a review of relevant studies, Alty (1991) proposed that certain media appeared to be more suitable for specific purposes than others. Alty noted that, for example, text appeared to be better suited to convey details, whereas graphical diagrams seemed more appropriate to convey ideas. Similarly, videos and animations seemed to be well-suited for procedural "action" information (see also Michas & Berry, 2000) and audio seemed more appropriate to stimulate imagination. Arens, Hovy, & Vossers (1993) expanded upon this classification. They proposed a two-stage generalisation of given information, which provided rules to match characteristics of the *information* with characteristics of the *media* on offer. Characteristics included the dimensionality, density, volume, and transience of information. For example, a map is a two-dimensional, dense medium, which corresponds with the properties of coordinate information. Additionally, the intrinsic semantic of a medium should be matched with the semantic of the information. For example, an ordered list is particularly suited to express an ordinal sequence, whilst a map is well-suited to display location information. The recommendations by the above authors were considered in decisions concerning media allocations for the iWeaver learning materials.

Offering multiple external representations (MERs) of the same learning material is often regarded as beneficial for the learning process. For example, the software "Where are We?" (Kastens, Kaplan, & Christine-Blick, 2001) teaches children how to read maps by offering them an abstract map and an interactive video representation of the real world simultaneously. In an evaluative study, children had to hunt treasures indicated on the map, add objects they found in the video representation to the map, and find their location on the map if they were "dropped" at a random position in the video representation. The authors reported that students were enthusiastic about the software. Subsequently, the students' transfer of skills was evaluated in a field lesson with reality-to-map and map-to-reality tasks. The project was regarded as highly successful by the researchers, because students' performance in the map-to-reality task improved significantly. However, the reality-to-map performance did not change significantly, which was attributed to inadequate test sensitivity.

One assumption that was derived from the literature was that multiple representations are potentially more effective, because they can address different learning styles (McCarthy, 1990; Koumi, 1994; Martinez & Bunderson, 2000). Ainsworth (1999) suggested that MERs have the potential to increase motivation because they can offer more variety. Furthermore, Ainsworth proposed that MERs can increase learning by promoting a deeper understanding because multiple viewpoints are presented, which can in turn facilitate abstraction. This assumption is compatible with cognitive flexibility theory (Spiro et al., 1992), which was discussed in the section "constructivist influences" in the last subchapter.

Despite these potential benefits of MERs, research on their effectiveness has so far produced mixed results (Ainsworth, 1999). Ainsworth looked for a possible reason for negative effects of MERs on learning and observed that learners had difficulties to translate between different representations (e.g., between a graphical and an algebraic representation). This means it was problematic for learners to see the relationship between the representations.

According to Ainsworth, these difficulties can be overcome by taking the specific functions MERs can have into account. She developed a functional taxonomy of MERs which distinguishes three major functions:

1. The first function is to *complement*, which means the representation provides new or enhanced information (e.g., if too much detail would clutter a map, it makes sense to divide the information into several different maps).

2. The second function is to *constrain* the interpretation of another unfamiliar representation (e.g., if a time/velocity graph tends to be misinterpreted, it helps to constrain its meaning by showing the actual moving object concurrently).
3. The third function is to *construct a deeper understanding* of a subject (e.g., perceptual variety helps to create a more adequate mental abstraction, which in turn is beneficial for the knowledge transfer).

Ainsworth suggested different approaches for handling problems with translations between multiple representations, depending on which of the three functions is applicable. For complementary functions, learners should be discouraged from translating. If translating can be difficult and it is not necessary, it should be avoided completely. If the function is constraining, translation should be automated. This can be achieved by a technique called "dyna-linking". When representations are dyna-linked, a manipulation in one representation has a simultaneous effect in another one. Dyna-linking has been shown to significantly reduce the translating effort (see Ainsworth, 1999). If dyna-linking is not applicable, because the representation does not afford interaction, Ainsworth recommended the use of clues. For example, matching format and operators (e.g., the modality, level of abstraction, labels and interfaces) can be beneficial.

In iWeaver, the learner could choose to visit a different representation of the same content. Possible reasons for this choice could be a change of preference or the need for further clarification. The new representation constrained the meaning of the representation visited earlier. Therefore, the likelihood of a misunderstanding was reduced by providing further clarification and an alternative viewpoint. Dyna-linking was used in several learning materials to visualise what happens concurrently in the program code, computer memory and on the screen.

2.3.4 Media Effect versus Multimedia Effect

One of the basic assumptions of this project was that certain combinations of media are more beneficial than others for learners, depending on their learning style and the context. A similar assumption was the centre of the "great media debate" at the end of 20th century, which revolved around the potential superiority of some media over others and the sense or non-sense of media comparison studies.

Clark (R. E. Clark, 1983; 1994) was one of the primary critics of these studies. He claims that a medium never influences learning. In his frequently cited review "Reconsidering Research on Learning from Media", Clark compared a medium with a delivery truck, which has no influence on its contents. He questioned conclusions of studies that technological media has had a positive effect on learning by formulating rival hypotheses which offered alternative explanations of the outcomes. According to Clark, different learning outcomes were not attributable to different media, but to the effects of error from uncontrolled variables, alternate instructional methods, the novelty effect (Binder, 1968) or other social interaction effects.

On the other hand, Clark's intellectual opponent Kozma (1991) argued that each medium has particular (but not necessarily unique) capabilities. For example, video and animation can present dynamic information and replay sections. These capabilities affect the way a learner perceives and processes information and therefore the medium has an influence on learning. Additionally, Kozma advocated a constructive approach to learning: he rejected the analogy of media and delivery trucks and argued that every learner interacts with media, content and instructional method as a whole in his or her own way to construct new knowledge.

Kozma's stance can also be interpreted from a learning style perspective. If the *interaction* of the learner with the medium is the crucial aspect, one could argue that this interaction is always influenced and determined by a person's prior experiences and preferences. This viewpoint shifts the focus from the medium to the learner. Following this line of thought, one could argue that learning success depends on a good match between a person's preferred learning style and a medium.

A crucial element of this academic debate was the definition of a medium. As pointed out in the beginning of this subchapter, a medium can be defined on (at least) three different levels: the technical, semiotic and sensory modality level. The definition of media was not always clear in the literature; it frequently included all three levels (e.g., Kozma, 1994), which lead to misunderstandings amongst scholars. Reeves (1996) clarified that the media comparison debate mainly revolved around a medium defined as a means of technical delivery (e.g., televised, computer-based or classroom-based instruction).

Most contemporary media scholars concur that it is not productive to compare different media on a technical delivery level (Koumi, 1994; Mayer, 2003). As Clark (1994) stated, it is impossible to separate the instructional method from the medium. Comparative studies on the delivery level will therefore always be vulnerable to various confounding factors. It is rarely clear which (possibly uncontrolled) variables were responsible for an observed improvement in the experimental group. As a consequence of this problem, media comparison research at a technical level was discouraged. Unfortunately, these problematic studies re-appeared in last few years to answer questions about the return on investment of e-learning projects. The new and old problems related to this development will be briefly described in the following subchapter of this literature review, which critically investigates the "no-significant-difference" phenomenon.

This exegesis uses the term multimedia on a semiotic level (different signs and signals in the form of different representational formats) rather than a technical level (transport devices for signals and symbols). As a result of the differing definitions of multimedia, most of the arguments, concerns and problems of the great media debate did not apply to this project. In fact, Mayer (2003) demonstrated that the beneficial multimedia effect occurs equally in computer-based and printed instructional materials. This was also true for other effects including the coherence effect, the personalisation effect and the spatial contiguity effect.

A resonating tenet from the great media debate is that it is more fruitful to focus on research that investigates *how* media can benefit the individual learner as opposed to comparing different modes of delivery. The point was aptly framed by Kozma (1994):

> I believe that if we move from "Do media influence learning?" to "In what ways can we use the capabilities of media to influence learning for particular students, tasks, and situations?" we will both advance the development of our field and contribute to … the improvement of education and training. (p. 18)

This study aimed to start answering this question.

2.3.5 Summary

This subchapter examined the concept of multimedia. For the scope of this project, multimedia was defined on a semiotic level (different signs and signals in the form of different representational formats) with the added criterion that interactivity must be available.

Next, relevant information processing theories were reviewed. Theories on dual coding, cognitive load and Mayer's cognitive theory of multimedia learning were summarised. Four of Mayer's seven multimedia principles have guided the choice of media and informed decisions on the combination of different media in this project.

It was proposed that certain media are more suitable for specific purposes than others. This means that a medium can potentially be more effective if its characteristics are matched with the characteristics of the information. Therefore, multiple external representations (MERs) of the same learning material were considered beneficial for the learning process. To help learners to translate between MERs, "dyna-linking" appeared to be an appropriate technique. Dyna-linking was used in several iWeaver learning materials, for example to visualise the effects of program code on computer memory.

One of the basic assumptions of this project was that certain combinations of media are more beneficial for learners than others, depending on their learning style and the context. This position was hotly debated by the two scholars Clark and Kozma in the great media debate at the end of 20th century. Clark argued that a medium never influences learning. On the contrary, Kozma claimed that a medium's capabilities always affect the way a learner perceives and processes information and therefore the medium does have an influence on learning.

A crucial element of this academic debate was the definition of a medium. As this exegesis defined media on a semiotic, rather than a technical level, the concerns of the great media debate did not apply. In addition, most media scholars later concurred that it was not productive to compare different media on a technical delivery level, as there are generally too many confounding factors involved.

2.4 E-learning

This review defines e-learning and outlines the reasons why e-learning was particularly suited for this project. The adaptive capacity of standard e-learning platforms is evaluated to explain why iWeaver had to be written from scratch. After a brief summary of current research and meta-studies on the effectiveness of e-learning, the "no significant difference" phenomenon is described and critically investigated. Finally, future trends of e-learning are highlighted which include a globally growing market, an increased focus on learner-centred approaches with technological progress as its precursor and blended learning as a future common ground between e-learning and classroom-based learning.

2.4.1 A Definition of E-learning

Rosenberg (2001) summarised existing definitions of e-learning and established three main criteria, which can be used to determine whether a certain form of learning can be considered e-learning.

According to Rosenberg, the first and most important feature of e-learning is that it is networked. It encompasses therefore all the benefits of an interconnected multi-user environment, including timely feedback, instant updates, ubiquitous retrieval and the possibility to share information with peers. In line with this criterion, learning programs on CD-ROMs or DVDs are per se not classified as e-learning. However, if a program is a "hybrid", which means its main components are stored on CD or DVD, but it also sends and receives data over the Internet, it could then be considered to be e-learning.

The second attribute of e-learning is that it is accessible via a standard Internet browser on a standard personal computer. The question how the standards are defined is debatable and dependent on the current state-of-the-art in software and hardware.

The third and last attribute of e-learning is that it extends traditional paradigms of training. This criterion serves the purpose of distinguishing e-learning from other common acronyms in the field.

Rosenberg clarifies that even web-based training (WBT) and computer-based learning (CBL) do not qualify as e-learning, if the concept of networked connectedness is missing. Following his criteria, Rosenberg infers that e-learning can be regarded as a subsection of distance education, but not all distance education is necessarily e-learning. For example, one-way television courses would qualify as distance education, but not as e-learning, because this technology does not normally allow for feedback and learners cannot communicate with peers.

2.4.2 E-learning as a Tool for Individualisation

E-learning can be better suited for individualised learning than a classroom-based environment. In a classroom environment, one teacher usually instructs many students simultaneously, which often constitutes a one-to-many communication. In such an environment it is challenging, if not impossible, to provide each student with a personally well-matched learning experience. In comparison, e-learning environments are capable of overcoming this limitation. In an e-learning environment, a one-to-one communication is possible because a web server is able to process tasks in parallel. This means the environment can respond to every learner and his or her needs individually with timely and precise adaptations.

A major reason why e-learning is currently a popular and growing market despite the academic disputes about its effectiveness is that its flexibility and reach meet the demands of learners (Rogers, 2001). Flexibility allows e-learners to learn just-in-time, from home, in a remote location, while travelling, and despite other commitments, including family or work. The same flexibility makes e-learning a suitable platform for individualising learning.

E-learning environments were often criticised for creating negative feelings of isolation and disconnectedness (see Zirkle, 2001), which increased attrition rates and decreased motivation. However, more recent findings suggested that these negative feelings were not caused by e-learning or the learning environment itself, but by the course design (Rovai, 2002). A well-designed course with ample interaction opportunities with peers and with the support of an experienced instructor or tutor is unlikely to have isolating effects.

2.4.3 Adaptive Capacity of Standard Platforms

After the decision to use e-learning was made, it had to be determined whether it was possible to use a commercially available e-learning platform for this project. Paulsen (2002) found that Australia had a strong preference for standard software packages: WebCT (WebCT Inc., 2004) was most widely used with Blackboard (Blackboard Inc., 2004) as the runner-up. As reasons, Paulsen listed that standard software were relatively uncomplicated to deploy and were often used in an attempt to minimise costs. Both platforms were reviewed for suitability for this project. The three main decision criteria were the possibility to (1) embed multimedia elements; (2) assess specific student preferences; and (3) adapt courses to these preferences.

Both platforms supported embedding multimedia elements. However, neither of the environments allowed an adaptation of course materials based on learner preferences. The two e-learning platforms offered only limited possibilities to collect and analyse student data and it seemed difficult to establish interfaces to third party programs (Solomon, 2003). As a result, it was decided to develop an entirely new learning environment from scratch, specific to the needs of this project.

2.4.4 Effectiveness Studies

A review of studies on the effectiveness of e-learning in comparison to classroom-based learning showed that this topic is inconclusive and controversial (Najjar, 1996; Liao, 1999; Knebel, 2001; Kerres, 2002; Olson & Wisher, 2002; Russell, 2002). Some researchers asserted that it is not possible to compare classroom-based learning with e-learning, because there are too many confounding factors involved and therefore independent variables cannot be controlled adequately.

Olson and Wisher (2002) conducted a meta-study on evaluations of e-learning courses in higher education which were published between 1996 and 2002. The authors found there was no statistically significant difference with regards to the effectiveness of e-learning courses compared to classroom-based courses. Interestingly, only 29 of the 47 examined studies (61 percent) used control groups. From these 29 studies only one study (Schutte, 1996) randomly assigned participants to the different delivery modes. In this particular study, the e-learning students performed better than the classroom-based students. However, after a retrospective analysis of student feedback, this outcome was not attributed to the alternative delivery mode, but to the increased collaborative effort of the students. The feedback indicated that e-learning students were frustrated with their inability to ask questions to an instructor and consequently spent more energy to communicate with peers. Schutte credited this increased communication effort of the e-learning group for their superior results.

Based on the results of their meta-study, Olson and Wisher (2002) suggested that the effect of e-learning systems could be increased by using individualised learning systems, which generate ad hoc problems, hints and aids customised to a specific learner. This suggestion was an inspiring factor for the individualised approach to learning taken by this project, but it has to be kept in mind that this approach has similarly improved the effectiveness of classroom-based learning (Felder & Silverman, 1988; McCarthy, 1990; Riding, 2000; Lefkowitz, 2001; O'Hare, 2004).

Comparative studies between distance education and classroom-based instruction often showed gaps or lacked in quality. Phipps and Merisotis (1999) completed an extensive review of existing original research on this topic. The authors reviewed about forty comparative studies (all conducted in the 1990's) and identified four reoccurring weaknesses: (1) inadequate control for external variables and therefore inadequately derived cause-and-effect relationships, (2) non-randomised allocation of subjects (whole classes were used frequently, which introduced confounding variables), (3) questionable reliability and validity of assessment instruments including surveys and questionnaires and lastly, (4) feelings and attitudes of students were not taken into account.

Apart form these four general weaknesses, Phipps and Merisotis observed several major gaps in the existing research base on e-learning. In particular, three of these gaps were addressed by this research project: Firstly, existing studies centred solely on group outcomes as opposed to factors that influence the outcomes of individual learners. According to Phipps and Merisotis, the focus of future research needs to be how individuals learn rather than how groups learn. Secondly, most studies disregarded the simultaneous effect of the variables "individual learning style" and "learning task" on the success of a particular technology. Phipps and Merisotis suggested that additional research should be conducted to reveal if, why and when a technology or medium is better suited to a learning task than another. Lastly, most studies investigated only the impact of an individual technology. According to Phipps and Merisotis, it would be much more beneficial to focus future research on more than one technology and expected synergetic effects. In a reflective article about the meta-study from 1999, Merisotis concluded succinctly:

> The polar views expressed in many policy discussions–that there is 'no significant difference' on the one extreme, and that distance education is inherently inferior on the other–defy reason. The real debate needs to focus on identifying which approaches work best for teaching students, period. (Merisotis, 1999, p. 50).

Identifying, developing and evaluating a better approach to e-learning constituted the defined aim of this research project.

The ongoing academic dispute and the multitude of media comparison studies inspired the compilation of an entire book dedicated to studies with "no significantly different" results

(Russell, 1999). This compilation continued to be extended through a website (Russell, 2002) and was later complemented by a second collection of studies with "significantly different" outcomes to provide a more balanced view of the field. Even though the citations on this site provided a good overview of the dichotomy of this topic, they did not offer any interpretation or explanation of this phenomenon. Some authors suggested that learning-style adaptive e-learning was the key to achieving a significant difference (Gilbert & Han, 1999; Martinez, 2001; Karagiannidis & Sampson, 2004). However, as discussed previously in this section, this phenomenon has most likely been caused by uncontrolled and/or unknown confounding factors in these studies.

In an attempt to justify large expenditures on e-learning initiatives in universities and to quantify the return on investment of e-learning in the corporate market, media comparison studies experienced a revival in the late 1990s. However, instead of trying to show the superiority of one form of delivery over another, it was frequently argued that finding nonsignificant difference between the comparison groups validates the assumption that the two modes of instruction are equally effective (e.g., Johnson, Aragon, Shaik, & Palma-Rivas, 2000; Tucker, 2001). However, as Lockee, Burton, and Cross (1999) and Cohen (1994) pointed out, this argument was based on flawed logic. Finding no statistically significant difference does not mean one can accept the null-hypothesis, which often stated that there is no difference between the comparison groups. Conversely, finding no statistically significant difference simply means that no conclusion whatsoever can be drawn from the data.

In contrast to comparison studies between delivery modes, similar studies *within* computer-based learning appeared to be more conclusive (Eklund & Brusilovsky, 1998; Martinez & Bunderson, 2000). It can be hypothesised that the reason why these comparative studies were more conclusive was that they were restricted to only one delivery mode. Thus, less confounding factors influenced the data collection, which in turn increased the internal validity of the studies. Therefore, the approach taken in this project to compare two different versions of an e-learning environment seemed adequate and promising.

2.4.5 Summary

This subchapter defined e-learning as networked learning that is accessible via a standard web browser and extends traditional paradigms of training.

It was argued that e-learning is potentially better suited for individualised learning than classroom-based learning, because a server can parallel process and cater for the needs of every learner. Consequently, adaptations can be timely and precise.

Next, the adaptive capacity of standard e-learning platforms including WebCT and Blackboard was assessed. Even though these platforms allowed the integration of multimedia elements, they proved to be too inflexible to be used for this project. For this reason, it was decided to program an adaptive environment from scratch.

A review of comparison studies between delivery modes showed that results were often inconclusive. Most researchers agree that it is not possible to simply compare classroom-based learning with e-learning, because there are too many confounding factors involved.

Gaps and weaknesses in the existing body of literature on e-learning were summarised by Phipps and Merisotis (1999) as four reoccurring weaknesses: (1) inadequate control for external variables, (2) non-randomised allocation of subjects, (3) questionable reliability and validity of assessment instruments, and (4) feelings and attitudes of students were not taken into account.

In contrast to comparison studies between delivery modes, similar studies *within* computer-based learning appeared to be more conclusive. It can be hypothesised that there were fewer confounding factors, because the comparisons were restricted to only one delivery mode. Therefore, the approach taken in this project to compare two different versions of an e-learning environment seemed to provide a good basis for obtaining meaningful results.

2.5 Learning Style Theories

The concept of learning styles has been subject to much criticism and doubt, but there has also been a substantial amount of supporting work. This subchapter cites supporting evidence, while taking criticism into account, and attempts to build a well-defined and stable theoretical framework as one of the foundation stones of this project.

Riding (2000) aptly put into words the same conflicting issues that arose while writing this subchapter:

> In order to pursue research, and particularly to develop a model and evaluate a construct, the researcher needs to have sufficient evidence to sustain belief that the construct may exist in order to maintain the energy to undertake the research. On the

> other hand, it is also necessary to have a degree of scepticism in order to maintain the openness required to evaluate the findings. (p. 366)

Three major review problems in this field were summarised in a recent report by the Learning Skills and Research Centre in the UK (Coffield et al., 2004): (1) Rather than engaging in constructive, critical dialogue, many theorists chose to ignore each other. This led to a fragmentation of the field and a plethora of competing style models. (2) Due to the potential for large financial gains for successful models, criticism is generally not welcome and supporting studies are favoured. (3) The enormous size of the body of literature is overwhelming. For example, Kolb (2001) stated that 1004 studies had been published that used his experiential learning theory. In 2005, Dunn and Dunn listed over 800 studies on their model on their website (http://www.learningstyles.net). Similarly, Coffield et al. estimated that over 2000 articles had been written on the Myers-Briggs Type Indicator.

This subchapter attempts to chart the diverse literature on learning styles by firstly defining the controversial term "learning style" and the context in which it is used in this exegesis. Next, some ongoing debates with and within the learning style field are highlighted. Most importantly, the question whether a learning style is stable or flexible is investigated. Then, issues and findings from research on the connection between learning styles and the brain are outlined. Following is a classification of major models, in order to situate this study in the field. The decision in favour of the "puzzle of learning" model (Rundle & Dunn, 2000, p. 3) (an adaptation of the Dunn and Dunn model) and the restrictions that were necessary to use it for this study are then justified. Critical and supporting work on the Dunn and Dunn model is summarised. Finally, several studies with regards to the matching hypothesis are outlined.

2.5.1 A Definition of Learning Style

Generally speaking, style theories are heuristics for studying learning behaviour; they attempt to simplify human complexity. Theorists in this field usually acknowledge that this simplification is not perfect. Nevertheless, style theories can be considered as a starting point to understanding the much more complicated process of learning.

Definitions of learning styles vary widely across the literature due to the multitude of learning style theories and authors. Coffield et al. (2004) identified as many as 71 models. Some authors use the terms "cognitive styles" and "learning styles" interchangeably.

However, following the definition in this exegesis, cognitive styles only encompass a subsection of learning styles. Other authors use their own terminology or slightly differing definitions to distinguish their model from other models. Common terms include “modality preferences”, “learning preferences” and “learning strategies” (Coffield et al., 2004).

Other terms that will be frequently used in this subchapter are “learning style dimension”, “learning style element” and “learning style profile”. A *learning style dimension* refers to a cluster of conceptually related learning style elements. For example, the Dunn and Dunn model includes an information processing dimension which is broken down into two dichotomous *learning style element* pairs (global/analytic and impulsive/reflective) and “hemisphericity” (Dunn & Dunn, 1993, p. 4). A *learning style profile* is defined as the combined psychometric results of an assessment instrument for every learning style element.

This study was based on an adaptation of the Dunn and Dunn model. Thus, it was necessary to include the respective definition of a learning style. Dunn and Dunn (1993, p. 2) defined learning style as “...the way in which *each* learner begins to concentrate on, process, and retain new and difficult information” (emphasis in original). However, for reasons outlined later in this subchapter (see section 2.5.5, p. 54), this study only focused on the perceptual and information processing dimensions of the model. Therefore, a slightly restricted definition of learning style by James and Blank (1993, p. 47) was adopted for this study. These authors defined learning style as “the complex manner in which, and the conditions under which, learners most efficiently and most effectively perceive, process, store and recall what they are attempting to learn”.

As a basis for this project, learning styles were not regarded as stable entities. In contrast, they were regarded as tendencies, which were expected to fluctuate, depending on the specific learning task at hand. This view aligns itself with contextualism, in that it emphasises the importance of the surrounding context in which an expression has to be interpreted (Kolb, 1984, p. 63). To some extent, this view is similar to Gardner’s perception of multiple intelligences. Gardner (1996) highlighted that in his view an intelligence is a capacity to interact with certain types of content in a specific manner. Most learning style instruments are multi-dimensional and measure a degree of preference for individual style elements. As a consequence, most people have multiple concurrent preferences to varying degrees, rather than absolute preferences. A central assumption of this study was that these preferences might vary (even within the same subject matter), depending on the context of a particular task or topic. To reflect this mediated definition of learning styles, the terms “learning style” and “learning preference” are used interchangeably in this document.

It is important to differentiate the concept of learning styles from general intelligence. The term learning style in this exegesis is meant to be a value free construct, which means a low score in the assessment of a learning style element is equally as desirable as a high score. This differentiation cancels out the field-dependent/field-independent (FD/FI) construct (Witkin, Moore, Goodenough, & Cox, 1977), which is measured by an embedded figures test. In previous studies, FD/FI styles were significantly correlated with intelligence (McKenna, 1990; Riding & Pearson, 1994). For this reason these studies were not relevant for this project, even though interactions between FD/FI learners and properties of computer-based learning environments have been reported (Handal & Herrington, 2004). In short, styles were considered to explain differences in performance that are not explained by differences in abilities.

Learning styles also have to be distinguished from learning strategies such as deep or surface learning. The differentiation can be made by considering the degree of consciousness involved (Sternberg & Grigorenko, 2001, p. 3). For this exegesis, styles are considered as mostly subconscious, trait-like characteristics of individuals that remain relatively stable for the same person under the same conditions (e.g., task, subject matter). In contrast, learning strategies are considered to be mostly conscious activities that can be learned and modified (Riding & Rayner, 1998, p. 79).

2.5.2 Dilemmas and Problems of the Field

The following review outlines the major issues and uncertainties in the learning styles field. The debates revolve around confounding factors in existing research, the origin of style, the risks of stereotyping learners and the stability of styles. It is argued that there is a general trend in the literature towards acknowledging flexibility in learning styles, which is in line with the direction of this study.

Confounding Factors

Kyllonen and Shute (1989) proposed a comprehensive taxonomy of learning skills, which linked learning with four factors: knowledge type (e.g., declarative and procedural), knowledge domain (subject matter), instructional delivery form (e.g., by analogy or by examples), and lastly, learning styles. According to this taxonomy, all four factors interact with each other. This means learning styles are only one out of four factors that can be credited if learning was successful (or blamed if unsuccessful). It also means that potential confounding factors (noise) need to be controlled wherever possible in the experimental procedure.

There is some evidence that participants do select a different instructional approach, depending on factors other than learning style. For example, one participant in the INSPIRE study (Papanikolaou, Grigoriadou, Kornilakis, & Magoulas, 2003, p. 253) reported that he selected the sequence of knowledge modules depending on his knowledge level of the subject matter: if he knew the theory already, he went directly to the exercise. Otherwise, he examined the theory first.

Curry (Delahoussaye, 2002) summarised several issues that plagued learning styles research: (1) design flaws due to overgeneralisation, (2) assessment of styles on only one occasion by one instrument, and (3) uncontrolled confounding factors such as ability, gender, time-on-task, and prior knowledge. In an earlier paper, Curry (1990) listed further problems, including (4) identification of the relevant characteristics in learners and instructional approaches, (5) selection of extreme rather than moderate styles for matching studies, (6) weaknesses in the validity and reliability of models, and (7) external threats such as the Hawthorne effect, experimenter bias and pre-testing (training) effects. For these reasons, Curry (Delahoussaye, 2002) conceded that the learning style research base was not as strong as it could be. She noted that the greatest contributions to the field were achieved by modest-scale studies that addressed one (or more) of the above issues.

Origin of Learning Style

Can learners change their styles or are they biologically imposed? Generally, some style elements are regarded as more hereditary than others. For example, peak alert time seems to be related to a "clock gene" (Archer et al., 2003). Dunn (1984) stated that some learning style elements of the Dunn and Dunn model are believed to be of biological origin, others to be more dependent on environmental factors. She contended that differing styles between parents and their offspring and between siblings were a source of confusion and required further research. But to date (to the knowledge of this researcher) there has been no longitudinal or twin study to investigate whether there is a biological basis for styles (Coffield et al., 2004, p. 12).

Stereotyping

Type theories have been criticised as overgeneralisations for three main reasons (Kolb, 1984, p. 63). Firstly, type theories can too easily lead to stereotypes, which trivialise human complexity. Secondly, type theories often have static and fixed connotations, which translate into self-fulfilling prophecies. Lastly, type theories tend to rely on idealised "pure" types, which are not representative of reality.

When taken to the extreme, learning style stereotyping can have harmful effects. For example Revell (2005) described a school in the UK, where children had to wear badges which indicated their style. Coffield et al. (2004) quoted a student who stated after going through a learning style test (perhaps with some irony): "I learned that I was a low auditory, kinaesthetic learner. So there is no point in me reading a book or listening to anyone for more than a few minutes" (p. 137).

Conscious of the dangers of stereotyping, James and Blank (1993) remind us that learning style data "should be treated as potentially useful—but not all-important—pieces of information in the decision making process" (p. 55).

Stability of Styles

Several theorists doubt the stability of learning styles. Aligning himself with the contextualist world view, Kolb (1984) suggested that "styles are not fixed *traits* but stable *states*. … [They are] enduring patterns of human individuality [that] arise from consistent patterns of transaction between the individual and his or her environment" (p. 63, emphasis in original). Kolb referred to these patterns of transaction as "possibility processing structures" (p. 63). Similarly, Valley (1997) stated that "while it is clear that individuals can exhibit a preference for learning in a particular way, it is less than clear that this preference is stable and reliable" (p. 45). Valley described several situations, in which learning style are expected to vary: (1) learning under time pressure compared to relaxed learning, (2) learning with varying media resources, (3) different subject matters, and (4) interaction with other learner attributes such as motivation, anxiety or prior knowledge. Yates (2000) summarised the stability debate neatly by stating that "people do not clearly fit into categories that accurately predict their behavior across diverse situations" (p. 352).

Some research has been carried out to investigate whether stylistically similar people use different approaches, depending on the task. For example, Pask (1988, pp. 97) used his "spies" and "smugglers" tests successively with 53 architecture students (an occupation that he associated with requiring frequent changes of perspective). These tests were designed to assess global and analytic styles in two different contexts and their results were highly correlated in earlier experiments. However, in this instance a post-hoc analysis showed that a significant number of students changed their style between the tests. Style variations per student were also reported for a subsequent task, in which students were observed during the design of an intruder alarm system.

It should be noted that very few controlled studies could be located by this researcher that investigated the stability of learning styles across tasks. This project contributed further knowledge to this area.

Trends Towards Acknowledging the Flexibility of Styles

The trend to give learners more freedom with regards to their learning style is reflected in the adaptive educational hypermedia field. Authoring systems such as AHA! (Stash, Cristea, & Bra, 2004) have started to integrate mechanisms that facilitate the adaptation of learning materials to styles. The authors recognised the disadvantages of stereotyping and gave learners the option to change their style "on the fly". Stash et al. suggested that future systems analyse browsing behaviour and inform the learners if their choices indicate that a change of style could be considered.

Other authors offered similar ideas to take flexible learning styles into account. For example, Valley (1997) suggested two approaches. Firstly, a courseware-controlled approach could present a default option, monitor performance and, if necessary, present alternative options. Secondly, a learner-controlled approach could let the learner select the most suitable option according to his or her current learning style preference.

Kolb, Boyatzis, and Mainemelis (2001) suggested that learning styles change as a function of an individual's career path and experience. The authors noted that research on Kolb's model mostly examined conditions of extreme styles. Therefore, they proposed to a new focus on "integrated learning" (p. 240), in which learning is conceptualised as a cycle or spiral, where the learner visits all bases. As a consequence, Boyatzis & Kolb (1993, as cited in Kolb et al., 2001) developed an adaptive style inventory. Kolb (Delahoussaye,

2002) stated this inventory was geared towards a more fine-grained description of individuality "to respect individual uniqueness and avoid the stereotyping" (p. 36). According to a cross-correlation study between instruments conducted by Mainemelis, Boyatzis and Kolb (1999, as cited in Kolb et al., 2001), individuals with a balanced learning style profile (i.e. no underdeveloped styles) are the most sophisticated, adaptively flexible learners.

The learning styles review by Coffield et al. (2004, p 139) generally rated models better that emphasised the influence of personal factors (e.g., motivation, environment, strategies) on styles. For example, the authors repeatedly commended Jackson's model (2005) for acknowledging that styles are affected by a mixture of biological, experiential and conscious influences (Coffield et al., 2004, p. 15, 58, 138). More generally, they suggested that it is possible that "this approach will prove more fruitful in organisational psychology, education and training than the many existing commercial applications which rely on theories of fixed personality traits" (p. 58).

2.5.3 Learning Style and the Brain

The psychometrics as well as the dimensions of learning styles are still hotly debated. One reason for this debate is that most learning style models were derived from phenomenological data as a result of direct observations of students' learning preferences. Naturally, models that are based on subjective observations by educators or researchers attract scientific scepticism.

Attempts were made to introduce a more objective view into the field by harnessing technologies from neuropsychology to measure brain-activity. For example, functional magnetic resonance imagining (fMRI) and positron emission tomography (PET) scans provided welcome tools to measure changes in blood flow (which is linked to neural activity) to examine brain-behaviour relationships.

Thies (1999-2000) was one of the first researchers who examined the Dunn and Dunn model from a neuropsychological perspective. He hypothesised that there is a correlation between learning styles and subcortical stimulation. Thies and other researchers grouped and regrouped the learning style elements in several papers (Thies, 1999-2000; Dunn, Thies, & Honigsfeld, 2001) in attempts to align their properties with different subcortical regions and neuropsychological functions of the brain. However, these groupings remained highly speculative, as no actual data had been collected.

Establishing causal relationships between brain activity and behaviour is difficult, due to knowledge gaps in neuropsychology. As Bruer (1997, p. 4) stated, “currently, we do not know enough about brain development and neural function to link that understanding directly, in any meaningful, defensible way to instruction and educational practice”. Bruer substantiated his claim by criticising brain imaging and recording techniques as too inaccurate. Similarly, Churchland (1995, p. 299, as cited in Connell, 2004, p. 9) noted that it was still impossible to define exactly what happens in active brain areas on an abstract level (e.g., how the observed neural activity encodes learning or target behaviour). In other words, activity in a brain region during a certain task does not necessarily mean this area is actually used to perform the task.

Nevertheless, a new technology named transcranial magnetic stimulation (TMS) (Transcranial magnetic stimulation, 2006) goes a long way in establishing a causal relationship between brain activity and cognitive functions. TMS allows researchers to temporarily disrupt the function of localised brain areas. If participants perform worse on the same task after an exposure, this represents much stronger evidence that this area is used to perform the task than a correlation of task and blood flow. Interestingly, TMS has also been shown to enhance cognitive abilities, including creative drawing and proofreading skills (Snyder et al., 2003). It would be an intriguing task for future studies to investigate the effects of TMS on learning styles.

One particular brain-behaviour study was relevant to this study, because it provided some evidence of a neurological basis of global and analytic information processing styles. McKay, Fischler, and Dunn (2003) used electroencephalograms (EEG) to record electrical activity of the brain and compared alpha levels of participants during an analytic and a holistic task. Alpha wares are measured in the frequency range from 8 Hz to 12 Hz and they are associated with a relaxed, alert state of consciousness. Participants were asked to read a highly structured “analytic” text and an unstructured, metaphor-rich, “holistic” poetry text. Results showed that brainwave levels were not significantly correlated during the reading activity. However, lower alpha levels during the rest period (baseline) were correlated with better recall of the analytic text. In contrast, there was no correlation of higher or lower alpha levels with accuracy of recall of the holistic text. As an explanation, the authors hypothesised that both texts had to be analytically analysed to at least some extent, which favoured the analytic style. The fact that lower alpha levels were not correlated with better recall of poetry, suggests that lower alpha levels are unlikely to be a predictor of cognitive ability in general, but rather an indicator of an analytic information processing style.

2.5.4 A Classification and Review of Major Models

Considering that a multitude of learning style models has been proposed, several attempts were made to create overviews by categorising these models. For example, Curry (1983) suggested after extensive reviews of the cognitive and learning styles literature, that learning style theories can be generally categorised into three different layers, akin to an onion (Figure 2-1). Curry's main categorisation criterion was the assumed stability of preferences in each layer over time.

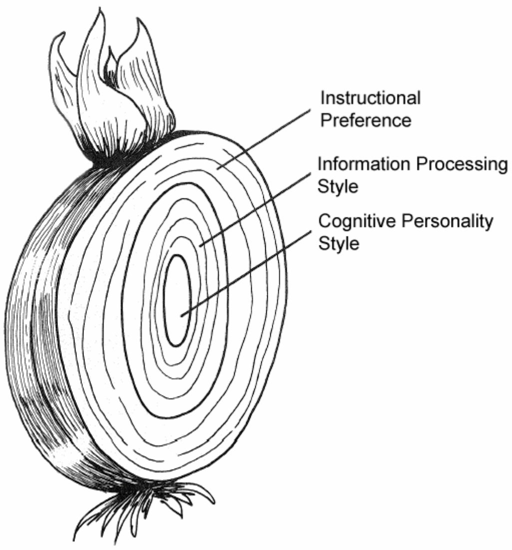


Figure 2-1. Curry's onion model of learning style theories (1983, p. 118). Reprinted with permission.

The outer shell of the onion model contains instructional preferences. Styles in this layer are concerned with "an affinity for various modes of information delivery" (Curry, 2000, p. 239). They are believed to be the least stable over time and easy to alter through interactions with other variables.

The middle layer of the onion model holds information processing styles. These styles deal with the way our brain processes information. Information processing influences the way learners think, solve problems, and remember. These styles are believed to be more time stable.

The core of the onion consists of cognitive personality styles. Styles in this layer are concerned with deep personality traits that indirectly influence how learners interact with their environment. These styles are believed to be the most time stable.

Due to the multi-dimensional nature of many style models, the following attempt to categorise them was aimed to reflect the general tendency of a model. Similarly, iWeaver was based on a two-dimensional model: the perceptual dimension (in the instructional preference layer) and the information processing dimension (in the respective middle layer). However, as the main focus of its adaptive features lay on the perceptual dimension, iWeaver was primarily placed in the instructional preference layer.

Instructional Preference Models

As mentioned before, instructional preference models are concerned with a predilection for different modes of information delivery and are believed to be the least stable over time. First, the Dunn and Dunn model will be briefly reviewed, followed by the Felder-Silverman model.

Curry (2000) placed the Dunn and Dunn model (1993) in the instructional preference layer, which she considered the least stable. This contradicts the classification by Coffield et al. (2004, p. 9), who placed the model at the opposite end of the stability spectrum. These contradicting impressions might have occurred due to the multi-dimensionality of the model. Dunn (1984) considered some style dimensions as fixed and genetically imposed and others as more flexible, because they are the result of experiences (see p. 43).

The theoretical cornerstones of the Dunn and Dunn model are two learning theories: cognitive processing and brain lateralisation. The model covers five learning style dimensions with environmental, emotional, sociological, physiological and psychological elements. A more recent version of this model, called “the puzzle of learning” (Rundle & Dunn, 2000), separated perceptual elements from the other physiological elements and positioned them in their own dimension. Figure 2-2 displays a visual representation of the model and highlights the two dimensions that were used for this project: the perceptual and the psychological dimension. As explained in the definition of terms, the psychological dimension is referred to as “information processing dimension” in this exegesis. An explanation for the restriction to two dimensions will be provided later in this subchapter (see section 2.5.5, p. 54). Additionally, a more detailed description of the dimensions follows in the method chapter (see section 3.2.6, p. 104 and section 3.2.7, p. 108). The Dunn and Dunn model is based on a set of theoretical assumptions (Dunn & Dunn, 1993, p. 6), including:

1. Most individuals can learn.
2. Instructional environments, resources, and approaches respond to diverse learning style strengths.
3. Everyone has strengths, but different people have very different strengths.
4. Individual instructional preferences exist and can be measured reliably.
5. Given responsive environments, resources, and approaches, students attain statistically higher scores in achievement and attitude tests with matched, rather than mismatched instructional methods.

There are several instruments and adaptations of the model for different age groups: the Learning Styles Inventory (1989) was intended for school children from 9-18; whereas the Productivity Environmental Preference Survey (1990) and the Building Excellence Survey (Rundle & Dunn, 2000) were designed for adult learners. Reliability and validity studies for this model and its instruments are reviewed later in this subchapter (see section 2.5.5, p. 54).

Figure 2-2. The puzzle of learning of the BES with project-relevant dimensions highlighted. Adapted from Rundle and Dunn (2000, p. 3) with permission.

Felder and Silverman proposed an index of learning styles (1988), which was partially based on Jung's (1933/1966) and Kolb's (1984) work. This model incorporates five antipodal element pairs. It measures a perceptual dimension (visual/verbal), an information processing dimension (global/sequential and active/reflective) and it takes into account different personality types (sensing/intuitive learners). The originally included inductive/deductive dimension was abandoned with the development of the assessment instrument (Felder & Soloman, 1996). The model is relatively new, comprehensive and freely available on the Internet. Even though the model lacked reliability and validity data when this project was commenced, the model's popularity increased in the meantime and several researchers have published supporting studies (available online at Felder, 2005b).

Information Processing Models

Information processing models are concerned with the way our brain processes information and are believed to be more stable than instructional preferences. First, Riding's basic cognitive style model will be reviewed, followed by Kolb's experiential learning theory.

Riding and Rayner (1998) argued that most cognitive style models can be reduced to two fundamental dimensions: holist/analytic (an individual organises information either in wholes or in parts) and verbal/imagery (an individual mentally represents information either verbally or in pictures). To assess the two dimensions, Riding (1991, as cited in Riding & Rayner, 1998) developed a cognitive style analysis (CSA) (Riding, 1991), which is computer-represented and measures response time. An advantage of the CSA compared to other instruments is that it is an objective test, which means the students do not need to self-report their behaviour. According to Riding, the CSA is context-free and not correlated with ability (Riding & Pearson, 1994). Riding (2000) cited a great number of supporting studies for the validity of his model.

Kolb (1984) was one of the pioneers in the learning styles field. He proposed an experiential theory of learning, building on the learning models of Lewin, Dewey and Piaget. Kolb's model extended learning from a merely cognitive process to a sequence of experiences. As a basis for his model, Kolb proposed the existence of two style dimensions: how a person prefers doing a task (experimenting versus observing) and how a person prefers experiencing (concrete experience versus abstract conceptualisation). Kolb arranged antipodal learning style pairs in four quadrants or "experiences". He emphasised that learners move through all four experiences, as pictured in Figure 2-3. To put his theory into practice, Kolb developed a learning style inventory, in which participants need to order several sets of four words. In his more recent work, Kolb (2001) emphasised that learners should attempt to develop a balanced learning style profile. He described this balance as adaptive flexibility: "the degree to which one changes learning style to respond to different learning situations" (Kolb et al., 2001, p. 243).

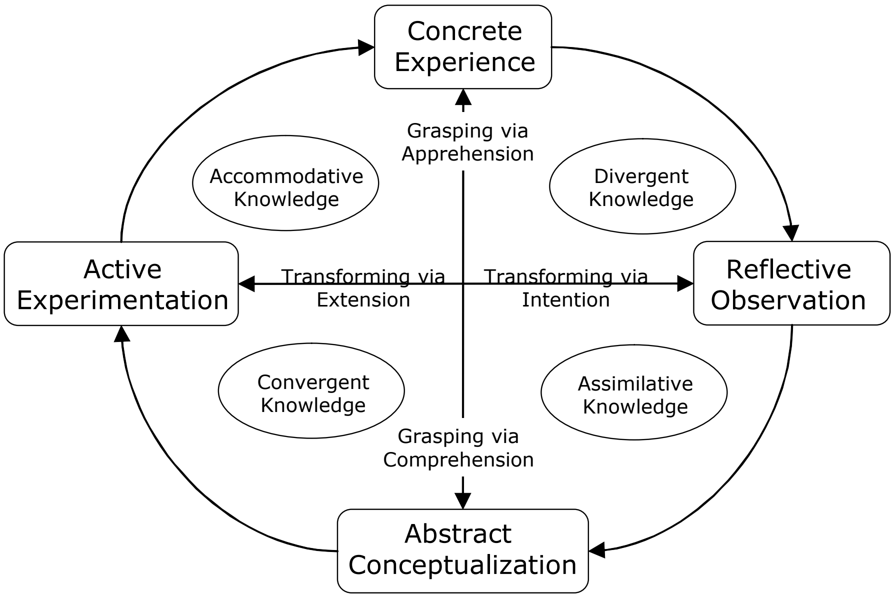


Figure 2-3. Kolb's dimensions of experiential learning (1984, p. 42). Reprinted with permission.

Cognitive Personality Models

Personality styles are defined by the way people interact with their surroundings and are believed to be the most time stable. This review touches briefly upon Carl Jung's early work on personality types, followed the Myers–Briggs Type Indicator (MBTI) and Gardner's theory of multiple intelligences.

Carl Jung is considered to be the father of many personality type theories, as he carried out the groundwork on psychological typing. Jung (1921/1976) differentiated between the basic "attitude types" (p. 330) extraverted and introverted, which are defined by their direction of interest. Later, Jung (1933/1966) added the more specific "function types" thinking/feeling and sensation/intuition, which are defined by how individuals adapt and orient themselves. As thinking and feeling require judgement, they are classified as rational functions, whereas sensation and intuition are the result of immediate perception and therefore non-rational. Jung referred to these types as the "four points of the compass" (p. 108), likening them to a tool for comparison and orientation to make psychology more critical. Several contemporary learning style theories can be traced back to Jung's psychological theory of types, such as Kolb's experiential learning theory and the MBTI (Myers, 1978).

The MBTI (Myers, 1978) draws heavily on Jungian theory. It attempts to measure concepts that determine how individuals perceive reality, reach conclusions and resolve conflicts. The MBTI consists of four bipolar dimensions: extraversion/introversion; sensing/intuitive; thinking/feeling and judging/perceiving.

Gardner was one of the early pioneers in individual differences research. He broadened the construct of intelligence in his theory of multiple intelligences. Gardner (1983/1993) described seven intellectual competences: verbal-linguistic, logical-mathematical, musical-rhythmic, bodily-kinaesthetic, visual-spatial, interpersonal, intrapersonal. An eighth intelligence, the naturalist was added later (1999, p. 47), when spiritualist and existential intelligences were considered as well. Multiple intelligence theory aligns with learning style theories in that it opposes homogenised instruction and encourages educators to employ pluralistic approaches to learning. However, Gardner (1996) contrasted the two theories by stating that learning styles are a general approach to non-specific content, whereas an intelligence is a capacity to do well with specific content.

2.5.5 Selection of a Model: Criteria, Criticism and Defence

In this section, the criteria that were established for selecting a learning style model are listed and explained. Based on these criteria, the Dunn and Dunn model was selected. Like most other learning style models, the Dunn and Dunn model has attracted criticism. The main points of criticism are acknowledged and answered, where applicable.

Three criteria were established for selecting a learning style model and the accompanying assessment instrument. They must:

1. encompass the perceptual and information processing dimensions,
2. be based on a strong research base, and
3. have a high degree of model validity and (to a lesser extent) instrument reliability.

Perceptual and Information Processing Dimensions

The selected model had to encompass the perceptual and information processing dimensions for three reasons. Firstly, these dimensions were grounded in the cognitivist-influenced view of learning adopted by this project (see section 2.2.3, p. 19). Secondly, it was relatively uncomplicated to accommodate these dimensions within the limitations of a multimedia e-learning environment. Thirdly, the two dimensions aligned well with the dimensions of other major models, which added to their validity. For example, the global/analytic elements are similar to Felder-Silverman's (1988) global/sequential elements and to Riding's (1998) holist/analytic elements. Likewise, the visual/verbal elements also appear in both models. Finally, the active/reflective elements have matching elements in Kolb's model (1984). Similar conceptual alignments of learning style elements and dimensions have been proposed by Brown, Cristea, Stewart, and Brailsford (2005) and Riding (2000).

Strength of the Research Base

According to a quantitative analysis of citation rates in the learning style literature (Desmedt & Valcke, 2004), Kolb has been the most cited author, followed by Rita Dunn. Citation rates cannot be used for conclusions about the quality of a model, but they offer information about the scientific impact of an author on a field. Therefore, it can be concluded that the Dunn and Dunn model has been the second-most most influential models in the learning style literature. Notwithstanding, it should be noted that a second analysis based on the term "cognitive style" yielded a different result, with Witkin as the most influential author.

In order to investigate the effect of matched instruction according to the Dunn and Dunn model, Dunn, Griggs, Olson, Gorman and Beasley (1995) conducted a meta-analysis of 36 experimental studies that used the model between 1980 and 1990, with a total of over 3000 participants. The analysis revealed a weighted average effect size *(r)* of .353 with a mean difference *(d)* of .755. With respect to the standard distribution curve, this suggests that students whose learning styles were accommodated would be expected to perform 75% of a standard deviation better than non-accommodated students.

Lovelace (2005) conducted another meta-analysis of 76 studies that had used the Dunn and Dunn model between 1980 and 2000. Lovelace calculated a moderate to large mean effect size (weighted and unweighted $r = .37$) for achievement and concluded the model was "both a practically and educationally significant construct" (p. 180). Lovelace also stated that "the data overwhelmingly supported the position that matching students' learning style preferences with complementary instruction improved academic achievement and student attitudes toward learning" (p. 181).

In addition to these two meta-studies, a review of three doctoral theses on applications of the model in classroom-based learning scenarios further corroborated the impression of its effectiveness (Martini, 1986; Lefkowitz, 2001; O'Hare, 2004).

Reliability and Validity

The selected model and instrument should have acceptable reliability and validity. Reliability either refers to the correlation of student results in test/retest scenarios or the extent to which a set of test items measures the same latent variable (Reliability (statistics), 2006). Construct validity refers to whether an instrument measures the underlying traits of a model that it claims to measure. Predictive validity is the predictive power of an instrument over the impact of a measured trait. Kolb et al. (2001, pp. 239) noted that the predictive validity of any psychometric test is generally average. Even the most sophisticated ability tests (e.g., IQ, GRE, GMAT), which are meant to link test results with academic achievement, rarely rise above a .5 correlation (e.g., between GMAT score and first-year grade point average).

Coffield et al. (2004) established four main criteria for selecting learning style models: internal consistency, reliability, construct validity and predictive validity. According to the review, the Dunn and Dunn model failed all but one (predictive validity) of these criteria. Coffield et al. summarised that “the research she [Rita Dunn] refers to is highly controversial, and much of it has been sharply criticised for its poor scholarship and for the possible influence of vested interests, because the Dunn centre conducts research into the instrument which it sells” (p. 122). The reviewers concluded that the model “should not be used in education or business” (p. 118). However, one of the main points of criticism of the model is the view that styles are regarded as fixed entities (p. 33). In the iWeaver project, this criticism was accounted for by examining whether a more flexible approach to learning styles is beneficial for the learner. Additionally, the two dimensions of the model that were used by iWeaver aligned well with other established models in the literature, as discussed earlier in this section. Moreover, the model had been successfully employed in several comparative studies (e.g., Martini, 1986; Dunn et al., 1995; Lefkowitz, 2001; O'Hare, 2004; Lovelace, 2005).

Over the years, Dunn, Dunn, and Price developed several instruments for the model: the Learning Styles Inventory (LSI) (1989), the Productivity Environmental Preference Survey

(PEPS) (1990), and a more recent addition, the Building Excellence Survey (BES) (Rundle & Dunn, 2000). The LSI was intended for school children from 9-18, while PEPS was the adult version of the instrument. The BES expanded PEPS by subdividing the perceptual elements and adding the analytic/global and reflective/impulsive elements (see Figure 2-2, p. 51). The BES was chosen over the more thoroughly evaluated PEPS, because of its inclusion of the information processing dimension.

The LSI and PEPS have been criticised by psychometricians in the mental measurements yearbooks. For example, Hughes (1992, pp. 460) questioned the research base of the Dunn and Dunn model, claiming that a majority of the references were unpublished doctoral dissertations, supervised by one of the co-authors of the model. However, Coffield et al. (2004, p. 20) counted 177 peer-reviewed journal papers on the model. Nevertheless, Hughes concluded that the LSI had “no redeeming values” (p. 461). More recent reviews with regards to the validity and reliability of PEPS by Kaiser (1998) and Rozecki (1998) identified problems with missing data and the quality of provided references.

On the other hand, several researchers provided supporting evidence for the Dunn and Dunn model and its instruments. For example, DeBello (1990) conducted a comparative analysis of 11 learning style models, which determined “one of the highest reliability and validity ratings” (p. 205) for the Dunn and Dunn model. Roberts (1999) provided support for the construct validity of the LSI. He used structural equation modelling to examine the factor structures of the LSI on the basis of test results from 1100 students. Findings revealed clearly defined factor structures, which were an adequate fit for the sample data. Nelson et al. (1993) found that test-retest reliability coefficients (Cronbach’s alpha) for the 20 PEPS elements ranged from .39 to .87, with 40% of the scales over .80. Similarly, in an evaluation of the BES conducted by Lewthwaite (1999, pp. 140,163), all reliability coefficients were in excess of .88. A factor analysis provided some construct validity support for the perceptual dimension and strong support for the information processing dimension. Finally, the two meta-analyses cited earlier in this section emphasised the predictive validity and added further grounds for the selection of the Dunn and Dunn model.

In summary, the validity of the Dunn and Dunn model and the reliability of the BES seemed adequate for the purpose of this project, despite criticism in the literature.

In line with the assumption that styles are not stable, it is the view of this researcher that the reliability of an instrument is not as important as the availability of a variety of learning experiences. As noted by Coffield et al. (2004, pp. 2), the idea that there is just one match for each style is more limiting than liberating. The instrument used in this study (BES) is expected to deliver an initial tendency or a starting point, which is then fine-tuned over the course of the learner's interaction with the environment.

2.5.6 Matching Learners

A basic assumption of this project was that some forms of instruction are more effective for learners with certain compatible characteristics than for other learners with non-compatible characteristics. Cronbach and Snow (1977) referred to this assumption as an "aptitude x treatment interaction" (ATI) (p. 5). However, to avoid ambiguity (e.g., aptitude is conceptually close to ability), this interaction is in this exegesis referred to as the "matching hypothesis". Snow (1989, pp. 21) summarised earlier studies and reviews with several conclusions, including (1) ATIs exist and are common in education. (2) ATIs are complex and threaten traditional research design, because they offer alternate hypothesis for results. (3) ATIs are difficult to generalise.

This section examines the matching hypothesis and serves, together with the review of adaptive environments in the next subchapter, as justification for the matching approaches in iWeaver. Only studies that included the same or similar learning style dimensions to those used in this project (perceptual and information processing) were selected for review. As the matching hypothesis equally applies to computer-based, paper-based and classroom-based instructional settings, a cross-section of studies is cited. The difference between the computer-based studies in this subchapter and the evaluation studies of adaptive environments in the next subchapter, is that adaptive environments contain a learner model, which is used for adaptation decisions by the computer. However, in the computer-based studies reviewed in this section, participants were manually matched or mismatched to static learning environments by the respective researchers.

For the following review of empirical studies, it is important to note that the quality of their research design varied. Some studies allocated participants to a treatment group according to their pre-assessed learning style, which could threaten the internal validity of the experiment by introducing bias. Other studies did not use a control group, which makes it difficult to discern the effect of a treatment. However, four of the eight primary studies that were reviewed randomly allocated participants and used control groups. Thus, these four studies (Riding & Douglas, 1993; Butler & Mautz, 1996; Monaghan & Stenning, 1998; A. V. Roberts et al., 2000) can be considered well-designed.

Matching Perceptual Preferences

Several researchers have conducted studies to test the matching hypothesis for perceptual preferences. For example, St Hill (2000) implemented a classroom-based course suitable for visual, aural, read/write and kinaesthetic (VARK) learning styles. The re-designed course materials were based on Fleming's VARK Model (www.vark-learn.com). The course resulted in a significant increase in high marks and the learning experience feedback sheets showed that students were much happier about the course than in the previous years. However, there was no direct control group. Thus, the novelty effect cannot be excluded as an alternative explanation for the improvement.

Hodges and Evans (1983) examined the effects of three instructional methods to teach 24 students with a mean age of 15 about geographic areas. Participants were selected from a larger group of 36 learners so that two even groups could be formed with 12 highly visual/spatial learners and 12 highly verbal/analytic learners. The three types of instructional methods were (1) tapes, lectures and discussion; (2) maps, slides, and games; and (3) a combined approach. In a repeated measures design, all students were exposed to the three methods sequentially over three lectures and each lecture was followed by a post-test. Results showed that visual/spatial learners performed significantly better with a matched instructional approach. However, no significant difference was found for verbal/analytic learners.

Martini (1986) investigated the effect of matching and mismatching instructional methods when teaching seventh grade students. 114 students were assessed for their visual, auditory, and tactile learning style with the LSI (Dunn et al., 1989). 30 students expressed a strong preference for one of the three styles and participated in the matching experiment. The topic "the human body" was taught in lessons, using three instructional strategies: printed materials, audio tapes, and interactive computer-assisted instruction. Students experienced one matched and two mismatched lessons. Statistically significant improvements were found for all three styles when students were taught with a complementary instructional strategy. There was also a significant improvement for all students when using computer-assisted instruction. However, tactile learners still outperformed students with other styles.

Similarly, Riding & Douglas (1993) compared the effect of different media in computer-based tutorials for fifty-nine 15-16-year-old students. Two types of tutorials on car brake systems were compared: a text-plus-text and a text-plus-picture tutorial. Students were randomly assigned to either of the conditions, then post-tested and finally assessed for visual or verbal styles with Riding's CSA (1991). Results showed that visual learners nearly doubled their scores when matched, whereas verbal learners achieved similar scores under both conditions.

Butler and Mautz (1996) conducted an experiment with 60 accounting students to compare textual with media-enriched materials. The participants answered an individual differences questionnaire, developed by Paivio (1986), which measured visual and verbal thinking skills and habits. Then, they were randomly allocated to two groups which differed only in the type of support materials they were given. One group received textual materials (on-screen) and the other group received media-enriched materials (additional graphics, animations and sound). Then, both groups attended a 30 minute presentation on systems theory. A recall test after the presentation revealed no statistically significant difference between the groups. Nevertheless, a statistically significant interaction was identified between the results of the individual differences questionnaire and the type of support materials: learners with an imagery preference improved their recall with media-enriched support materials, whereas learners with a verbal preference did worse when they received the media-enriched materials.

Roberts et al. (2000) investigated the effect of matching tactile-kinaesthetic resources with the respective learning style for 72 fourth-grade students. Learning style preferences were assessed with the LSI (Dunn et al., 1989), but students were unaware of the results. Students were randomly allocated to two groups with either traditional or tactually-enhanced learning materials. The materials covered four units of social studies, taught over a period of four weeks. In a repeated measures design, groups switched conditions every week. Results showed that tactile learner achieved significantly higher post-test scores and had a more positive attitude towards the lesson with matched support materials. In comparison, non-tactile learners had no significant benefit from the additional tactile resources.

A summary of studies that were employed to construct the matched media experiences in the iWeaver environment is provided in Table 2-1.

Table 2-1

Summary of Matching Studies for Perceptual Preferences

Reference	Preferences	Media materials	Findings
St Hill (2000)	visual text, auditory, tactile, visual pictures	classroom-based course materials suitable for different learning styles	The course resulted in a significant increase in high marks and feedback sheets showed that students were happier about the course than in previous years. However, no direct control group was used.
Hodges & Evans (1983)	(visual text + auditory), visual pictures	tapes, lectures, discussion / maps, slides, games	Visual pictures learners performed better with their matched instructional approach. No significant difference for visual text learners.
Martini (1986)	visual text, auditory, tactile	print materials / tapes / interactive computer-based learning (CBL)	Significant differences were detected for all three styles when matched. There was also a significant improvement for all students for CBL, but tactile learners still outperformed the other styles.
Riding & Douglas (1993)	visual text, visual pictures	CBL with text + text / text + pictures	Visual pictures learners nearly doubled their scores when matched, whereas visual text learners had similar scores under both conditions.
Butler & Mautz (1996)	visual text, visual pictures	CBL with textual / multimedia materials	Visual text and visual pictures learners did significantly better when the materials matched their learning style.
Roberts et al. (2000)	tactile	traditional lecture / lecture with added tactile resources (e.g., task cards)	Tactile learner achieved significantly higher post-test scores and had a more positive attitude towards the lesson with matched instruction. Learners with other styles had no significant benefit from the tactile resources.

Matching Information Processing Preferences

An often cited paper in support of the matching hypothesis is a meta-analysis conducted by Hayes and Allinson (1993). The authors reviewed 17 studies, most of which used information processing models. They concluded that 10 out of the 17 studies provided “some support for the proposition that instructional strategies would be differentially effective for students with different learning styles” (p. 75). Considering the significance of this conclusion, the paper was analysed in more detail. 6 out of the 17 studies referred to the FI/FD construct, which was found to be correlated with intelligence (McKenna, 1990; Riding & Pearson, 1994) and should therefore not be included in learning style-related reviews. From the remaining eleven studies, four reported no support or inconclusive results. Two studies showed marginal support and a further three reported support for the matching hypotheses, but no significance level was given or no control group was used. The remaining two studies reported a statistically significant difference for matching. Given that 7 out of the 11 studies reported some level of support, Hayes’ and Allinson’s tentative conclusion in favour of the matching hypothesis seemed warranted.

In a study by Monaghan and Stenning (1998), the researchers investigated a possible interaction of problem solving methods with information processing styles with 17 first-year undergraduate students. In a pre-test, the students were assessed for spatial ability and serial/holistic preferences. Next, students were paired according to similar pre-test results and then randomly allocated to two groups, in which they proceeded to solve syllogisms with the help of a tutor. The tutor helped the students by either showing them how to use Euler circles (holistic approach) or a natural deduction method (serial approach). The researchers found several statistically significant interactions between styles and problem solving method: high spatial/holistic learners made fewer errors and required fewer interventions from the tutor when taught using Euler circles compared to low spatial/serial learners. Interestingly, this interaction was symmetrically reversed for the natural deduction method, which cancelled out general intelligence as a cause.

Ford and Chen (2001) compared performance of holistic and analytic learners in a web-based course that taught HTML programming to 73 postgraduate students. Even though the authors referred to FD/FI as cognitive styles, they used Riding’s CSA (1991) to assess styles, which warranted the inclusion of the study in this review. First, the students were tested for their holist/analytic preference. Next, groups of participants with distinct styles and with intermediate styles were divided in half and then exposed to a matched or a mismatched version of the learning environment: “depth first” or “breadth first”. The results for learning gain indicated that matched students performed significantly better than mismatched students.

A summary of studies that support approaches for information processing preferences is provided in Table 2-2. It is of note that no studies could be located which investigated matching of impulsive and reflective learners. For this reason, two additional studies were included which substantiated the benefit of potential approaches for these learning styles.

Table 2-2

Summary of Matching Studies for Information Processing Preferences

Reference	Preferences	Approach	Findings
Monaghan and Stenning (1998)	analytic / global	holistic approach / serial approach to problem solving	Holistic learners made fewer errors and required fewer tutor interventions when taught using the holistic approach.
Ford & Chen (2001)	analytic / global	“depth first” (analytic) / “breath first” (global)	Matched students performed significantly better than mismatched students.
Bajraktarevic, Hall, & Fullick [a] (2003)	analytic / global	analytic: small chunks of information, “fwd” and “back” links / global: table of contents, overview, access to more links	Students achieved significantly higher scores in matched sessions than in mismatched sessions.
Kölling & Rosenberg (2001)	n/a (impulsive properties)	encourage novice-level students to start programming	It is a more productive approach to give students example code to read and to work with, rather than giving them a blank page.
Katayama, Shambaugh, & Doctor (2005)	n/a (reflective properties)	comparison of different note-taking techniques	Processing and physically typing notes leads to better knowledge retention than copying and pasting.

Note. [a] The study by Bajraktarevic et al. is reviewed in the next subchapter on p. 87.

In summary, the findings reported in this section go some way towards corroborating the matching hypothesis. However, there is an alternative view in this field, which is discussed in the next section.

2.5.7 Mismatching Learners

Even though mainly supporting studies have been cited in this section thus far, the matching hypothesis is still controversial, in accord with learning style theory in general. For example, there have been several studies in which style matching had no effect. Harris, Dwyer, and Leeming (2003) found no significant differences, when they attempted to match two versions of an e-learning environment (text-only and media/interaction-rich) with active and reflective learners according to Kolb's learning style model (1984). In a meta-analytic approach, Kavale and Forness (1987) examined 39 early studies on modality-matched teaching of participants with learning disabilities. The authors ranked the studies in three groups according to their design quality and compared weighted average effect sizes (d). The best-designed studies showed a negligible effect size ($d = .037$, moderate studies also showed a negligible effect ($d = .125$) and the lowest ranked studies showed a small effect ($d = .208$) according to Cohen's classification of effect sizes (1992). This result prompted Kavale and Forness to recommend that the modality model should be abandoned for teaching participants with learning disabilities.

On the opposite side of the spectrum of matching research, some studies showed that mismatching is more beneficial than matching. For example, Kelly and Tangney (2004; 2005) (reviewed in section 2.6.6, p. 88) conducted experiments with matching preferences for multiple intelligences. They found that low activity students had a significantly higher relative learning gain when the environment was mismatched to their needs, rather than matched. In an evaluation of the European 3DE project (Militello & Ovcin, 2003) (reviewed in section 2.6.6, p. 84), which used Kolb's model (1984), mismatching produced better results in two of the four tested countries. Additionally, the order of matching and mismatching seemed to play a role in some cases. Similarly contradicting results were found by McKay (2000): verbalisers performed best with graphical metaphors, whereas some imagers performed better with text-only materials. Likewise, results of a study by Dekeyser (2001) indicated that visual learners interacted less frequently with graphical materials than verbal learners. As a possible explanation Vermunt (1992, as cited in Dekeyser, 2001) proposed that an incongruence between learning style and instructional strategy could lead to "constructive friction" (p. 100), which can in turn stimulate students' learning and thinking capabilities. On the other hand, Roberts (1999) proposed as one conclusion of his thesis that a match between instruction and learning style leads to "cognitive comfort" (p. 77) for the students and therefore to increased learning. This proposition accords with the conclusions of matching studies cited earlier in this section. As Ford and Chen (2001, p. 21) noted, it appears that "the effects of matching and mismatching information presentation strategy with cognitive style may not be simple, and may entail complex interactions with other factors such as gender, and different forms of learning."

A possible solution for the matching/mismatching discussion would be to simply offer the learner free choice between all available instructional variations, so they can select the one that best suits their needs. However, this approach may lead to frustration and confusion if there is insufficient guidance (Carver et al., 1996). A possible explanation for this effect is offered by cognitive load theory (Sweller, 1988), which holds that it is beneficial for the learner to keep the extraneous load at a relatively low level to facilitate the acquisition of new schemata. In an e-learning environment, this can be achieved by adapting navigation or content depending on a model of the learner. Refining this adaptation process is the goal of adaptive educational hypermedia environments (Brusilovsky, 1996, 2001) as discussed in the next subchapter.

2.5.8 Summary

This subchapter defined the term "learning style" and related terms such as learning style dimension, element and profile. It was highlighted that this study considered learning style as a context-dependent, flexible construct. Learning style was differentiated from general intelligence and learning strategies, such as deep or surface learning.

Major issues and uncertainties in the learning styles field were outlined. The debates revolve around confounding factors in existing research, the origin of style, the risks of stereotyping learners and whether styles are stable or flexible. It was argued that there was a general trend in the literature towards acknowledging a flexibility in styles, which was in line with the direction of this study. A lack of research on learning style stability across different tasks was noted.

Next, research that attempted to connect learning styles with brain functions was reviewed. Even though most associations of styles with brain regions are currently speculative, there is some evidence that baseline alpha levels are a predictor of an analytic style. Generally, it was difficult to establish a causal relationship between brain function and behaviour, because most studies are correlative. Nevertheless, a new technology, transcranial magnetic stimulation, seemed to have the potential to establish causality in the future.

Major learning style models were classified according to the three layers of Curry's onion model (1983). Curry categorised models with regards to the perceived stability of their styles. Due to the multi-dimensionality of many models, it can be difficult to unambiguously allocate a model to a layer. A working example is the adapted Dunn and Dunn model (see Figure 2-2, p. 51) used in this study: it can be located in the least stable instructional preference layer and equally in the more stable information processing layer.

It was then justified why the Dunn and Dunn model was selected for this study. Firstly, it encompassed the perceptual and the information processing dimension, which were grounded in the cognitivist-influenced view of learning adopted by this project. In addition, both dimensions were relatively uncomplicated to accommodate in an e-learning environment and they conceptually aligned well with other models. Secondly, the model was based on a strong research foundation, as demonstrated by two meta analyses (Dunn et al., 1995; Lovelace, 2005). Lastly, the model had a high degree of validity and there was sufficient evidence for the reliability of the assessment instrument. Even though the Dunn and Dunn model had been criticised in the literature, its validity and the reliability of the instrument seemed adequate for the purpose of this project.

Next, the matching hypothesis was investigated. This hypothesis holds that some instructional formats are more effective for learners with compatible styles than for learners with non-compatible styles. Several primary studies and one meta-analysis in support of the matching hypothesis were critically reviewed. These studies in combination with evaluation results of adaptive environments in the next subchapter were used to build a framework for the matching approaches in iWeaver.

In the final section of this subchapter, research opposing the matching hypothesis was discussed. Some studies have found no effect or even negative effects for matched learning materials. It was argued that an environment where the participant is offered a guided choice of learning options can be a fruitful approach to resolving the matching/mismatching discussion.

2.6 Adaptive Educational Hypermedia

This subchapter defines the term “adaptive educational hypermedia” (AEH) and contrasts it with an “intelligent tutoring system” (ITS). Next, the dichotomy of learner control and system control is described. Then, this subchapter follows Brusilovsky’s (2001) proposal of a taxonomy for AEH and divides the field into two research areas: (1) which components of an environment can be adapted and (2) to what learner model these components adapt to. Following this, examples for adaptation techniques are introduced, some of which were used in iWeaver. Finally, several existing AEH systems are reviewed, with a focus on those systems that adapt to individual learning styles. It is outlined how iWeaver differs from existing approaches and what its novel aspects are.

2.6.1 Adaptive Educational Hypermedia and Intelligent Tutoring Systems

The basic idea behind an adaptive interface is that a computer software adapts its behaviour and properties to a user. The aim is to make the interface more user-friendly, more effective (e.g., tasks can be carried out more successfully) and more efficient (e.g., the learning process is accelerated). There are two major research streams in adaptive educational interfaces: intelligent tutoring systems and adaptive educational hypermedia.

According to Brusilovsky (1996, p. 88), adaptive hypermedia environments are “all hypertext and hypermedia systems which reflect some features of the user in the user model and apply this model to adapt various visible aspects of the system to the user”. The term “adaptive *educational* hypermedia”, as used in this exegesis, extends the definition by applying it to systems that facilitate learning. Learning was defined in an earlier subchapter (section 2.2.1, p. 16) as a potential change in behaviour that results from experience.

In comparison, Woolf et al. (2001, p. 100) stated that intelligent tutoring systems are based on “explicit representations of tutoring, student knowledge, …rules of inference about possible ways to teach content knowledge and dynamic generation of customised paths through the knowledge in response to student behavior”.

As is evident, the two definitions share the same criterion: adaptation to a model of the learner by adjusting the teaching approach. Due to these similarities, it is sometimes not easy (and quite possibly not even useful) to classify an adaptive system as one or the other. For this study, two main criteria differentiate an ITS from AEH. Firstly, AEH is, by definition, implemented by using hypermedia, whereas in an ITS the use of hypermedia is optional. Secondly, an ITS primarily focuses on customised problem solving support and less on educational materials. In contrast, AEH is primarily concerned with adapting educational materials to alleviate learner difficulties with regards to comprehension and orientation. Following this differentiation, iWeaver is classified as an AEH environment.

Despite this classification, it is worthwhile examining the background of ITSs briefly. These systems were the predecessors of AEH and their rationale, successes and problems had a profound impact on the field of educational technology. The following paragraphs also substantiate why iWeaver was developed as AEH and not as an ITS.

Merrill, Reiser, Merrill and Landes (1995) analysed strategies in human tutoring. They described tutoring as a particularly interactive process, which involves a substantial amount of feedback and confirmation. The authors observed that tutors typically prevent students from “floundering” (p. 353) in their problem solving process. Tutors help students to save time, confusion and frustration by directly guiding them to more profitable learning paths if the cost exceeds the benefits of self-recovery in case of an error.

Attempts to let a computer mimic a human tutor were motivated by a general belief that human tutoring is a highly efficient and effective educational method. Bloom (1984) reported on two doctoral dissertations which compared a conventional learning (control) group with a mastery learning group and a human tutoring group (using “good” tutors). A striking difference of almost two standard deviations (*SD*) was found between the control group and the tutoring group, which means the results of the average tutored student were above 98% of the control group students. These results were replicated by the same researchers with four different samples of students at different grades and for two different subjects (probability and cartography). A thoroughly designed meta-analysis of 65 human tutoring studies (52 of which reported results on academic achievement) was conducted around the same time by Cohen, Kulik and Kulik (1982). Even though this analysis yielded a lower average effect size of .40 *SD*, the analysis still confirmed “definite and positive effects on the academic performance and attitudes of those who receive tutoring” (p. 244). Intelligent tutoring systems try to recreate this positive effect with a computerised tutor that interacts with the learners. It attempts to guide their learning and problem solving processes, much like a human tutor would.

Some ITSs have been quite successful. An interesting, and for this study highly relevant, web-based ITS was the Environment for Learning Programming (ELP) that was developed by Truong, Bancroft and Roe (2002; 2005). The ELP allowed novice learners to “fill in the gaps” in program code, which made it easy to quickly produce an executable program. In addition, the ELP contained a program analyser which gave learners feedback on the quality and accuracy of their work. In a qualitative evaluation of the ELP, 63% of the learners voted that ELP was a useful tool for novice programmers.

In 1993/1994, an ITS for teaching algebra was used in about 100 schools in the USA (Koedinger, Anderson, Hadley, & Mark, 1997). On average, students in the experimental class outperformed students in comparative classes by 15% on standardised tests and by up to 100% in specific tests on the subject. A meta-analysis of computer-aided instruction conducted by Regian, Seidel, Schuler and Radtke (1996) identified three systems that could be classified as “intelligent”. Evaluations of these three systems resulted in an average time reduction of instruction of 55% compared to a conventional learning setting. However, the comparative studies reported in this paragraph should be looked at critically, considering the frequent confounding factors in media comparison studies (see section 2.4.4, p. 36).

These successes are encouraging, but unfortunately the development of an ITS is difficult and time-consuming: for example Murray (1999, p. 122) reported after a 16 months case study that one hour of ITS instruction required an estimated 100 hours of development time. Furthermore, ITSs were mainly devised for procedural domains (e.g., mathematics), in which systematic problem solving is an intrinsic learning approach. These ITSs were often subject-specific and needed to be developed from scratch for every new topic. For these reasons, research is now focussing on authoring systems for ITSs, which aim to reduce the development effort. An example of such a system, which even included learning style-specific adaptation, was developed by De Bra and Stash (2004). However, Murray (1999) argued that, while authoring systems can make low-level decisions easier, they still require the author to consider the big picture and to reconceptualise content in a flexible and modular fashion. This process is not an easy task, even when scaffolded by an authoring system.

In addition to the practical issues in ITS development, there are still many unresolved problems with imitating a human tutor. For example, Woolf et al. (2001) identified research issues such as generating believable, life-like responses in an instructional dialogue. In essence, it proved to be difficult to program a computer to appropriately interpret and act upon the diverse needs of human learners.

In 1997, Sandberg and Andriessen (1997) looked at contributions to the Artificial Intelligence in Education (AIED) conferences in the last few years. The authors noted that the number of contributions presenting ITS research, as well as the number of themes associated with ITSs, was declining. They suggested that this decline was caused by a generally increased focus on metacognition (learning to learn) and reflection (knowing when, where and why). These processes are hard to formalise and thus the tutoring paradigm can not address them easily. This development could be seen as one of the driving factors for AEH systems, which are more suitable for metacognition and reflection, because they are primarily concerned with the adaptation of educational materials as opposed to problem solving support.

2.6.2 Locus of Control

One of the major research issues in the field of adaptive interfaces is the "adaptivity versus adaptability" debate. In *adaptive* systems, the locus of control lies with the system, whereas in *adaptable* systems the locus of control lies with the learner. Therefore, adaptable systems are also referred to as customisable systems.

Dieterich, Malinowski, Kühme and Schneider-Hufschmidt (1993, p. 15) conducted an early survey of literature on adaptive user interfaces and identified four distinct phases of an adaptation process:

1. initiative (a need for adaptation is suggested),
2. proposal (of alternatives for the adaptation),
3. decision (selection of one alternative), and finally
4. execution (adaptation is executed).

The more these four stages are controlled by the system, the more adaptive is the environment. Conversely, the more stages are controlled by the user, the more adaptable is the environment. Dieterich et al. concluded from their survey that a mixed approach, where the system and the user share control, seems most promising. This result was corroborated by several other empirical evaluations of AEH systems, which showed that users prefer to have control over personalisation techniques and want to understand a system's rationale for displaying particular content (Bontcheva, 2002; Alpert, Karat, Karat, Brodie, & Vergo, 2003; Papanikolaou et al., 2003, pp. 252).

It is generally acknowledged that every learner model is just the "best guess" of a system. This problem is exemplified in a humorous article by Zaslow (2002) in which the author described several cases of misguided adaptations of the digital recording device TiVo and how affected owners desperately tried to "counter-program" the device (with varying success). Thus, it makes sense to involve the learner at least to a certain extent in the modelling process. As Kono, Ikeda and Mizoguchi (1994) pointed out, all student models are essentially hypothetical and often contain contradictions, which makes them inconsistent. Carver (personal communication, 9 October, 2003) added to this thought by stating that every learner model is at least partially wrong, which is why learners need to have the option to override system choices. In a frequently quoted paper, Kay (2001) also highlighted the need to give control over the learning process back to the learner. Kay pointed out that the learner model should be "scrutable". In other words, it should be accessible by the learner and it should be clear how the system arrived at its conclusions. Kay argues that learning effectiveness can be improved by giving the learner more control and responsibility.

Conversely, giving learners control over the adaptation can also cause problems. The more complex the adaptation options are, the greater the likelihood that learners feel overwhelmed, which is explained by cognitive load theory (Chandler & Sweller, 1996). In addition, the less familiar learners are with the adaptive features of an interface, the less the likelihood that they will use them (Papanikolaou et al., 2003, p. 254). It is conceivable that the learners' general computer proficiency is inversely related to the amount of trust they have in the system's adaptation choices.

In summary, this section showed that it is advisable to give learners control over the adaptation and to encourage them to make choices. Yet, as the review of existing adaptive environments in the learning style field showed, only few systems allowed learners to influence the adaptation. In contrast, iWeaver offered the learner guided choices according to a clear and visible learner model. This approach is described in more detail in the method chapter (section 3.3.3, p. 114).

2.6.3 Benefits of Choice

Giving students a choice can increase learner control. A number of researchers suggested that learners prefer to have control of personalisation techniques and that this increased control is beneficial for the learning process (e.g., Dieterich et al., 1993; J. Kay, 2001).

Learner control is an implicit feature of self-guided contract activity packages (CAPs), which are commonly employed in classroom-based studies on the Dunn and Dunn model (e.g., Lefkowitz, 2001; O'Hare, 2004). A CAP is a collection of learning materials, which offers alternatives for activities and resources that are designed to appeal to perceptual preferences and other dimensions of the model. In a study conducted by Lefkowitz (2001, p. 66), qualitative feedback on CAPs indicated that students enjoyed having choices. According to Lefkowitz and O'Hare, CAPs improve learning because they stimulate multiple senses and students assume responsibility for their learning process. Offering learners a choice between different media experiences in iWeaver re-created a similar scenario to a CAP.

As discussed previously, having a choice between multiple external representations (see section 2.3.3, p. 28) can provide learners with alternative viewpoints of a topic and thus may trigger different computational processes, which enable learners to draw new inferences about the topic. Therefore, multiple versions of instructional materials can promote cognitive flexibility (Spiro et al., 1992). In addition, it can be beneficial to allow users to "drift" in their preferences (Koychev, 2000) during the learning experience.

However, giving learners a choice can result in mismatches between preferences and the customised learning materials. Therefore, the choice approach contradicted the matching hypothesis (see section 2.5.6, p. 58) to some extent. On the other hand, some learning style studies reported beneficial effects for mismatching learners (see section 2.5.7, p. 64). These contradictory findings contributed to the suspicion that choice can be beneficial for learners, even at the "cost" of a mismatch between style and learning materials.

2.6.4 Adaptive Components of an Environment

Brusilovsky (1996) published an influential paper in which he proposed a taxonomy for adaptive hypermedia environments. He divided existing research into "adaptive presentation" (adaptation on a page level) and "adaptive navigation" (adaptation on a curriculum level) approaches. Furthermore, he summarised methods and techniques that were used in these two approaches. In this section, brief outlines of both approaches are presented, including their goals and examples of techniques.

The goal of adaptive presentation is to adapt content at the hypermedia page level. Some examples for adaptive presentation techniques are comparative explanations; conditional text by insertion or removal of fragments (Figure 2-4); stretchtext; altering, sorting or dimming of text fragments (Brusilovsky, 2001), and adapted multimedia presentations.

> In **Xanadu** there was only one protocol, so that part could be missing. Within a node every possible (contiguous) subpart could be the destination of a link.

> In **Xanadu** (a fully distributed hypertext system, developed by Ted Nelson at Brown University from 1965 on) there was only one protocol, so that part could be missing. Within a node every possible (contiguous) subpart could be the destination of a link.

Figure 2-4. Example for conditional text in AHA! (De Bra, 2002, p. 61, emphasis added).

Despite promising results of evaluations of environments that use adaptive presentation techniques, iWeaver did not adapt content at the page level. The main reason for this decision was the limited scope of this project, which did not allow for a finer granularity of the learning materials.

The goal of adaptive navigation is to support learners in finding their optimal learning path through the environment. This is achieved by adapting the appearance or position of hyperlinks or menu items. The behaviour of menus in Microsoft Office applications is a good example for adaptive navigation. Figure 2-5 provides an example for link hiding and Figure 2-6 highlights a link sorting feature in Microsoft Word 2003. Figure 2-7 displays an example for link annotation and incremental linking in the Adaptive Statistics Tutor (Specht, 1998). The effectiveness of these techniques has been demonstrated in several evaluation studies (Eklund & Brusilovsky, 1998; Specht, 1998; McGrenere, Baecker, & Booth, 2002).

Another technique that has been used in information-rich learning environments is progressive disclosure (Hix & Hartson, 1993). This technique progressively increases the complexity of menus or navigation trees by adding more choices. The more the learner becomes familiar with an interface or a knowledge domain, the more navigation options become visible. As a result, the learner experiences less cognitive load, because all accessible content has been visited before.

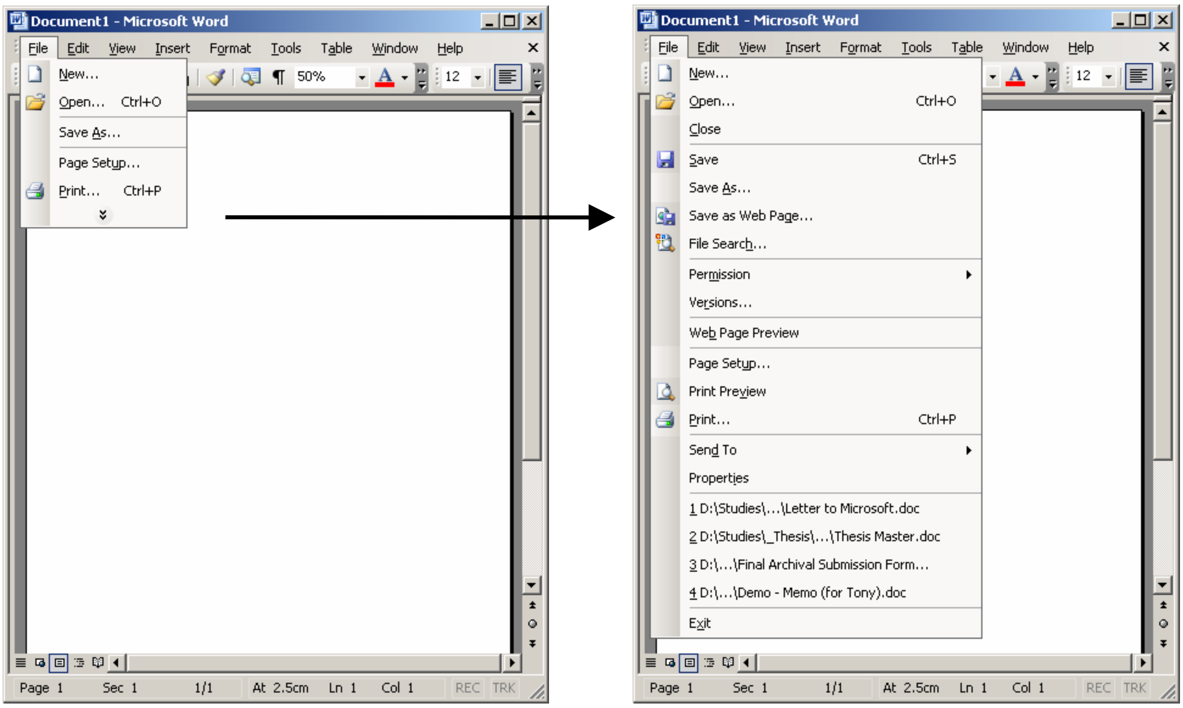


Figure 2-5. Example for link hiding in Microsoft Word 2003. The less frequently used options are hidden from the menu. (Microsoft product screen shots reprinted with permission from Microsoft Corporation.)

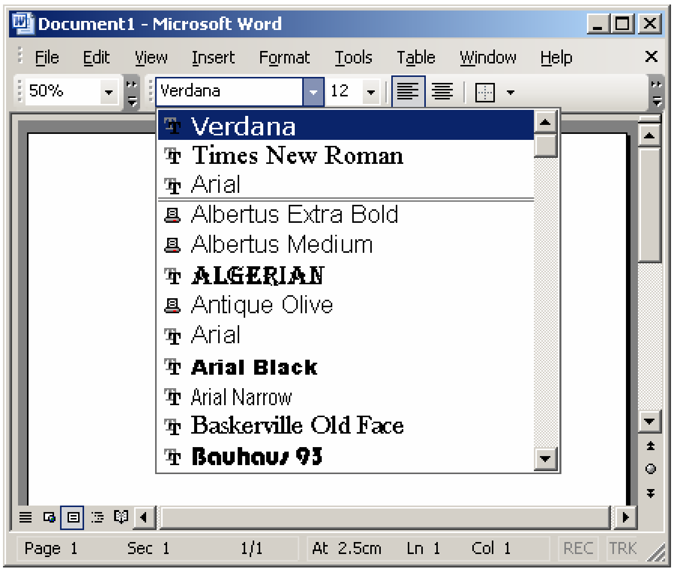


Figure 2-6. Example for link sorting in Microsoft Word 2003. Shortcuts to the most recently used fonts are added to the top of the complete list to allow faster access. (Microsoft product screen shot reprinted with permission from Microsoft Corporation.)

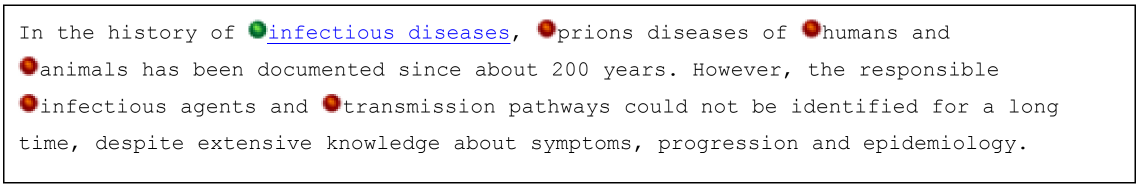


Figure 2-7. Example for link annotation and incremental linking in the Adaptive Statistics Tutor (Specht, 1998, Figure 1, personal translation from German). The colour of the bullet point indicates whether a topic is ready to be learned or not. If the topic is ready to be learned, the respective link appears.

iWeaver incorporated the adaptive navigation techniques link sorting, link hiding and link annotation, which are described in the method chapter. The main goal was to suggest different media experiences depending on the learner's current preferences, whilst minimising cognitive load.

2.6.5 Adaptive Learner Modelling

The adaptation of an educational environment is usually based on a central learner model, which is equivalent to a virtual representation of the learner in the memory of the computer. As Rich noted, "most systems that interact with human users contain, even if only implicitly, some sort of model of the creatures they will be dealing with" (1979, p. 1). The difficult questions are: which parameters should this model include and how should these parameters be measured?

Apart from learning styles, several other parameters have been considered in learner models. Examples include prior knowledge and experience (Mayer & Gallini, 1990), instructional goals, performance related information (e.g., results of exercises), layout preferences (Brusilovsky, 2000), current work and inferred future plans (Carberry, 2001), and emotions or intentions (Martinez, 2001). An interesting approach to measuring the emotional state of students has been developed by Callaghan and Shen (Simonite, 2007): students wore a Bluetooth ring that measured heart rate, blood pressure and perspiration. These data were communicated to a learning environment, which then estimated the level of attention and interest. Accordingly, the flow and format of learning materials were adjusted.

In order to find a common denominator for learner models, the Institute of Electrical and Electronics Engineers (IEEE) proposed a standard named “Public and Private Information for Learners (PAPI) (IEEE, 2000). PAPI included cognitive preferences, but was unfortunately never finalised. Nevertheless, several existing adaptive environments, which are reviewed in a later part of this subchapter, used learning style profiles exclusively as (or as a part of) their learner model.

Data for the learner model can be collected implicitly, explicitly or in a combined approach. An adaptive system gathers data implicitly by observing user behaviour such as time spent on a topic, navigational choices, and results of exercises. In contrast, data are gathered explicitly by approaching the learner directly with questionnaires or feedback forms. Advantages of the implicit approach are that it is less time-consuming and less intrusive. However, assumptions based on implicit data are more likely to be incorrect and thus introduce another confounding factor. For this reason, iWeaver used a mainly explicit approach to build the learner model: a standardised instrument was used to assess the learning style profile and feedback forms were used to gather subjective data for media experiences.

Subjective feedback is important, because user preferences and interests might unexpectedly change during the interaction with the learning environment, due to a hidden context. This phenomenon is referred to as “concept drift” (e.g., Widmer & Kubat, 1996, p. 70) in machine learning research. Koychev (2000) found that the effectiveness of a system’s adaptability is improved if the last observation is regarded as more significant than previous observations.

The two main research directions with regards to matching an environment to a user are *content-based* and *collaborative* approaches. These two approaches were defined by Zukerman and Albrecht as follows:

> In the content-based approach, the behaviour of a user is predicted from his/her past behaviour, while in the collaborative approach, the behaviour of a user is predicted from the behaviour of other like-minded people (2001, p. 2).

The two approaches are not mutually exclusive, thus it makes sense to combine them by using an adequate predictive model. Zukerman and Albrecht (2001) reviewed predictive models and found that Bayesian networks (Pearl, 1988) are particularly suited for a combined approach. These networks were assessed as more flexible, extensible and accurate than competing predictive models such as neural networks. However, due to the primary intention of the iWeaver environment to promote choice, a sophisticated recommendation algorithm such as an adaptive Bayesian modifier (Castillo, Gama, & Breda, 2003) was regarded as unnecessary. Instead, a relatively simple adaptation algorithm was adopted, which is described in the section "adaptive process" in the method chapter.

A simplified example of collaborative matching is the personalised recommendation in online stores such as Amazon (http://www.amazon.com). The computer attempts to infer future preferences by analysing customers' purchase histories in conjunction with their personal information. These patterns are then compared with those of other customers. An extensive collection and review of websites that use collaborative and content matching is available online in a tutorial on personalised recommendation techniques by Jameson (2002).

Conlan (2000) identified three common content-based matching approaches. The first approach uses *stereotypes*. Based on certain variables (e.g., performance in tests or results of a questionnaire), new learners are categorised into stereotypes. Examples for these stereotypes are a classification of their prior knowledge (e.g., novice, intermediate, advanced) and their learning style (e.g., verbal, auditory, kinaesthetic). The second approach uses an *overlay model*. In this approach, the learner's knowledge is continually measured and then remodelled in computer memory. The computer matches the model with an existing content model (also referred to as a "domain model"). Following this, the computer identifies existing prerequisites and only offers content that is ready to be learned. The complexity of the overlay model depends on the granularity of the content. Finally, the *combination model* combines the stereotype and the overlay model. This can be achieved by stereotyping the learner initially and then progressively adjusting the stereotype with the acquisition of more data on learner characteristics, as pictured in Figure 2-8. These data are fed back into the learner model.

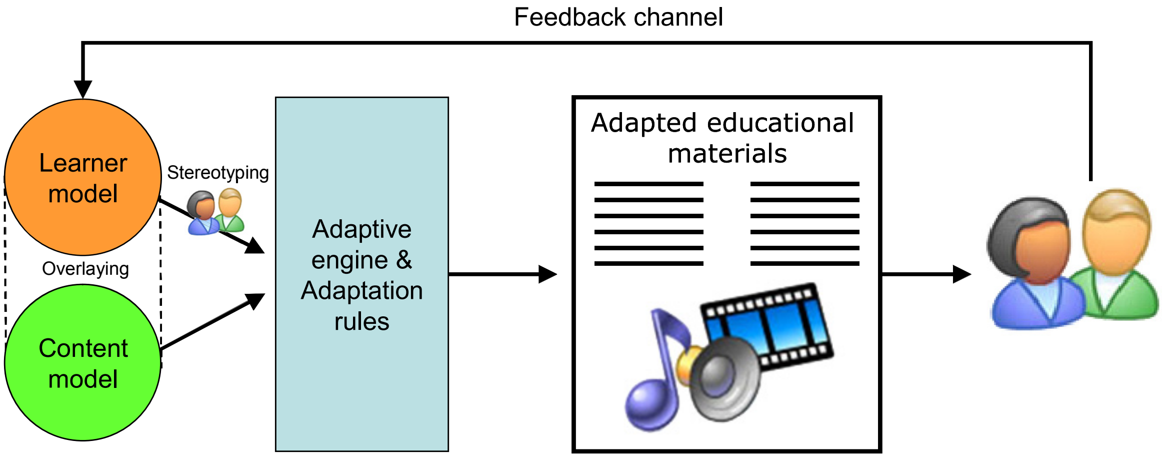


Figure 2-8. Schematic view of a combination model.

The combination model was most suitable for iWeaver. As the primary concern of the environment was the adaptation to learning styles, a stereotype model was used initially. Learners were not locked in to these stereotypes; they could still change their preferences throughout the learning process. These changes were recorded and helped to finetune subsequent recommendations, which is explained in detail in the method chapter (section 3.3.3, p. 114).

2.6.6 Learning-Style Adaptive Environments

Several educational hypermedia systems that adapt to learning styles have been developed over the past few years. This section compares and critically reviews nine existing adaptive environments that contained a learner model and specifically took learning styles into account. Environments are sorted in chronological order. All reviews have an identical structure to facilitate comparisons. First, the learning topic is described, followed by the employed learning style model and the learner modelling approach. Next, the adaptive components are analysed and the locus of control is determined. If an evaluation was reported, findings are summarised. Lastly, limitations of the environment are outlined. The concluding section of this subchapter explains why iWeaver represents a different and unprecedented approach in this field.

CS383

The CS383 (Carver et al., 1996) appears to have been the first AEH system that incorporated individual learning styles. The project was motivated by the problem that learners were confused by a plethora of multimedia materials that was available in a computer systems course. They were uncertain how to use these resources effectively.

Topic: CS383 was a computer systems course in the widest sense. It covered a range of topics including Internet, networks, artificial intelligence, computer graphics and office automation.

Model: CS383 used the Felder & Silverman learning style model (Felder & Silverman, 1988) and the respective "index of learning styles questionnaire" (Felder & Soloman, 1996).

Modelling Approach: The learning style profile was assessed in an initial survey.

Adaptive Components: Every resource type (e.g., glossary terms, movies, sound files, graphics) was rated out of 100% with regards to suitability for a particular learning style. The participant's learning style profile was then compared with the ratings of available resource types (by using an overlay model) and the best matching resource was suggested.

Locus of control: CS383 adapted itself once, after the survey. Learners could choose different resources to those suggested, but they could not influence future suggestions nor change their learner model.

Evaluation: No formal evaluation was reported. The researchers collected casual learner feedback and described it as uniformly positive.

Limitations: CS383 showed four limitations in the design of the environment. Firstly, active and reflective learners were not addressed explicitly, because Carver regarded the existing components as inherently suitable for both learner types (this raises definition issues regarding what "active" learning means; for example, Carver asserted that "making choices" was sufficient to satisfy active learners). Secondly, learners were classified as stereotypes at the beginning of the course and there was no ongoing adaptation. Thirdly, the media materials existed first and then they were classified as to how suitable they were for specific learning styles. Fourthly and lastly, learners could not influence their learner model in the environment.

CAMELEON

CAMELEON (Laroussi & Benahmed, 1998) is an acronym for Computer Aided Medium for Learning On Network. The paper reported on a work in progress; the completed project is described in the thesis by Laroussi (2001).

Topic: No topic was reported in the paper.

Model: The system used the Felder & Silverman learning style model (Felder & Silverman, 1988) and the respective “index of learning styles questionnaire”.

Modelling Approach: The learning style profile was assessed in an initial survey.

Adaptive Components: Available media types and course tools were rated on a scale from 1 to 100 on how suitable they were for particular learning styles.

Locus of control: CAMELEON adapted itself once, after the survey. It assembled a set sequence of materials for individual learners based on their learning style. However, learners could choose to ignore their learning style and freely explore the environment.

Evaluation: A short, informal evaluation was reported in the thesis (Laroussi, 2001). Students were asked five questions such as “Could you work effectively with CAMELEON?” (p. 167) with yes/no answers. Results indicated that students enjoyed and appreciated the environment. However, the questions could have been leading the students.

Limitations: CAMELEON showed two limitations in the design of the environment. Firstly, the active/reflective learning style elements were dismissed based on the assumption that these learners are inherently catered for by the nature of an AEH system. Secondly, the media materials existed first and then they were rated on a scale as to how suitable they were for specific learning styles.

Arthur

Similar to CS383, Arthur (Gilbert & Han, 1999; Gilbert, 2000; Gilbert & Han, 2002) was also a web-based environment. A novel aspect of Arthur was that the instructional materials were specifically designed for learning styles. Arthur used a metaphor of different virtual instructors, who each presented instructional materials in a different perceptual style.

Topic: Arthur taught computer programming in C++ in phase one of the evaluation and then Planck's Constant in phase two.

Model: Arthur was based on a perceptual model proposed by Sarasin (1998) with auditory, visual and tactile elements. However, no psychometrical instrument was used.

Modelling Approach: The initial teaching style allocation to a learner was random. After a lesson, the performance in multiple choice exercises was measured to determine whether the currently allocated style was a match or not. If less than 80% of the answers were correct, case-based reasoning (collaborative matching) was used to compare the learner with other learners who made similar mistakes. If a matching learner was found, the teaching style recommendations of the two learners were aligned.

Adaptive Components: Arthur used two adaptation dimensions. Firstly, there were four different presentation styles: visual-interactive (interactive Java applets), auditory-text (streaming audio), auditory-lecture (streaming audio and video) and a text-only presentation. Secondly, the order of explanations and examples could be interchanged.

Locus of control: During phase one of the evaluation, Arthur was adaptable. If learners achieved less than 80% in a multiple choice test, they could freely choose their new learning style. In phase two, Arthur was adaptive: the system made the choice for the learners by using case-based reasoning, as described above.

Evaluation: Two evaluations were reported (Gilbert & Han, 2000, 2002). In phase one, 89 participants used an adaptable version and in phase two, 21 participants used an adaptive version. Results from phase one can be used as supportive evidence for adaptive instruction in general. Gilbert and Han reported that it took students on average 1.72 attempts to pass a given concept by using 1.42 different instructional methods. This indicates that it was beneficial for students to repeat a concept in a different style.

Limitations: Arthur showed three limitations. Firstly, the "allocate first, correct later" method is problematic, because its accuracy is questionable and it might frustrate learners if they are initially mismatched. The second limitation was the absence of an assessment instrument. Finally, the two reported evaluations did not use a control group, which means the results offered no insights about differences between adaptive, adaptable or static learning environments.

SILPA

SILPA (Martinez & Bunderson, 2000; Martinez, 2001) is an acronym for the term "system for intentional learning and performance assessment". It represents a unique approach to adapting hypermedia, because it includes conative factors such as emotions and intentions.

Topic: Martinez used an introduction to the Internet named "Discovering the World Wide Web" for her environment.

Model: Martinez used her own learning style model, the "learning orientation construct" (LOC).

Modelling Approach: The LOC included four orientations: transforming, performing, conforming, and resistant. Learning attributes such as motivation, self-directedness and goal setting strategies varied for each orientation. The learning orientations were assessed at the start of the course by a corresponding "learning orientation questionnaire".

Adaptive Components: There were three versions of SILPA for the first three orientations—resistant learners were excluded. The transforming version of SILPA exposed matching learners to an intervention named "intentional learning training" at the start of the course. Both the transforming and the performing version included an "iCenter", which provided metacognitive assistance to learners. iCenter offered learning resources, a learning progress map, help for setting goals and for reflecting on learning preferences. In contrast, the conforming version of SILPA did not include iCenter. It consisted of a restricted, linear-sequenced, menu-driven environment.

Locus of control: Transforming and performing learners could self-elect to visit all other versions of the environment (adaptable); conforming learners were locked to their version (adaptive).

Evaluation: 71 participants were tested for their learning orientations and then randomly allocated to one of the three versions of SILPA. There were four dependent variables: learner satisfaction, learning efficacy, intentional learning performance, and achievement. The results showed a statistically significant positive effect on satisfaction and learning efficacy, when the environment matched with the learning orientation.

Limitations: SILPA showed two limitations. Firstly, Martinez used her own model, which was relatively new and consequently had a limited corroborating research base. Secondly, only certain learners could change between the three versions and their choices were not considered in the learner model.

iMANIC

iMANIC (Stern, 2001; Woolf et al., 2001, pp. 131-138) is the web-based version of an earlier adaptive environment named MANIC (multimedia asynchronous networked individualised courseware). Even though MANIC was classified as an ITS by its author, it demonstrates numerous properties of AEH systems. Therefore, it was included in this review.

Topic: iMANIC taught an introductory course on computer networking.

Model: No concrete model was referenced, but the adaptation options indicated the perceptual VAK model was used in combination with the information processing elements global and analytic.

Modelling Approach: iMANIC adapted to explicitly expressed media preferences and individual learner's knowledge level. This level was measured by quizzes, time spent on topic, and whether a topic was accessed repeatedly.

Adaptive Components: The adaptation techniques included stretchtext (easy/hard explanations), generated slides with different media types (audio/video/text) and content sequencing (e.g., definition first or example first). Preferred media types and content sequences were predicted by using a naïve Bayes classifier. The suggestion for the next topic was dependent on the measured knowledge level of the preceding topics.

Locus of control: iMANIC was mainly adaptive. The content adaptation was based on previous elections to view or hide certain objects. However, the system also allowed for limited learner control: learners could select a topic that contradicted the system's recommendation.

Evaluation: A small online evaluation was described in (Stern, 2001, p. 112). Data were collected in a repeated measures design under adaptive and non-adaptive conditions. However, many students quit the evaluation before they reached the midway-point. Therefore, only the data from 10 students could be used for the statistical analysis. As a result, only three limited conclusions were offered: (1) repeated measures designs have to be executed with care. (2) The calculated Bayes classifier differed between individuals, thus students seemed to learn differently. (3) The computer tutor was able to learn student's preferences, but it "must be able to continue to adapt and learn since the best policies for a given student may change" (p. 136).

Limitations: iMANIC showed three limitations in the design of the environment. Firstly, learners self-assessed their learning style preferences, rather than using an instrument that was tested for validity and reliability. Secondly, the media materials existed first and then they were classified as to how suitable they were for specific learning styles. Lastly, the time spent on a topic was assumed a measure of how well a topic was learned. This assumption was acknowledged as flawed, because for example, the learner could have left the room for a few minutes.

3DE

3DE (Corso et al., 2001, 2002; Corso & Ovcin, 2004) is an acronym for "Design, Development and Delivery—Electronic Environment for Educational Multimedia". It was a European multi-national project, which included researchers, developers and participants from Italy, France, Spain and Finland. The project website is http://www.3deproject.com.

Topic: Several authors worked on different topics in parallel, for example on an electronics course and a course about semiconductors.

Model: 3DE used the Honey and Mumford learning style model, which is based on Kolb's model (1984). Accordingly, the system divided learners into four styles: activists, reflectors, pragmatists and theorists.

Modelling Approach: At the start of a course, the learner had to fill in a learning style questionnaire. The original learning style questionnaire with 52 questions was considered excessive by participants and was subsequently reduced to 26 questions.

Adaptive Components: A custom course compiler assembled "micromodules" to coherent courses. The compiler considered the personal learning style, learning goals, previous knowledge and the preferences of a learner for the course adaptation.

Locus of control: 3DE suggested a customised learning path, but still allowed for limited learner control. In a prototype version, learners could choose a different style in order to develop their “weaker” styles, but only at boundary points between themes. However, this feature was not offered in the evaluation, in order to magnify the effects of matching and mismatching.

Evaluation: A cross-cultural experiment was conducted in four countries (Finland, France, Italy, and Spain) to investigate in what way a matched or mismatched style influences learning performance (Militello & Ovcin, 2003). In each of the countries 40 participants were selected based on their learning style profile. The participants were divided into two groups with an even style distribution. They studied two learning modules on occupational health and safety, followed by a knowledge test after each module. In a repeated measures design, one group received the first module matched for their best learning style and then the second module matched for their worst style. The other group received their modules in the opposite matching order.

An analysis of all test scores revealed a statistically significant difference between best and worst matched learning style, which supports the matching hypothesis. However, at closer examination of the individual results, only two out of four panels (French and Italian) showed a statistically significant difference in their test scores. The authors surmised that the stronger technical background of those two panels reduced noise (e.g., difficulties with the comprehension of context) and therefore emphasised the effect of personalised instruction. Another unexpected observation was that some scores (e.g., those of Italian theorists) were better when the instruction was adapted for the *worst* style, which leaves room for further questions. Additionally, the order of matching and mismatching seemed to play a role: in the Finnish and Spanish panels, the scores for the best learning style were only higher if that style was matched first.

Limitations: 3DE did not explicitly support ongoing assessment and adaptation. It was possible for learners to switch learning styles at boundary points between different themes, but this feature was not offered in the evaluation.

INSPIRE

INSPIRE (Papanikolaou, Grigoriadou, Kornilakis, & Magoulas, 2002; Papanikolaou et al., 2003) is an acronym for the term “intelligent system for personalised instruction in a remote environment. INSPIRE was in many ways similar to iWeaver.

Topic: The papers described an application of INSPIRE to teach an introductory course on computer architecture, but the environment was generic and could also be used for other topics.

Model: INSPIRE used Honey and Mumford's learning style model, which is based on Kolb's experiential learning model (1984). Accordingly, the system divided learners into four types: activists, reflectors, pragmatists and theorists.

Modelling Approach: INSPIRE adapted to a learner's knowledge level and learning style.

Adaptive Components: INSPIRE adapted presentation, navigation and sequencing of the curriculum. Sequencing of materials was dependent on the learning style. The estimated level of knowledge was indicated by a measuring cup metaphor. A flashlight icon proposed which page to visit next (link annotation).

Locus of control: The learners could inspect the full model and adjust their learning style and level of knowledge. They could also switch the adaptation completely off. As such, the locus of control was shared between the learner and the system.

Evaluation: INSPIRE was evaluated with an experimental study: 23 undergraduate students were working with the environment for two and a half hours as part of their mark. Measurements were open and closed questions and clickstream data (navigational choices, total time spent on certain material types, test scores). Results revealed different access patterns for different learning styles. Students were satisfied with the adaptive approach. They found the adaptive interface easy to understand and commented that it was easier to find specific information compared to reading handouts. Some students also noted that the availability of multiple types of knowledge modules kept them alert and concentrated. Most students preferred to have access to their learner model and control over the system.

Limitations: INSPIRE showed several limitations in the design of the environment as well as in the evaluative study. Firstly, the study was executed without a control group. Secondly, only about 50% of the learners filled in and submitted the learning style questionnaire; the rest self-assessed their learning style or ignored the feature. As mentioned before, self-assessment does not have the same validity and reliability as other instruments. Lastly, learner interaction with the system was relatively short (two and a half hours). This had the side-effect that some learners avoided adaptive features because they were not yet familiar with them. For example, almost two thirds of the participants never changed their learning style.

With regards to the design of INSPIRE, two limitations were identified. Firstly, the learning style model focused solely on the information procession dimension. Other dimensions, such as the perceptual dimension, were not considered. Secondly, INSPIRE did not provide different learners with different versions of educational material, but with a different sequence of knowledge modules (e.g., activities, examples, hints from theory, exercises). Whilst this approach is resource-efficient as it re-uses existing materials for the adaptation, it might not be sufficient to merely alter the sequence of knowledge modules to accommodate different learning styles.

ILASH

ILASH (Bajraktarevic & Fullick, 2003; Bajraktarevic et al., 2003) is an acronym constructed from the term "incorporating learning strategies in hypermedia".

Topic: Two web-based courses were used as exemplary topics: "countries of the world" and "ozone layer depletion".

Model: ILASH used the Felder & Silverman learning style model (Felder & Silverman, 1988) and the respective "index of learning styles questionnaire" (Felder & Soloman, 1996), but only the global/analytic elements were considered in the adaptation. ILASH also considered the knowledge state of each learner.

Modelling Approach: Learning style profiles were assessed in the initial questionnaire. The students' knowledge level was measured to adapt the navigation, but this feature was not used as an independent variable.

Adaptive Components: There were two versions of ILASH: (1) a sequential version that included small chunks of information and only "forward" and "back" links and (2) a global version that contained tables of contents, overviews, summaries, and was more interlinked. Adaptive navigation techniques were used to highlight links to content that was ready/not ready to be learned. Progression to the next topic depended on mastery of check points.

Locus of control: The system was in full control of the learning style adaptation.

Evaluation: An empirical evaluation was carried out with 21 Year-10 students in a repeated measures design. First, the students were exposed to a matched version of the environment for the first course, then to a mismatched version for the second course. With regards to student achievement, statistically significant differences were found between pre- and post-test: students achieved higher scores in matched courses than in mismatched courses.

Limitations: ILASH showed two limitations. Firstly, its matching/mismatching approach was solely based on the information procession dimension and the perceptual dimension was not considered. Secondly, due to the focus of this study on the effects of matching and mismatching, learners could not switch between styles.

EDUCE

EDUCE (Kelly & Tangney, 2004, 2005; Kelly, 2005) was named with reference to the Latin expression "educere", which means "lead out, bring out or develop from latent or potential existence." EDUCE is similar to iWeaver, because it was built to investigate the effects of adaptation to perceptual styles and the continual adaptation to learner behaviour.

Topic: The EDUCE learning materials were computer based tutorials on the topics "static electricity" and "electricity in the home".

Model: Gardner's theory of multiple intelligences (1983/1993) was used to create different versions of the learning content.

Modelling Approach: A multiple intelligence inventory named MIDAS was completed by students before they entered the learning environment. In EDUCE, multiple factors were measured for a continuing adaptation, including time spent on a resource, order and repetition of resource visits, and success in attempts to answer questions.

Adaptive Components: The student's multiple intelligence profile was matched and mismatched with different, custom-designed types of resources. EDUCE's scope was limited to four out of the eight intelligences (Gardner, 1999): logical/mathematical, verbal/linguistic, visual/spatial, musical/rhythmic.

Locus of control: Four adaptation approaches were compared in two reported evaluations: free choice (no adaptation), one single adaptation (static profile), adaptive plus choice (static profile), and adaptive plus choice (dynamic profile).

Evaluation: Two evaluations were carried out in a repeated measures design; the first with 70 students (average age 14) and the second with 47 boys (average age 13). Independent variables were “choice” and “presentation strategy”. Students were intentionally matched and mismatched with learning resources. Results of both studies indicated that low activity students learned better with learning resources they did not prefer, whereas the level of control had no conclusive effect on learning gain.

Limitations: In comparison to iWeaver’s approach, the adaptive plus choice (dynamic profile) condition in EDUCE was similar. However, a possible limitation of the EDUCE approach was that the environment automatically pre-selected a matched or mismatched resource first and only thereafter learners were given a choice of other resources. Thus, a free choice (dynamic profile) condition, as offered by iWeaver, was not investigated. Additionally, EDUCE provided no clues for the learner how well suited the offered resources were.

2.6.7 Conclusions and Novel Aspects of iWeaver

According to earlier literature reviews on adaptive systems conducted by Chin (2001) and McGrenere (2002), a major problem of this research field is the lack of evaluation studies. McGrenere suggested that this problem is related to the greater number of variables in adaptive interfaces, which renders user studies more complex. The problem is exacerbated in learning-style adaptive environments, because learning style models are often multi-dimensional. McGrenere concluded that further work is required, which compares adaptive with static user interfaces to determine the advantages and disadvantages of each interface type.

The review of adaptive environments in the previous section confirms the problem of lacking evaluations to some extent. Seven out of the nine environments were formally evaluated, but only four evaluations (SILPA, 3DE, ILASH, EDUCE) were well-designed with randomly allocated participants and control groups. Thoroughly designed evaluations are crucial in this field to isolate flaws and minimise confounding factors. Hence it was regarded as essential to evaluate iWeaver in an experimental design with a control group.

In summary, three general deficits were identified in the design of the nine reviewed environments.

1. Limited learning style models. Three environments (INSPIRE, iMANIC, and Arthur) did not use an instrument to assess learning styles, but relied on self-assessment. Using subjective self-assessment as the main driver for adaptation can be problematic, as it does not have the same reliability and validity as assessment instruments from established learning style models. Furthermore, four environments (INSPIRE, 3DE, SILPA and ILASH) did not include the perceptual dimension, despite the wide recognition of this dimension in the literature (see section 2.5.5, p. 54). Two environments (CS383 and CAMELEON) used the Felder and Silverman model, which lacked reliability and validity studies at the time this project was commenced. In the meantime, however, several studies corroborated this model (Felder, 2005a).

2. Limited adaptive components. The adaptive components of most reviewed environments with the exception of 3DE, Arthur and EDUCE were compiled from pre-existing media materials. These materials were recycled from earlier courses and then classified as to how suitable they were for specific styles or they were slightly adapted. In contrast, iWeaver used custom-designed multimedia representations and learning tools that were specifically developed for this project. The design decisions were based on an adaptation framework that was developed by reviewing studies with successful perceptual style adaptations (see method chapter, section 3.2.6, p. 104).

3. Limited learner control. Three environments (CS383, CAMELEON and ILASH) based their adaptation solely on an initial assessment of the learning style profile, which was then expected to remain stable. Three environments (Arthur, SILPA and 3DE) allowed the learner to switch between learning styles, but only under certain conditions. Only one environment (EDUCE) used learner behaviour and expressed media preferences to further finetune the learner model.

In line with the argument in the learning styles subchapter (see section 2.5.2, p. 42) that there is a trend to acknowledge flexibility in learning styles, it seemed counter-productive to lock learners to a statically adapted learning style profile without learner control. Rather, a flexible adaptation approach, which attempted to leverage the benefits of choice (see section 2.6.3, p. 72), seemed more adequate. Consequently, iWeaver allowed learners to choose and switch between learning styles at virtually any point in the learning process. These choices were recorded and used to continuously revise the learner model and to adapt future recommendations.

2.6.8 Summary

This subchapter defined the terms “adaptive educational hypermedia” and “intelligent tutoring systems”. Even though both research fields share the same idea of adapting the teaching approach to the learner, they differ in their focus. ITSs mainly employ problem solving support, whereas AEH adapt educational materials. Following this differentiation, iWeaver was classified as an AEH environment.

ITSs were the predecessors of AEH and their rationale, successes and problems had a profound impact on adaptivity research. ITSs tried to imitate human tutors and duplicate their effectiveness. Several ITSs were successful, but their application was mostly limited to procedural domains. Additionally, their development proved to be difficult and time-consuming. Authoring systems tried to overcome these deficits, but only succeeded in scaffolding low-level decisions. Authors still needed to reconceptualise content in a flexible fashion, which was the actual difficult task. Another problem was that metacognition and reflection became important processes for learning environments. However, these processes were hard to formalise in an ITS, which contributed to the increased focus on AEH.

Next, this subchapter investigated the issue of learner control and the dichotomy of adaptivity and adaptability. In adaptive systems, the locus of control lies with the system, whereas in adaptable systems the locus of control lies with the learner. Currently, there is a trend towards giving the learner more responsibility over the adaptation process. Increased control has several advantages, including improved learner confidence in system choices and more accurate learner models. Nevertheless, increased control can also cause problems. For example, learners could be overwhelmed by too many choices or ignore unfamiliar adaptation options.

Extending from the concept of learner control, the potential benefits of choice were summarised. Having a choice of media experiences in iWeaver created a similar scenario to self-guided contract activity packages (CAPs). CAPs include learning materials for multiple styles and have been successfully employed in classroom-based environments. Additionally, a choice between multiple external representations promotes cognitive flexibility and it allows for drifting user preferences. Furthermore, giving learners a choice can potentially resolve the discussion on whether matching or mismatching styles is more beneficial.

One major research area in adaptivity concerns which components of an environment can be adapted. This area can be subdivided in adaptive presentation and adaptive navigation. The goal of adaptive presentation is to adapt content at the hypermedia page level, whereas the goal of adaptive navigation is to support learners in finding their optimal learnng path through the environment. Due to the coarse granularity of iWeaver's learning components, it made sense to use adaptive navigation techniques such as link sorting, link hiding and link annotation.

A second major research area in adaptivity concerns what the environment can be adapted to. The adaptation is usually based on a central learner model, which is held in computer memory. Several parameters such as prior knowledge or learning goals can be integrated into the learner model. Parameters can be measured either implicitly by deriving them from learner behaviour or explicitly by asking the learner directly. Both methods were used in iWeaver. To recommend media experiences, iWeaver used a combination model by stereotyping a learner initially and then adjusting the model later.

Finally, this subchapter critically reviewed and compared nine educational hypermedia systems that adapt to learning styles. Consistent with other literature reviews, it was found that adaptive environments were often limited in their evaluations. For example, only four of nine reviewed environments were evaluated empirically in well-designed studies.

Three general design issues were identified in existing environments. Firstly, the applied learning style models had limitations. Several were based on self-assessment; others did not include the perceptual dimension, which is widely recognised in the literature. Secondly, adaptive components were rarely custom-designed. Instead, existing media were often re-used from earlier courses. Thirdly, existing environments often restricted learner control. This project attempted to overcome the identified limitations by (1) using a well-researched and more comprehensive learning style model, (2) using custom-designed media representations and learning tools, and (3) allowing learners to choose and switch between styles at any time.

3 METHOD

3.1 Introduction

This chapter describes the technical instrument that was developed as part of this project and its evaluation approach. The main outcome of this chapter was the final prototype of iWeaver, which is considered as an answer to the first research question on how an e-learning environment can adapt itself to accommodate individual learning styles.

First, didactical details of the learning materials are discussed, followed by an overview of how a learner progresses through the environment. Then, the user interface and navigation of iWeaver are introduced together with the media experiences and learning tools that were developed to cater for different learning preferences. The next subchapter covers the design and production of iWeaver. Following, the experimental design used for the data collection is detailed. The last subchapter is a report of the actual experimental evaluation of iWeaver. It also describes the statistical analysis approach and the steps that were taken to avoid threats to the validity of the evaluation.

3.2 Didactic and Interface Design

This subchapter describes the learning materials and the considerations that were taken into account for the design of the user interface and the navigation. Next, the learning style assessment instrument is explained and a high level view of the "flow" of the learner through the environment is provided. Finally, the iWeaver approach to adapt learning materials and tools to learning preferences is detailed.

3.2.1 Learning Objectives and Course Content

In order to construct an e-learning environment, the topic "computer programming" was selected. A short course with title "An Introduction to Java" was created, consisting of seven lessons, which are listed in Table A-1 and Figure A-1 in the appendix.. The course was based on the first two out of six modules of an online course that was offered by the tele-akademie in Furtwangen, Germany.

The computer programming topic was chosen for several reasons. Firstly, expert-refined and validated learning materials were available, which were kindly provided by the tele-akademie (see appendix, section A2). Secondly, it was a relatively straightforward task to re-design the materials of a computer-related topic for a computer-based environment. Thirdly, Java was considered a timely and desirable learning objective for potential participants. Lastly, computer programming is an abstract topic, which opened opportunities to develop different representations for the same concept by employing different media experiences.

The course was designed to teach generic programming skills by using Java as an exemplary language. The learning materials covered the following learning objectives:

1. Find and resolve syntactic and semantic errors.
2. Structure a program and make it reader-friendly.
3. Create and use variables of different data types.
4. Correctly and efficiently integrate decision points into programs.
5. Correctly and efficiently integrate loops into programs.
6. Create and access an array with multiple values.

Even though the lessons were interrelated, they did not depend on each other as prerequisites. Therefore, mastery of a lesson was not a requirement to progress and past lessons could be revisited for clarification. This means even if a participant performed poorly in one lesson, he or she could still do well in the next lesson.

As a first step, the learning materials needed to be translated from German to English. This work was carried out mainly by the researcher, but with support from a professional translator. Once translated, the learning materials formed the basis for the course content. Then, the materials were instructionally enhanced by employing signal words (Mautone & Mayer, 2001) to improve the flow of the text. New terms were visually distinguished by printing them in blue and italic on their first occurrence. In addition, paragraph structure was improved by introducing topic sentences where required. By subdividing the materials into smaller chunks (Gagné, Briggs, & Wager, 1992, p. 68; Matlin, 2002, p. 173) with individual headlines, a tree-like content hierarchy was created.

Several studies indicated that a tree-like structure is helpful for novice learners and ill-structured materials. For example, experiments conducted by Pollock, Chandler and Sweller (2002), showed that cognitive load is reduced for novices, if ill-structured content (i.e., high element interactivity) is taught in a serial manner. Similarly, Shin, Schallert and Savenye (1994) investigated the effect of content structures in a hypermedia learning environment and found that hierarchical (as opposed to networked) structures led to higher test grades. In accord with these findings a hierarchical, tree-like content structure was built that revealed content pages progressively.

Following the textual version, three additional versions of the learning materials were designed, to accommodate the different perceptual styles, as described in section 3.2.6 (p. 104). Concurrently, several learning tools were created to support different information processing styles and to offer the learner more options to interact with the environment.

The course content of iWeaver was considered validated. They represent a subsection of a Java course that has been taught online (with online tutor support) since 1996 at the tele-akademie and required no prior programming knowledge. iWeaver was based on the 2002 revision of the learning materials. Between 1996 and 2002, the course ran on average twice a year. During and after each course, content improvement suggestions and general feedback was collected from participating tutors and students as part of the quality control protocol of the tele-akademie. A subject matter expert and instructional designers integrated these suggestions (wherever possible) into the content. As a result of these continuing improvements, the Java learning contents were considered validated, well-designed and well-structured.

3.2.2 The Building Excellence Survey

The initial learning style assessment in iWeaver was carried out with the BES (Rundle & Dunn, 2000). The assessment covered the six dimensions of the "puzzle of learning" as pictured in Figure 2-2 (see p. 51), which was derived from the Dunn and Dunn model (1993). The BES uses stem and leaf statements that have to be rated on a five point Likert scale, as pictured in Figure 3-1.

From the six dimensions of the puzzle of learning (perceptual, psychological, environmental, physiological, emotional, and sociological, see Figure 2-2, p. 51), two were accommodated with individual media representations and learning tools: the perceptual and the psychological (information processing) dimension. As explained in the background chapter, it was relatively uncomplicated to accommodate these preferences within an e-learning environment. In addition, their properties align well with the dimensions of other established learning style models.

To transfer the BES from its paper-based version into an online version for iWeaver, several minor alterations were required. For example, the paper-based version asked participants to contextualise their answers by selecting and imagining themselves in a learning situation. The selection included statements such as “you need to learn how to operate a new piece of equipment” and “you have to study for an important exam”. In contrast, the learning situation in the iWeaver version is permanently set to “you are sitting in a training session learning a new software program”. The learning situation was made static and clearly visible during the entire survey (pictured in Figure 3-1) for two reasons. Firstly, it removed the context variable from the learning style assessment by making the context closest to the task at hand (learning a new programming language). Secondly, participants in the pilot tests often forgot about their initial selection and asked the experimenter for clarification about the context of their replies.

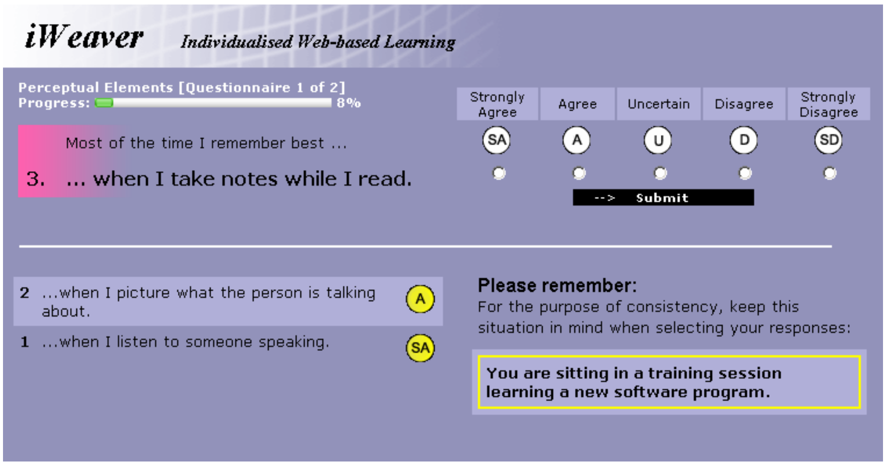


Figure 3-1. Sample question from the Building Excellence Survey (Rundle & Dunn, 2000).

Another difference between the online version and the paper-based version was that participants were not able to “peek ahead” in the online version. Statements appeared on the screen sequentially, so participants could not see how many more questions they still had to answer. A negative side-effect of this alteration was a risk for learners to lose track of their progress and to become frustrated. To compensate for this deficit, the different learning style dimensions were colour-coded and a progress bar was introduced to visualise a participant’s progression through the survey.

On completion of the BES, participants received the results of their learning style assessment and a brief interpretation based on the "guide to individual excellence" (Rundle & Dunn, 2000). An excerpt of this interpretation can be found in the appendix, section C4. To encourage participants to choose multiple media experiences, they were reminded that their learning style profile was meant to be viewed as an indication only and that it may change depending on the context.

To keep participants motivated at the start of the evaluation, the BES was divided into two sections. The two dimensions that were relevant for iWeaver were assessed before the evaluation and the four dimensions that were irrelevant afterwards.

3.2.3 Learner Progression through iWeaver

To provide a big picture of iWeaver, the diagram in Figure 3-2 displays the progression of a learner through the environment. For simplicity reasons, only essential steps are displayed in the diagram; a more detailed description of a lesson sequence follows later in this section.

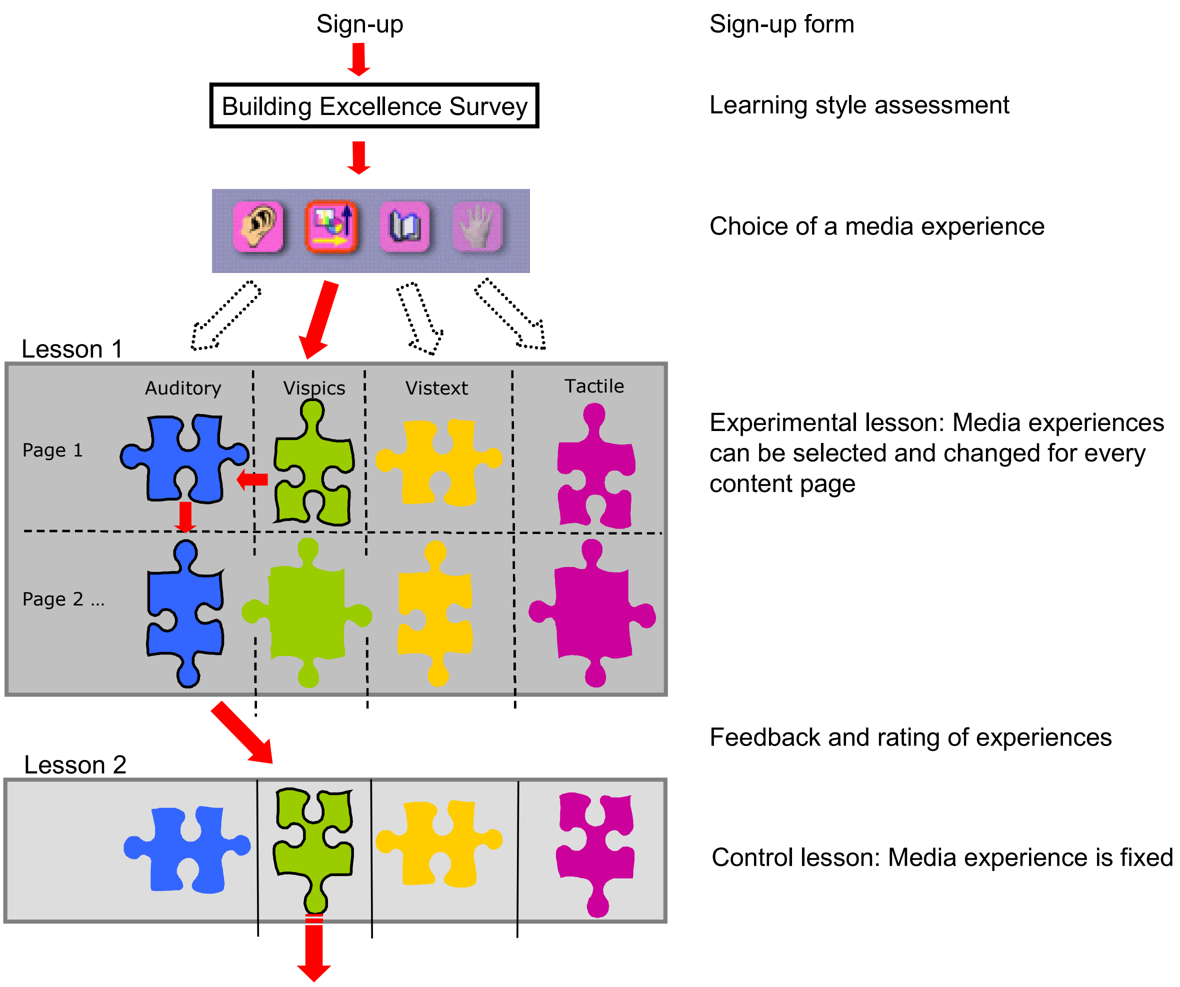


Figure 3-2. Flowchart of iWeaver detailing the stepwise progression of the learner.

To begin with, participants signed up to iWeaver by using a form (see appendix, Figure C-1). Next, participants answered the first two sections of the BES. The results were displayed on the screen with a brief interpretation. These results were stored as a learning style profile, which was used for the initial adaptation of iWeaver. A learner's most-preferred style was recorded as the control style for the no choice lessons. In case of even scores for several most-preferred styles, one of them was randomly selected as the control style.

To investigate the impact of choice, lessons alternated between two conditions: either participants had a choice between four media experiences (dynamically adaptive), or they had no choice (statically adapted). In the latter case, only one media experience was displayed, which was matched for their control style. In contrast, in choice lessons, participants were free to switch experiences for every content page. Between lessons, participants were assessed and had to leave feedback. This feedback, in combination with the participants' navigational data, influenced the adaptive recommendation of media experiences (see section 3.3.3, p. 114) for the next choice lesson.

Every lesson followed the same sequence, as pictured in Figure 3-3. At the beginning of a lesson, participants were pre-tested with multiple choice questions. No feedback on performance was provided after the pre-test. In the next step, participants were shown a short introductory text on the lesson's topic. This text acted as an advance organiser in choice and no choice lessons and it was also meant to assist participants in choosing a media experience in a choice lesson.

At the beginning of a choice lesson, participants had to choose one out of four media experiences (Figure 3-14, p. 115). Experiences were presented as a weighted recommendation, based on the initially measured learning style profile. For the remainder of the lesson, learners were free to switch between experiences by using the media experience bar. In contrast, in a no choice lesson, participants could not choose or switch between media experiences, but learning content was presented with the media experience matched for the participant's control style. The two groups switched between the choice and no choice condition after each lesson.

At the end of each lesson there was a post-test, in which learners were again asked the questions from the pre-test. However, this time iWeaver provided feedback on their performance and gave the correct answers after the test. The post-test section was followed by a lesson summary and a lesson feedback form. In this form, participants rated the media experience(s) they used in that lesson and answered questions about their perceived enjoyment, progress, and motivation as described later in this chapter (section 3.4.6, p. 128). Participants could also leave additional comments in free-text fields.

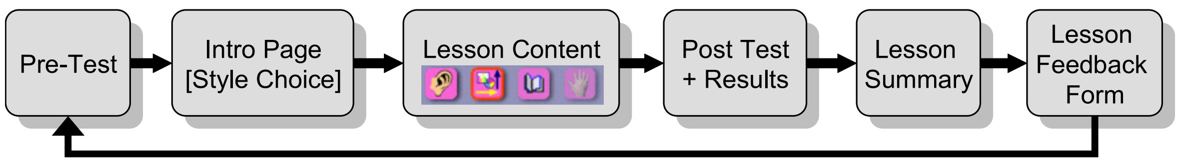


Figure 3-3. Lesson sequence from pre-test to lesson feedback.

After the completion of the last lesson, participants could answer the remaining four sections of the BES and finally they could examine their complete learning style interpretation.

3.2.4 Navigation and User Interface

It is essential that usability issues are considered and eliminated wherever possible to avoid a negative impact on the teaching and learning process (Bourges-Waldegg, Moreno, & Rojano, 2000). This section describes the user interface and the guidelines that were taken into account for its design.

Figure 3-4 depicts the main user interface of iWeaver, with individual components described below. Note that when learners switched between experiences (via the media experience bar), merely the content area in the centre of the screen changed. Therefore, the screenshots of the different media experiences in the continuation of this subchapter were taken of the content area only to conserve space.

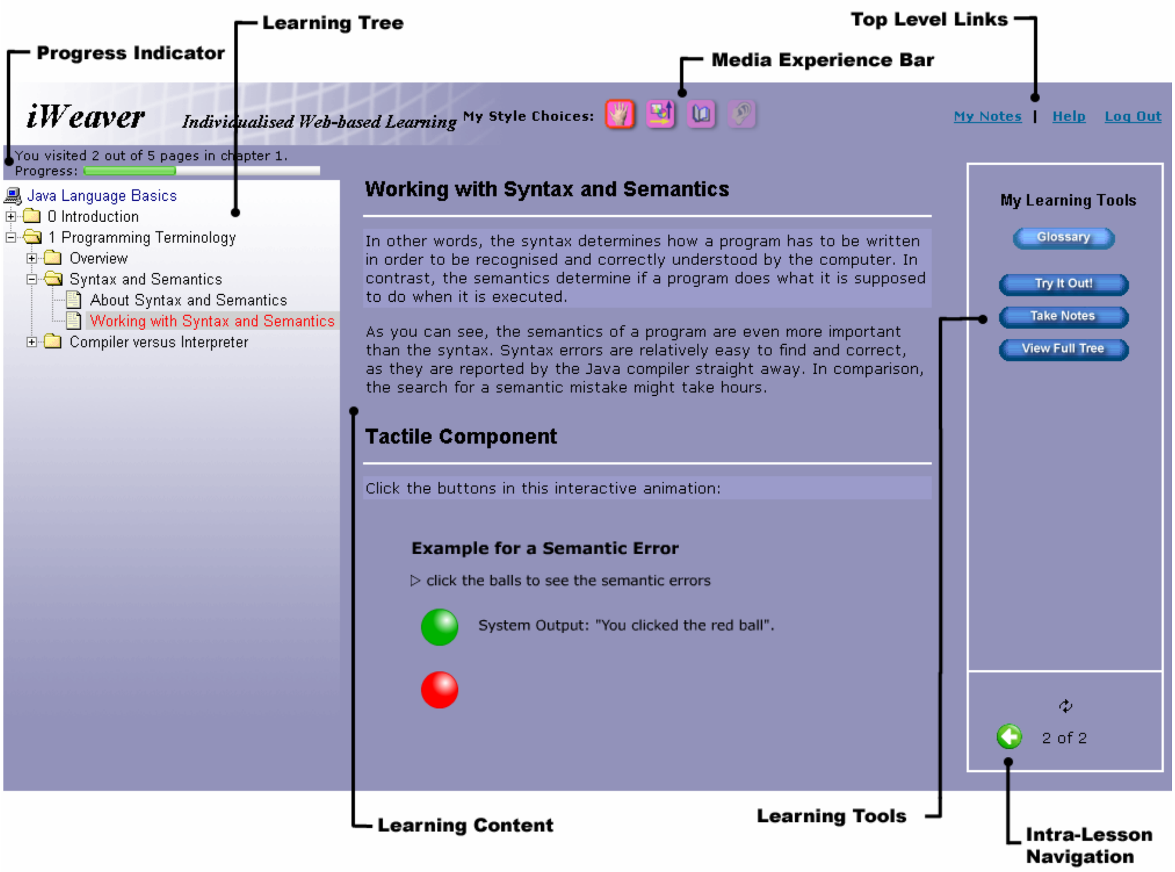


Figure 3-4. Screenshot of the main user interface of iWeaver. Individual components are identified.

- *Progress indicator.* A visual progress bar indicated the progress of the learning in the current lesson.

- *Learning tree.* The learning content was accessible in a hierarchical, tree-like fashion with the aid of a collapsible JavaScript tree menu (Wang, 2002). The tree grew with the progression of the learner.
- *Media experience bar.* The media experience bar allowed instant and central access to the different media experiences. Learners could switch between experiences on a page level.
- *Top level links.* These links gave learners access to all notes they had taken thus far. A help page explained certain features of iWeaver and a “log out” link allowed the learner to exit the environment.
- *Learning tools.* The learner had access to four learning tools: the glossary, the try-it tool (an online compiler), the note-taking tool and the full-tree view.
- *Intra-lesson navigation.* A small navigation bar offered “previous” and “next” arrows for the content pages of the current lesson. An “assessment” button appeared in this section as soon as all content pages were visited, which led to the post-test for this lesson.
- *Learning content.* The central screen area was reserved for the learning content, presented in the different media experiences.

The navigation was implemented using a JavaScript tree menu (Wang, 2002), as depicted in Figure 3-5. The tree menu was similar to the Windows Explorer tree structure with expandable and collapsible submenus (branches) and content leaves. It was the central navigation device for learners and therefore specific attention was paid to this tool.

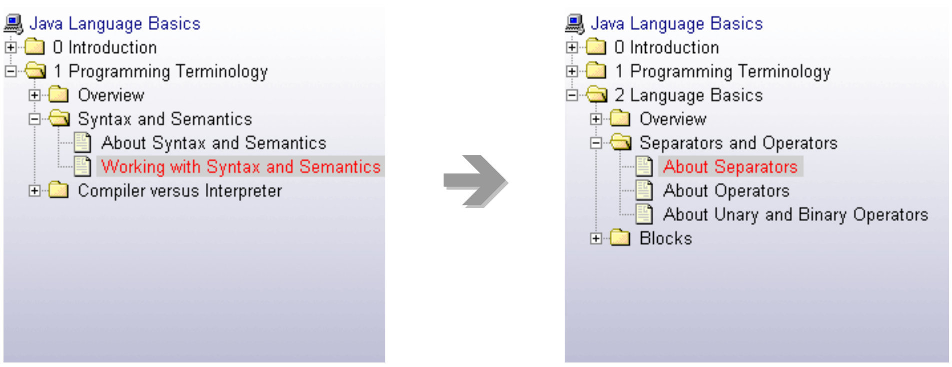


Figure 3-5. Screenshot of the tree menu navigation.

One particular challenge in the design of adaptive environments is to maintain a balance between connectivity (the distance between pages) and cognitive overhead (the difficulty of deciding where to go next) (Bollen, 1999). In a highly connected environment, it takes very few clicks to access desired pages, because they are extensively interlinked. However, especially in unfamiliar domains, the number of links increases the cognitive load. The more links learners can choose from, the more likely they experience the "serendipity" effect (getting distracted by clicking non-relevant but interesting information) (Holzinger, 2000), or the "lost in space" effect (Conklin, 1987, p. 38).

As a consequence of these issues, the menu was dynamically generated and cumulative, depending on learner progress. This meant, the more content the learner had visited, the more complex the tree became. This concept was referred to as "progressive disclosure" by Hix and Hartson (1993), who supported its use for information-rich user interfaces. A progressive increase in complexity of menu items is beneficial because the learner is not likely to experience cognitive overload effects, as all visible and accessible content has been visited before. Additional support for this approach was provided by Dufresne and Turcotte (1997), who likewise found that a more restricted navigation is advantageous for complex materials.

As mentioned before, an important part of well-designed usability is that the learner maintains a sense of orientation; if learners get "lost in space" (Conklin, 1987, p. 38), it is more likely they lose their motivation. To address the "lost in space" problem, early hypertext researchers suggested that a user interface should be designed so that users can always answer the following questions: "Where am I?", "What can I do here?", "How did I get here?" and "Where can I go, and how do I get there?" (Nievergelt & Weydert, 1980, p. 327). These questions were fundamental for early hyperlinked interfaces and are still applicable for modern web designs.

Where am I? The interface offered several cues to the learner to prevent her or him from getting lost. For example, the progress indicator in the top left section of the screen showed the learner's progress in visual and textual form. The media experience bar (top centre) indicated the currently selected media experience and the learning tree (left) highlighted the currently viewed content page.

What can I do here? The learner could navigate content either via the tree menu or via the intra-lesson navigation at the bottom right of the screen. Learning tools were located in a prominent position and showed tooltips when the mouse pointer hovered over a button (Figure 3-6) with small explanations or hints. Tooltips also existed for the media experience icons and for the top level links.

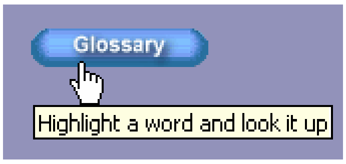


Figure 3-6. Screenshot of a tooltip to assist learners.

How did I get here? In a learning environment, this question can relate to what content has already been covered. This information was referred to as “past trails” by Nievergelt and Weydert (1980, p. 336). iWeaver provided these trails with three methods. Firstly, the progress indicator stated that a lesson had been already completed if the learner re-visited finished lessons. Secondly, the learning tree showed already visited pages in a different colour (blue instead of black). Lastly, there were transition screens between the different stages of a lesson (e.g., between the post-test, lesson feedback and the next lesson) to avoid confusion and to inform the learner about the system’s state.

Where can I go, and how do I get there? The learner typically progressed through iWeaver in a hierarchical manner. As the learning tree grew, new pages were added below the last branch. The new branch was expanded and the first content page was displayed when the learner entered a new lesson. To encourage choice, the media experience bar was located prominently in the top centre of the screen. When all content pages of the current lesson had been visited, an orange-coloured assessment button appeared below the intra-lesson navigation. Orange was chosen as a contrasting colour to the ambient blue of the background to attract the learner’s attention.

In addition to the aforementioned measures to prevent the learner from getting lost, further literature was consulted to improve the user interface. For example, Nielsen (1994) provided a set of heuristic criteria for the design and evaluation of interfaces, which are cited frequently in usability literature.

3.2.5 Preference Accommodation

iWeaver's matching approaches were based on the description of styles and recommended strategies in Rundle and Dunn (2000), whilst attempting to leverage the benefits of choice, as described in section 2.6.3 (p. 72). For classroom-based environments, Dunn and Dunn (1993) suggested to offer students self-guided contract activity packages (CAPs) and multi-sensory instructional packages, which can be compared to the different media experiences in iWeaver. There are several theses on the Dunn and Dunn model in different vocational fields, which investigated and corroborated the effect of CAPs in comparison to traditional classroom-based learning (e.g., Lefkowitz, 2001; O'Hare, 2004). Similar to iWeaver, students chose which activities or resources appealed to them in the CAPs. However, researchers did not monitor which materials from the package the students actually used. Therefore, these studies can only be regarded as evidence for the effectiveness of the model as a whole and not as evidence for the more specific effect of executing choice.

In general, learning style theories rarely provide specific and evidence-based strategies on how to accommodate styles. Recommendations to match specific styles are often generic and vague. Therefore, several studies were consulted that successfully employed matching approaches. These studies have already been described in the background chapter (section 2.5.6, p. 58). The specific application of the findings of these studies to construct the media experiences and learning tools of iWeaver follows in the remainder of this subchapter.

3.2.6 Media Experiences for Perceptual Preferences

According to Rundle and Dunn (2000), perceptual preferences refer to the way people perceive information with their senses. Table 3-1 lists the four elements of the perceptual dimension iWeaver adapted to, their properties and the corresponding media experiences with reference to the studies summarised in Table 2-1 (see p. 61). Note that the fifth perceptual element (internal kinaesthetic) was not included in the iWeaver adaptation, as this element exceeded the project's scope.

Table 3-1

Media Experiences for Perceptual Preferences

Preference	Description	Media Experience
Visual Text	Preference to perceive materials as text	Text pages with rich formatting, highlighted source code
Visual Pictures	Preference to perceive materials as pictures	Figures, illustrations, diagrams, flowcharts, animations
Tactile Kinaesthetic	Preference to interact physically with learning material	Interactive flash animations ("interactivelets")
Auditory	Preference to listen to instructional content	PowerPoint-style content: slides with supporting audio

To pre-empt concerns about media comparison studies (see sections 2.3.4, p. 30 and 2.4.4, p. 36), it should be noted that media experiences in the iWeaver environment were not intended to be atomic, but were designed with a main emphasis on the medium that is suited for the respective learning style. This approach was chosen in order to deal with the following dilemma: a participant selects a visual representation as a preference, but the topic requires an understanding of highly dense details (for which text would be a more suitable medium, according to Alty (1991)). A solution to this apparent contradiction was to regulate the media emphasis: the media experience was mainly visual, while the details were still displayed as an additional section of text on the screen. In other words: multiple representations in iWeaver were not mutually exclusive—they complemented or constrained each other.

When assessing the equivalence of media experiences, it is important to take the interaction between learner and medium into account (Kozma, 1991). As such, learning materials in one media experience could be subjectively perceived as "better" than learning materials in another media experience. However, this project was carried out under the assumption that this perception is dependent on the learning style of the interpreter. Therefore, it would be difficult to objectively assess the equivalence of learning materials in different media.

According to Rundle and Dunn (2000), visual text learners remember material best by reading it. Therefore, the matched media experience was a text-only version of the content, which comprised rich text formatting such as annotated source code sections and highlighted key concepts, as pictured in Figure 3-7.

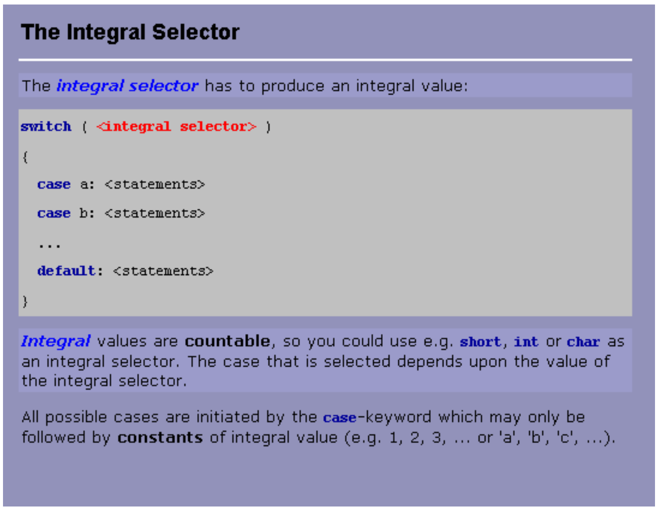


Figure 3-7. Example of a visual text experience.

Rundle and Dunn (2000) emphasised that visual learners prefer information represented in a pictorial fashion and create mental images according to what they hear or see. These learners were accommodated by supplementing text with illustrations, diagrams, flowcharts or non-interactive animations. Visual metaphors supported the creation of mental images, such as the example in Figure 3-8 explaining the Java switch-statement.

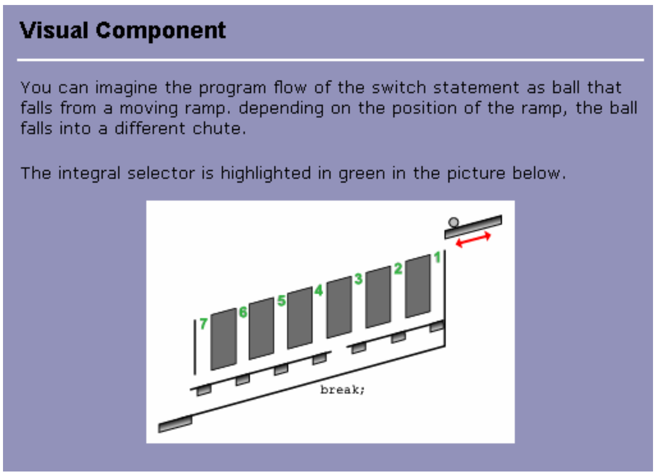


Figure 3-8. Example of a visual pictures experience.

Rundle and Dunn (2000) claimed that tactile-kinaesthetic learners prefer to physically interact with what they learn. In a computer-based environment, interaction is restricted to the input devices, including mouse and keyboard. Therefore, the tactile experience was a highly interactive version of the learning content. Figure 3-9 depicts a tactile version of the switch-statement: the learner could set variables and click buttons to step through the code. Technically, these experiences were interactive flash animations. However, to underline the difference to non-interactive animations, they are referred to as "interactivelets" in this exegesis. The interactivelet in Figure 3-9 consisted for three sections: the program code, an output window and a flow chart. The three sections were linked, so that changes in one section had an effect in the other sections as well. This technique was referred to as dyna-linking (Ainsworth, 1999).

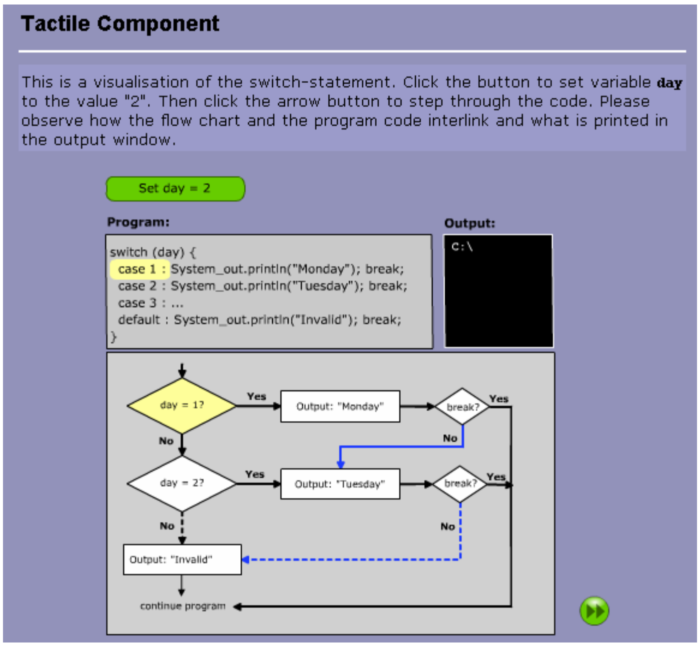


Figure 3-9. Example of a tactile-kinaesthetic experience.

Rundle and Dunn (2000) proposed that auditory learners prefer listening to instructional content. Therefore, the auditory experience presented the content in an audible style, similar to playing back a recorded PowerPoint presentation. The content was read to the learner whilst the key concepts were shown verbally redundant in bullet-point style on HTML pages, as pictured in Figure 3-10. Verbal redundancy refers to the simultaneous exposure of a learner to text and corresponding audio and has been shown to increase comprehension (Moreno & Mayer, 2002). The learner was able to pause and resume the audio, scroll back and forth on the RealPlayer interface or click different content pages in the navigation tree to navigate within the audio stream. An elaboration of the technical details of this experience follows in the section on its production in the next subchapter.

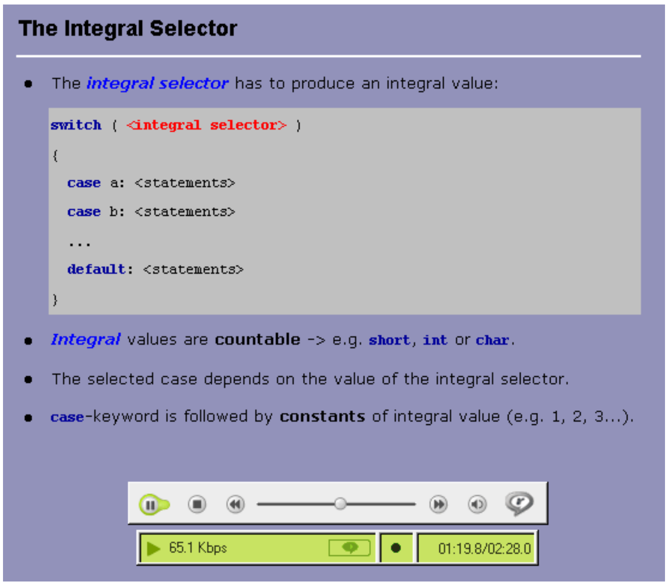


Figure 3-10. Example of an auditory experience.

3.2.7 Learning Tools for Information Processing Preferences

iWeaver offered a number of learning tools (pictured in Figure 3-11) as an addition to the described media experiences. These tools were tailored towards the different preferences in the information processing dimension of the Dunn and Dunn model, which covers different ways in which people process information and solve problems. However, as the tools were believed to be of general benefit to all learners (a view shared by Shute and Gluck (1996, p. 351)), they were accessible to all learners without restrictions or adaptation.

Figure 3-11. Screenshot of the learning tools selection bar.

The toolbar was located on the right side of the screen. Tools were represented as individual buttons and launched in a pop-up window. The advantage of the extra window was that learners were able to use the tool concurrently with the media experience, without losing the reference to the current content.

Table 3-2 lists the four information processing preferences and their properties according to Rundle and Dunn (2000). The preferences are complemented by custom-designed tools in iWeaver with reference to the studies summarised in Table 2-2 (see p. 63). Note that the analytic preference was not accommodated by a specific tool, because the default serial structure of the content was considered to accommodate analytic preferences.

Table 3-2

Learning Tools for Information Processing Preferences

Preference	Description	Learning Tool
Impulsive	Preference to try out new material immediately	Try-it tool allows immediate experience with source code
Reflective	Preference to take time to think about a problem	Note-taking tool with questions that encourage reflection
Global	Preference to get the big picture first, details later	Full-tree view as an advance organiser (Ausubel, 1968, p. 168)
Analytic	Preference to process information sequentially: details first, working towards the big picture	Sequential materials with key points and components (default)

In addition to the try-it tool, the note-taking tool, and the full-tree view, iWeaver also provided an online glossary. These four learning tools are now described in detail.

Try-it tool. The learner was presented with the piece of program code that addressed a newly learnt concept. Either gaps had to be filled in or the learner was encouraged to change parts of the code. A similar idea has been independently implemented by Truong et al. (2002; 2005) with their “web environment for learning to program” (ELP). However, in the ELP learners had to download a file to their computer, which could then be executed locally. The iWeaver try-it tool executed code via a simulated console in an applet that was embedded in a web page, as pictured in Figure 3-12. Technical details on the try-it tool follow in section 3.3.6 (p. 119).

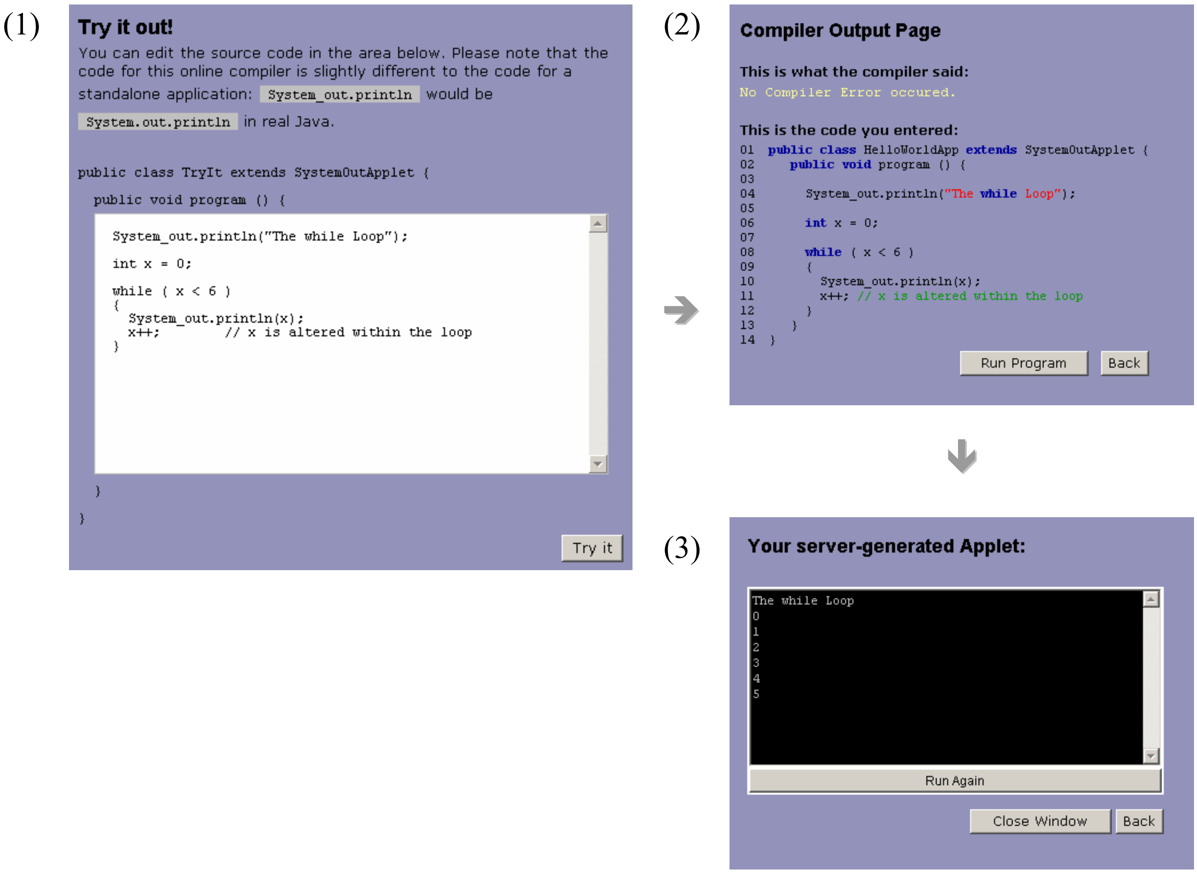


Figure 3-12. Screenshots of the try-it tool: an online compiler. The compiler consists of three steps: (1) the example in a textbox; (2) compiler feedback and (3) output in a simulated console via an applet.

From a didactical perspective, the try-it tool allowed learners to immediately apply new knowledge (Knowles & Associates, 1984, p. 12). In line with the work of Kölling and Rosenberg (2001), it was considered more productive to give students example code to read and to work with, rather than giving them a blank page. Consequently, the example from the current learning content (sometimes slightly adapted) was displayed, when the learner used the try-it tool. Some examples contained deliberate errors or omissions that needed to be fixed before the program could be compiled. Hints on how to fix the errors were provided as comments embedded in the source code. Additionally, the learner was encouraged to change sections of the code. These techniques attempted to encourage the learner to actively engage and interact with the program code. The try-it tool was designed to cater for the needs of impulsive learners, who prefer to try out new ideas straight away (Rundle & Dunn, 2000).

Note-taking tool. A context-aware note-taking tool was offered to all learners. It allowed note-taking on the level of each learning unit. Notes for the current lesson could be accessed via the learning tools bar and old notes via the top level links. The existence of previously taken notes was indicated by a slight visual difference in the tool button: the label changed from “Take Notes” to “View / Edit Notes”. According to Rundle and Dunn (2000), note-taking can be particularly beneficial for reflective learners, who prefer to take their time to structure their thoughts, and textual learners, who generally prefer to write down key points of new materials.

Full-tree tool. Learners were able to access a full-tree view of the learning materials to get the big picture of what lies ahead. According to Rundle and Dunn (2000), global learners prefer to get the big picture first, before going into the details. Ford and Chen (2001) provided some support for this particular matching approach. The full-tree view also acted as an advance organiser (Ausubel, 1968, p. 148). Advance organisers attempt to activate previous knowledge of the learner and contextualise the upcoming learning experience by anchoring it in a logical structure.

Glossary. The glossary was not targeting a specific learning style, but can be a useful tool when large numbers of new terms are introduced. Learners could simply highlight an unfamiliar term in the content section of the screen and press the glossary button to look up a definition.

3.3 iWeaver Design and Production

This subchapter describes the technical details of iWeaver’s implementation. First, the system architecture and the learner and content model are illustrated. Next, the algorithms and techniques of iWeaver’s adaptive features are explained. Then, selected details for the media experiences and learning tools are described, with a focus on the development process of the auditory materials and the try-it tool. Finally, the system requirements to run iWeaver are listed and installation instructions are provided.

3.3.1 System Architecture

The diagram in Figure 3-13 illustrates the schematic system architecture of the iWeaver learning environment on a process and a technology level:

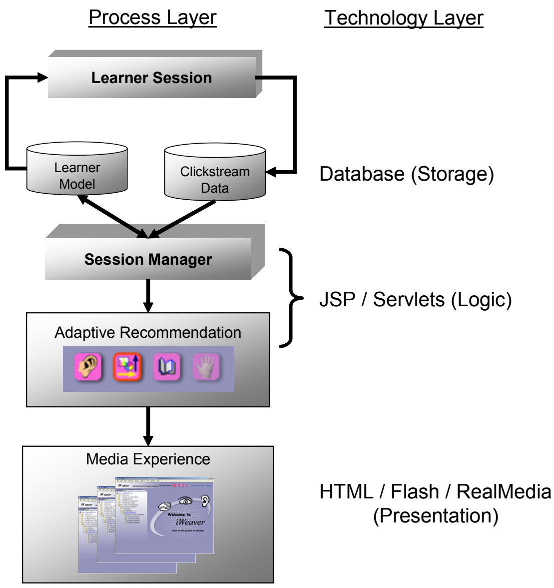


Figure 3-13. System architecture of iWeaver.

When a learner logged in via a web browser, a session was initiated that stored all learner-specific data. This session encapsulated the current state of the learner and included variables such as the current learning preferences, current content page, current experience. Every interaction of the learner with the environment was recorded in the database, for instance choices made, rankings given or tools used.

At the end of each lesson, the session manager evaluated the clickstream data and compared them with the learner model, which was then updated if required. In other words, the learner model was periodically refined and synchronised with the behaviour of the learner. If the learner model was updated, these changes were fed back to the learner session.

The updated learner model was used to calculate the order and opacity of icons in the adaptive recommendation. The adaptive recommendation prompted a choice by the learner and as a result, a media experience was generated using JavaServer Pages (JSP) and Java Servlets.

The media experiences consisted of a variety of media, including HTML and richly formatted text, interactive and non-interactive Flash animations, still pictures, diagrams and RealMedia files (synchronised with HTML pages via SMIL).

3.3.2 Learner and Content Model

The learner model used by iWeaver was primarily based on the participant's learning style profile. The model also included demographic data (as provided in the sign-up form), pre- and post-test answers, lesson feedback (including experience ratings), and all navigational choices. The current learning style profile, experience ratings and navigational choices were used for adaptive recommendations, which are described in the following two sections.

On a macro level, the content model was conceivably basic: there were four versions of the content, tailored for the four perceptual preferences: visual text, visual pictures, tactile-kinaesthetic, and auditory. Every media experience contained a textual component.

On a micro level the learning content was structured according to Merrill's component display theory (CDT) (1994). CDT was one of the first instructional design theories that separated content from instructional strategy and it was therefore an important contribution to the field of educational technology (Kovalchick & Dawson, 2002). The theory comprises four primary presentation forms: rules (general form), instances (concrete examples), practice, and recall. A secondary layer of components includes prerequisites, objectives, helps, mnemonics and feedback. According to CDT, instruction is most effective if all primary and secondary components are present in the instructional materials. The theory is compatible with learning style adapted instruction, because it emphasises learner control. In line with CDT, learners should be able to select and jump between components that best suit their needs and preferences.

Table 3-3 displays the components of an exemplary learning sequence for the concept “the while-loop” in alignment with CDT.

Table 3-3

Components of an Exemplary iWeaver Learning Sequence

Component	iWeaver equivalent activity / content
Objective	Correctly and efficiently integrate loops into your programs
Rule	Content page: The syntax of the while-loop in general form
Example	Content page: The while-loop in a concrete example
Elaboration	Content page: Avoiding infinite loops
Elaboration	Revisit the materials in another media experience
Practice	Work with an example in the try-it tool
Recall	Post-test at the end of the lesson
Feedback	Post-test results, correct answers and a lesson summary are provided

3.3.3 Adaptive Components

iWeaver’s adaptation mechanism was an attempt to mediate between two seemingly opposing goals of the environment. On the one hand, the interface was meant to restrict options and reduce cognitive load. On the other hand, iWeaver aimed to give the learner more control by offering choices. Brusilovsky (2000) suggested a solution to this dilemma by offering adaptive navigation support. He highlighted that it is possible for the interface to “integrate the power of machine and human intelligence: a user is free to make a choice while still seeing an opinion of an intelligent system” (section 3).

iWeaver implemented a combination of adaptive navigation and adaptive content presentation techniques (see section 2.6.3, p. 72) to express the importance, status and relevance of hyperlinks. As link sorting has been shown to improve selection time and reduce cognitive overhead (Brusilovsky, 1996; Bollen, 1999), it was used to guide learners to their best-suited media experience. Additionally, link annotation (Eklund & Sinclair,

2000) was used to provide visual cues to the learner through adaptive link fading. Link fading was implemented by reducing the opacity of icons for experiences that were considered unlikely to be chosen. Lastly, link hiding was used to temporarily hide interface elements. For example, the assessment button was hidden from the learner until all content pages of a lesson were visited and the media experience bar was hidden under the “no choice” condition.

Three major aspects of the user interface were adaptive: firstly, the content navigation (Figure 3-5, p. 101) progressively expanded when the learner completed a lesson. Secondly, the media experience in lessons under the no choice condition was matched to the participant’s control style (statically adapted). Thirdly and lastly, the recommendation of media experiences in the lessons under the choice condition was based on the complete and current learning style profile (dynamically adaptive). This recommendation was executed by adjusting two display variables: (1) the order of experiences and (2) the opacity of their icons. The more opaque and the further left an icon was (an example is pictured in Figure 3-14), the more suitable for the learner this experience was considered. This adaptation approach was referred to as a combination model (Conlan, 2000), because it initially relied on a base model, which was then gradually finetuned to better suit the learner. Thus, the choice condition avoided stereotyping learners by offering a view on the model as a whole, with weighted recommendations. The aim of these recommendations was to reduce the cognitive load of learners, by assisting their decision making process.

Figure 3-14. Adapted recommendation of media experiences. The order and opacity of icons is adapted according to suitability.

3.3.4 Adaptation Process

Learners had to choose a media experience before entering a lesson under the choice condition. Then, they could switch between experiences within the lesson by using the media experience bar, pictured earlier in Figure 3-4 (see p. 100) in the top section of the interface. The icon highlighted with a border indicated the currently active experience.

The opacity of icons ranged from a 100% maximum to a 25% minimum. If two experiences had the same value in the learner model, their opacity was the same and the last opacity level was omitted.

The recommendations could change for the next choice lesson as a result of explicit and implicit feedback form a participant. Participants were prompted for explicit feedback at the end of each lesson. If participants used multiple experiences in that lesson, they were asked to rank them (Figure 3-15, p. 125 and Figure 3-16, p. 125) according to which experience they found most beneficial for them. If they gave an experience the primary rank and that experience differed from their first preference according to the current learner model, the model was adjusted. The primary-ranked experience was given more weight and the weight of the previous first preference was reduced. This redistribution of weights may or may not have been sufficient to result in a changed media recommendation bar for the next choice lesson.

In addition, iWeaver considered implicit feedback on media experiences. If participants used only one experience in a lesson which was not their first experience, this behaviour was considered an implicit vote for that experience. As a result, iWeaver used the same adaptation logic as for the explicit ranking described above: the weight of their first preference was decreased and the weight of the used experience was increased accordingly. It should be noted that the success of a participant in a lesson (e.g., the number of correct answers in the post-test) did not have any influence on the adaptation algorithm.

As the main drive of this research was to compare a choice with a no choice condition, all experiences were available continually in lessons under the choice condition. Considering that learners were encouraged to execute choice and to essentially question the system's recommendations, a sophisticated recommendation algorithm such as an adaptive Bayesian modifier (Castillo et al., 2003), was regarded as unnecessary. Instead, the adaptation algorithm to order and shade the icons was relatively simple and modelled after the weighting algorithm of the BES: an adaptation decision to add weight to an experience was considered equivalent to a "strongly agree" vote for that experience in the BES. Therefore, if the weight of an experience had to be increased, 10 points were added to the prior value. Vice versa, if the weight had to be decreased, 10 points were deducted. This algorithm was aligned with machine learning approaches to handle drifting user preferences and interests (Koychev, 2000). Koychev found that the effectiveness of a system's adaptability is improved if the last observation is regarded as more significant than previous observations.

In addition to adapting interface components and navigation, the persistently stored learner model was also employed to remember the state of a learner. iWeaver recorded all navigation choices persistently in the database. With the aid of these data, it was always possible for learners to log out (or close the browser window, restart the computer), log back in and continue where they left off. For example, a learner could quit the BES at question 32 by closing the browser window. If the learner logged back in, he or she returned to question 32.

The described mechanisms provided learners with an adaptive, yet easily manageable user interface that provided rich learning options.

3.3.5 Production of Media Experiences

From a technical point of view, the HTML pages with the adapted learning content were dynamically generated using a MySQL or a Microsoft Access database. Animations and interactivelets were created with Macromedia Flash. The Flash format was chosen over alternatives including Shockwave and Scalable Vector Graphics (SVG) because of its widespread support in Internet browsers, the compact size of the output files, and its built-in ActionScript capability. ActionScript allows the development of sophisticated animations and interactivelets.

To produce the auditory media experience from the textual materials, there were two options: speech synthesis (Speech synthesis, 2006) or a manual recording of a speaker. Speech synthesis is the process of converting a written text to speech with a computer program (a so called "engine"). In general, speech synthesis has the advantage that it is more flexible, dynamic and scalable compared to a recording. For example, a section does not need to be re-recorded, re-cut and re-encoded if the underlying text has changed. The speech synthesis engine simply reads the changed text to the learner and no further changes are necessary. An e-learning course is also easily extendable by using this technology.

Despite the advantages of speech synthesis, manual recording was chosen for this project, because speech synthesis was considered too impersonal and too difficult to understand. From the time when speech synthesis engines were first introduced, they have improved substantially. Modern engines such as AT&T Naturalvoices (AT&T Labs, 2002) can even imitate different accents. Nevertheless, their output still sounded more like a computer than a human voice. Mayer (2003) provided evidence for a personalisation effect: students learn more deeply if materials are presented in a conversational style that creates a personal connection with the student, compared to formal, impersonal style. As a consequence of Mayer's research and several trials of speech synthesis engines, it was decided to manually record the materials. The loss of flexibility was counter-balanced by basing the recordings on a finalised version of the learning materials. Furthermore, the quality of the readings was enhanced by taking into account research on the auditory rendition of text elements (Giere & Burmeister, 2002).

The audio clips were recorded over three days with professional recording equipment in the studio of the Centre for Animation & Interactive Media at RMIT University. Afterwards, the materials were cut, filtered, normalised and finally compressed with the RealMedia-codec. The RealMedia codec was selected, because a subjective codec comparison gave the impression that this codec produced superior results for voice-only audio. This observation has been confirmed by a blind comparison conducted by Stokas (2002).

In the current prototype, progressive downloading (Kozamernik, 2002) was used as the streaming technology to deliver the auditory content. In comparison to real-time streaming, progressive downloading causes no re-buffering delay if the learner decides to scroll or skip backwards in the audio stream. This re-buffering delay in real-time streaming took from three to seven seconds in tests, depending on the connection speed. According to an experiment conducted by Wisher and Curnow (1999) on the impact of delayed display of images, a transmission lag of only two seconds distracted about half the students. By extension, similar effects were expected for audio delays. As a result, progressive downloading was chosen as transmission technology and the media was stored on a server on the local area network to minimise download times.

The linking of HTML content pages with corresponding trigger points in the audio stream was achieved through the Synchronised Multimedia Integration Language (SMIL) (W3C, 2001). A comparison of the three most popular SMIL players, Microsoft Media Player, Apple Quicktime Player and the RealOne Player from RealNetworks revealed that the RealOne Player was most suited for this project, because it was possible to embed it into a web page, it supported the SMIL 2.0 platform and it was available for the Windows as well as the Macintosh operating system.

SMIL 2.0 is a recommended W3C standard, which is specifically suited for the timely synchronisation of different media types. It is an XML-based language that is stored in simple text files. As opposed to using a static video file, the modular approach of SMIL is to loosely combine separate media elements in a flexible fashion. This facilitates content maintenance and guarantees the future scalability of the learning environment.

3.3.6 Production of Learning Tools

The note-taking tool, the online glossary and the full-tree view, were implemented using mainly JavaScript and context-aware database queries. For example, the glossary button uses a small JavaScript method to search for highlighted words in the learning content frame. The method then opens a new window, which displays the result of a database query on these words.

An interesting learning tool to describe in detail is the try-it tool that launched the online compiler. A click on the “Try It Out” button opened a new window with a text box that contained a source code example for the currently presented concept (Figure 3-12, p. 110, part 1). The example could be freely altered in the text box. Some examples were incomplete or contained bugs that needed to be corrected by the learner, before the source code could be compiled successfully.

The submission of the text box handed the source code over to a Java bean on the web server. This bean wrote the code into a java-file on the server’s hard disk. The file was then compiled and the source code was displayed with highlighted keywords and indented code blocks to facilitate reading (Figure 3-12, p. 110, part 2). In case of a compilation error, the erroneous source code was displayed with an error message. The affected line numbers where the error occurred were highlighted in the source code to make it easier to track and correct them. The learner then had the opportunity to go back to the text box, correct the error and compile the program again. If no compilation error occurred, the learner could click the “run program” button and an applet was created which displayed the output of the program (Figure 3-12, p. 110, part 3).

The applet simulated a system console by re-routing print commands to a modified text area. This technique is referred to as “wrapping”. Due to the security restrictions in applets, it was not possible to re-route the standard System.out stream directly to the text area. As an alternative, a new TextBoxStream class was written, which was available to the learner in the form of a System_out object. This object essentially behaved the same way as the System.out stream: everything that was printed to this object was displayed on the screen. The only difference was that the output occurred in an applet and not in a console window. As a result of this new stream class, the syntax to print text or variables to the screen differed slightly between the online compiler and standard Java. This difference was explained to the learner in the introductory text of the online compiler.

A specific problem with the online compiler was the behaviour of the applet cache of browsers, respectively the classloader of the Java plug-in. Neither of these caching mechanisms was built to handle dynamically changing applets. Hence, once an applet was loaded, it was permanently cached by the web browser. The learner would have had to manually empty the cache (or restart the browser) in order to force a reload of the applet. This extra step could have been potentially overlooked or forgotten by learners, even if instructions were provided, leading to frustration and confusion, because code changes would seem to have no effect. To tackle the caching problem, an automated solution was developed: every time an applet was compiled, it was written into a newly created, uniquely and randomly named directory. This forced the Java runtime mechanism to reload the updated applet, because its URL had changed (but not the class name). The described approach appeared to be the simplest and most effective solution to the caching problem.

There were several benefits of offering an online compiler over letting the learner use a separate development environment. Firstly, the web-based online compiler did not need to be installed on the learner’s computer, so it was easily and readily accessible. Secondly, a related benefit was that it could be used on any computer with just a web browser installed and restricted access (e.g., at a university or in a public library). Thirdly and lastly, it was context-aware: it was launched with a source code example that directly demonstrated the currently presented programming concept.

3.3.7 Software, Hardware and Installation

A fully functional version of the iWeaver environment with installation instructions is included on the DVD that accompanies this exegesis. However, due to copyright restrictions, the initial learning style assessment with the Building Excellence Survey had to be omitted. Consequently, new sign-ups with a fresh learning style assessment are not possible in this version. Nevertheless, a guest log-in can be used with a pre-established learning style profile, which is continuously adapted as described previously in this subchapter. For future research projects, the missing component may be obtained from the author of this exegesis if a written permission from the copyright holders (Rundle & Dunn, 2000) can be produced.

It is also possible to adapt the provided iWeaver source code for future projects. Due to the modular architecture of the project, the process of adapting the environment to another learning style model should be straightforward. Researchers interested in using iWeaver source code should contact the author of this study.

There are several minimum system requirements to run iWeaver on the server and on the client side. All required software was freely available on the Internet at the point of writing.

Server Technologies. For single user purposes, a Pentium III with 500 MHz and 320 MB of RAM is sufficient. iWeaver was mainly written in Java by using Java ServerPages and Servlets. Consequently, the server computer requires an installation of the Java 2 Standard Edition 1.5 and the Tomcat Web Container 5.5.9. As iWeaver is a web application, it is easily portable and runs on any hardware platform for which a version of Tomcat is available.

As the database backend, iWeaver can either use a Microsoft Access or a MySQL database. For any use exceeding a single user, the migration to a MySQL database is strongly recommended, as in tests, Microsoft Access did not handle the amount of requests generated by iWeaver in a graceful fashion (see also 15 Seconds Discussion List, 2001). The result was a severe slow down in the page rendering engine, which made iWeaver almost unusable. These slow downs also occurred (in rare cases) with single users. To migrate from Access to MySQL, the MySQL migration toolkit (MySQL AB, 2006) or DBManger Professional (DBTools Software, 2006) can be used. The latter tool has the advantage that it can migrate in both directions.

Client Technologies. iWeaver was tested on Firefox 1.5, Internet Explorer 6 and Maxthon 1.5.6. As a precaution, access was restricted to these three browser types by an initial browser test script. iWeaver was tested on both Windows XP and Mac OS X operating systems. A minimum screen resolution of 1024x768 pixels is required. Client computers also need a local installation of Flash Player 6, RealPlayer 10 and the Java Runtime Environment 1.4.

3.4 Experimental Design

The preceding subchapters proposed an answer to the first research question of this project on how an e-learning environment can adapt itself to accommodate individual learning styles. The previous subchapters described technical and didactical details of iWeaver, whereas the following subchapter elaborates on the experimental design and procedure to answer the second research question: whether it is more beneficial for participants to learn with a choice of media experiences, or to learn with only one, best-matched media experience.

First, general problems with the evaluation of adaptive environments and iWeaver-specific solutions are described. Then follows a summary of the pilot tests that were carried out before the main evaluation. The next section describes how data were collected during the evaluation and the profile of the participants. Then, the experimental design is explained, including a definition of the independent and dependent variables, and the data analysis approach. The final section details the experimental procedure with a typical learning sequence.

3.4.1 Evaluating Adaptive Systems

Evaluation studies with adaptive user interfaces are more complex than with static interfaces because of the greater number of variables that need to be considered (McGrenere, 2002). To assist researchers with this problem, Weibelzahl (2005) published a useful collection of tips, problems and potential pitfalls with the evaluation of adaptive systems. For example, Weibelzahl recommended splitting the evaluation into several small experiments, to allow for flexibility and to reduce the risk of a potentially flawed design. He advised against an adaptive/non-adaptive comparison, because if adaptivity is a key component of the system, switching it off potentially renders the system useless. As a possible alternative, Weibelzahl recommended comparing different sets of adaptation decisions whilst keeping the variants very similar in functionality and layout. This approach reduces confounding factors and therefore allows a better chance of detecting the effects of the adaptivity by itself. In recognition of Weibelzahl's recommendations, the two versions of iWeaver that were compared in the experimental evaluation were both adaptive; the difference was the granularity of adaptation. Choice lessons offered a view of the complete learning style model and sorted recommendations according to how well media experiences fitted the model. In comparison, no choice lessons were only adapted to the control style.

Weibelzahl suggested a repeated measures design for the evaluation to reduce the variance and increase the significance of differences. However, he also warned of carry-over effects (see section 3.5.7, p. 136), which might occur if participants get used to one version and then have problems interacting with the other version.

3.4.2 Participant Profile

The generic target group of iWeaver consisted of adults with an interest to learn computer programming. The environment was designed for computer-literate participants, who could confidently navigate the Internet and use a web browser. Broadband Internet access was a requirement, due to the streaming media and generally media-rich learning components. Ideal participants had little or no prior experience with Java to avoid ceiling effects in the pre- and post-tests. Internet and computer literacy were important to reduce usability issues and novelty effects. A desirable prerequisite was that participants expressed diverse learning styles with preferences across multiple media. As a result, participants were expected to be inclined to try learning with different forms of media.

Given these requirements, it was decided to evaluate iWeaver with multimedia students. Multimedia students matched the participant profile, as they were likely to be largely computer- and web-literate, with limited or no prior programming experience. Additionally, a diversity in learning styles was expected in a sample of a student population (St Hill, 2000).

3.4.3 Data Collection Instruments

This section lists and describes the instruments and tools that were used to collect data from the participants. The procedure and all instruments in this project were reviewed and approved by the RMIT ethics committee. The respective documentation, including the plain language statement for participants and samples of the data collection instruments can be found in the appendix (section C).

Firstly, participants were asked to fill in a sign-up form (Figure C-1). In this form, they provided basic demographic data (e.g., gender and age) and chose a nickname to render the data anonymous. Participants could provide an email address if they wanted their learning style interpretation emailed to them. At the end of the form, participants were asked to indicate prior experience with computers, the Internet, e-learning, various programming languages and their general interest in programming and Java. Experience and interest levels had to be indicated on six-point Likert scales ranging from “None” to “A Lot”. Then, data were collected with the Building Excellence Survey (described in section 3.2.2, p. 95) in order to populate the initial learning style profile.

Every lesson was assessed by a series of seven pre-test and equivalent post-test questions with five possible answers per question. The position of the correct answer was randomised by a random number generator. A number of sample questions can be found in the appendix (Figure C-3 to Figure C-5). To assure validity, the instructional materials and the test materials were reviewed independently by two expert judges. Both judges were working professionals in the IT industry, who had worked as Java tutors for several semesters in the past and had approximately four and six years of full-time programming experience.

Participants provided subjective data by leaving feedback after each lesson. The feedback form was divided into two sections: “Used Media Experiences” (Figure 3-15 and Figure 3-16) and “Additional Questions” (Figure 3-17).

The used media experiences section differed slightly between the choice and the no choice condition. After the choice condition, participants were asked to rank the media experiences they visited according to which one was the most beneficial for them. Then, they had to mark the highest ranked experience on a six-point Likert scale from “mediocre” to “great” (Figure 3-15). In contrast, participants under the no choice condition only had to mark the single media experience they encountered (Figure 3-16).

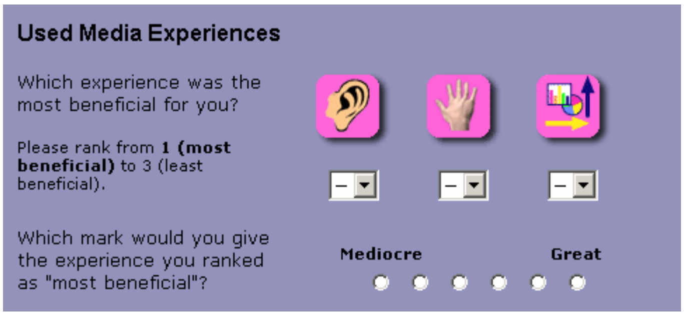


Figure 3-15. Lesson feedback: Section for media experiences (choice condition).

Figure 3-16. Lesson feedback: Section for media experiences (no choice condition).

The additional questions section was the same under both conditions. Learners were asked to subjectively answer the three questions with regards to their perceived enjoyment, progress, and motivation on six-point Likert scales (Figure 3-17).

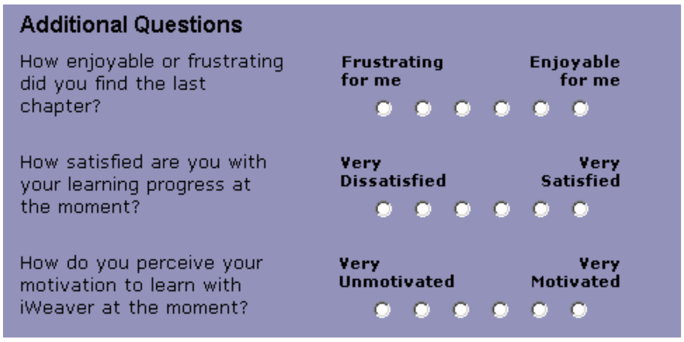


Figure 3-17. Lesson feedback: Section with additional questions.

In both feedback sections, learners had the opportunity to leave qualitative feedback in a free-text field. The text fields were prompted by the open-ended question “Anything else you would like to comment on?”. A screenshot of the complete lesson feedback form can be found in the appendix, Figure C-6.

In addition to explicit feedback, clickstream data were recorded in the database. These data included every page impression, media experience choice and learning tool usage of the participants.

3.4.4 Pilot Tests before the Evaluation

An iterative design process for new software programs, web sites, learning environments and user interfaces in general can significantly increase usability (e.g., Nielsen, 1993). Apart from improving the user interface, the pilot studies of iWeaver also had the purpose of improving the technical robustness of the environment, to estimate the time it takes participants to complete certain parts and to improve the quality of the learning materials. In short, an iterative design process was adopted to increase the likelihood for a positive learner experience. Early versions of the iWeaver interface were assessed by two experts in "cognitive walk-throughs" (Polson, Lewis, Rieman, & Wharton, 1992) and small-scale pilot tests with six individual participants were conducted. Pilot participants were computer- and web-literate adults, three male and three female with a mean age of 28.83 ($SD = 2.64$). In addition, the sign-up and feedback forms were tested with a small pilot group, representative of the target audience, to eliminate ambiguities. Pilot studies were conducted with incomplete versions of iWeaver, so no data were collected.

The cognitive walk-throughs revealed several usability defects, which were subsequently addressed. For example, an earlier version of the note-taking tool was too convoluted. Learners could take different notes for the same content for every media experience. This was unnecessarily complex, because it assumed a multi-dimensional view of the learning materials. As a result, the note-taking tool was simplified so that learners could take notes per lesson (as opposed to per page) and it was irrelevant, which media experience they have currently activated. The experts also noted that it was too cumbersome to switch between media experiences, as it required three clicks. Papanikolaou et al. (2003, p. 254) suggested that the likelihood for the use of adaptive features decreases if users are unfamiliar with the interface. To counter this effect, the adaptive features were made more prominent and the media experience choice was simplified and relocated to the top of the page. As a result, only one click was required to switch between experiences in the final version of the interface.

Access to the learning tools was simplified in a similar fashion. In an earlier version of iWeaver, the tools that did not match the learning style profile of a learner were hidden, but accessible via an "expand" button. However, because of the manageable number of available tools, which were potentially useful for participants with variable learning preferences, it was decided to leave all tools visible at all times. This decision was consistent with Shute and Gluck (1996, p. 351), who observed the positive effect of learning tools and concluded from their research that “it seems that every extra chance that learners have to take the initiative to augment their learning during instruction can only have a positive impact”.

Pilot tests showed that participants needed about 30 minutes to complete the six sections of the BES. This was considered excessive and therefore detrimental for the learners' motivation. As a consequence, the BES was split into two parts and the initial learning style assessment only covered the two dimensions iWeaver adapted to. This reduced the completion time for the survey to an average of about 10 minutes.

During the pilot tests, several irregularities with different Internet browsers were detected. As a consequence, the allowed browsers were restricted to Microsoft Internet Explorer and Mozilla Firefox (see section 3.3.7, p. 121 for more detailed system requirements). The pilot tests also revealed that Microsoft Access was not a suitable database backend for the main study, which prompted a migration to the MySQL database.

The pilot tests helped to refine the experimental design of the evaluation. Originally, it was planned to switch participants between conditions only once, after lesson four. However, it became evident that there was a risk that participants would drop out before reaching the midway mark. This would have meant that the aim of the repeated measures design (to collect data under both conditions from every learner) would not have been reached for many learners. Therefore, the design was adapted to cross students over after each lesson, as described in the next section.

3.4.5 Repeated Measures Design

The second research question asked whether it is more beneficial for participants to learn with a choice of media experiences, or to learn with only one media experience, matched for their most-preferred learning style. In order to answer this question, it was necessary to formally define its independent and dependent variables, and to devise an experimental design to collect data.

The independent variable was the level of choice. To investigate the impact of choice, participants were randomly allocated to either of two conditions at the start of the evaluation: *choice* (dynamically adaptive) and *no choice* (statically adapted). Participants then switched to the opposite condition after each lesson.

Due to their perceived benefits, repeated measures (cross-over) designs are becoming more common in learning style studies in recent years (e.g., A. V. Roberts et al., 2000; Lefkowitz, 2001; O'Hare, 2004; Kelly & Tangney, 2005). Therefore, a repeated measures design was used to collect data during the iWeaver evaluation. After each lesson, the two groups crossed over to the other condition to counter-balance for lesson-difficulty. This design had the major benefit that participants acted as their own control, which reduced between-subject variability. A disadvantage of a repeated measures design is that carry-over effects (also called order, sequencing, or practice effects) can occur, which means that the effect from one condition can carry over to the comparison condition. This problem is discussed in more detail at the end of the next subchapter under "threats to validity" (see section 3.5.7, p. 136).

Repeated measures evaluations commonly have one cross-point at a midway mark. However, if participants are volunteers and the learning topic is not part of a curriculum, there is a risk that participants drop out *before* reaching the mid-way mark (lesson 4 in the case of iWeaver). As discussed previously, this effect was experienced in the pilot tests of this project and similarly in a study conducted by Stern (2001, p. 116). Consequently, the risk of a mid-way design was that data may not be collected from each leaner under both conditions. In order to counteract this risk, multiple cross-over points were used during the evaluation instead of one single cross-over point.

Participants were starting with either a choice or a no choice condition depending on their identification number, which they were assigned when they signed up. Odd user numbers had no choice in odd lessons and a choice in even lessons. For even identification numbers the sequence was reversed.

3.4.6 Dependent Variables

The four dependent variables in this study were *learning gain*, *enjoyment* of the last visited lesson, perceived learning *progress*, and *motivation*. These variables and their respective data collection instruments were discussed earlier in section 3.4.3 (p. 124). Learning gain was objectively measured as the difference between pre-test and post-test scores. The remaining three variables (enjoyment, progress, and motivation) were measured through a feedback form after every completed lesson as described in section 3.4.3. Table 3-4 summarises the independent (IV) and dependent variables (DV) and lists their possible values.

Table 3-4

Summary of Independent and Dependent Variables and their Possible Values

Type	Variable	Possible Values	Max. Value
IV	level of choice	choice / no choice	-
DV	learning gain	(post-test score – pre-test score) / nr of lessons under the condition	7
DV	enjoyment of a lesson	1 to 6 on a Likert scale	6
DV	perceived learning progress	1 to 6 on a Likert scale	6
DV	motivation	1 to 6 on a Likert scale	6

The collected data originated from two alternating conditions: choice and no choice. Due to the odd number of seven lessons, participants who completed all lessons would provide more data under one condition than under the other. Therefore, in order to compare the two conditions for every participant, dependent variables were scaled to account for the number of lessons completed under each condition. For instance, if a participant completed three choice lessons and four no choice lessons, the results for each condition were added up and divided by three or four respectively. It should be noted that minor fluctuations in lesson difficulty were unlikely to have an impact on the results, due to the counter-balanced design with participants starting in opposing conditions and switching each lesson. For example, if motivation degraded over time, it would degrade for both conditions.

3.5 Experimental Evaluation

This subchapter describes the data collection process. It provides details on the learners that participated in the experimental evaluation, the location of the evaluation, and the hardware and software that was used. Next, the procedure of the collection is described. Finally, the data analysis approach is elaborated and an explanation is given as to why effect sizes were calculated in addition to statistical probability values.

3.5.1 Participants

The study was carried out with 63 first and second year students of the advanced diploma of multimedia (ADoM) (RMIT University, 2006a). ADoM is a two-year RMIT TAFE course with a focus on a variety of digital design approaches including imaging, video, interactive authoring, animation, games development, and web page authoring. The participants were mainly young adults of mixed gender (28 female, 35 male) ranging from 18 to 52 years. The mean age was 24.92 (*SD* = 6.20), median age was 23 and the mode age was 20.

Several steps were undertaken to ensure that participants were motivated as Java was not part of the normal curriculum for ADoM students. Students were assured that the programming concepts taught in the course were of generic nature and that Java was simply used as an instructional vehicle. This meant the concepts were transferable to other programming languages that ADoM students may encounter during their course, such as JavaScript or ActionScript. In addition, the research topic was related to their general interest areas (online environments and multimedia), therefore participants were considered to have a certain level of intrinsic motivation. Finally, participants received a free, comprehensive and personal learning style report, which usually attracts a fee. It was hoped that students were further motivated to complete all seven lessons by the split of the learning style assessment into two parts, where the second part (which was irrelevant to the adaptations in iWeaver) could only be completed after the last lesson. Other than the free learning style assessment no reward incentives were provided to the students.

The workshop sessions during which the evaluation took place were a part of the normal curriculum, so participants did not have to sacrifice any of their spare time. The workshops that were used for the evaluation were Interactive Multimedia I (2^{nd} year) and Web Design II (1^{st} year). Physical presence at the workshop session was mandatory. However, participation in the evaluation was voluntary.

3.5.2 Location and Equipment

Six evaluation sessions were conducted with an average of 10 participants in each session. The sessions were held on-campus in the ADoM multimedia labs at RMIT University (TAFE division) in Melbourne. Originally, it was considered appropriate to conduct the evaluation by giving participants home access, but this idea was not pursued due to a higher risk of drop-outs (e.g., as experienced by Stern (2001, p. 115)). Additionally, an on-campus evaluation reduced the risk of technical problems by providing a fast Internet connection and a unified hardware and software platform on all client computers.

The technical setup during the evaluation sessions consisted of a local server running iWeaver with MySQL and Tomcat on a dual core Pentium 4, 3 GHz, 1 GB of RAM and the Windows XP Media Centre Edition operating system. The client computers were G5 iMacs with 1.8 GHz PowerPC processors and 2 GB RAM, running Mac OS X 10.4.4. The programs Flash Player 6, Firefox 1.5, RealPlayer 10 and the Java Runtime Environment 1.4 were also installed. Client computers were equipped with 20 inch widescreen LCD displays with a 1280x800 pixels screen resolution. Individual headphones were attached to each computer, so learners could listen to the auditory media experiences without disturbing others.

3.5.3 Evaluation Sessions

The six evaluation sessions were conducted with different groups of students over a period of three days. The duration of individual sessions averaged about 90 minutes, held during three to four hour workshops.

At the start of a session, the project and the user interface of iWeaver were briefly introduced and demonstrated. The students were informed that the research was concerned with learning styles in general. However, the specific focus of the investigation on the effect of choice was not revealed. Students were told that the media recommendations were based on what the environment “assumes” suits their style best. Further, students were told that these assumptions might not always be correct and as such, they were encouraged to try out other media experiences as well.

The role of the researcher was defined as technical support, who only intervened in the event of technical problems (e.g., time-outs) and only answered questions of general nature (e.g., about the user interface). No content questions were answered in an effort not to influence the evaluation. Students were assured that they could close their browser or reboot their computer at any time and continue later where they left off.

The progression of the participants through the environment has been described earlier (section 3.2.3, p. 97). Participants completed the initial learning styles assessment in about 10 minutes. They were advised to only skim the interpretation in order to save time and with reference to the possibility of getting their results as an email for a more in-depth read at a later time. After about 40 minutes of interaction with iWeaver, the students were encouraged to take a break and most of them did. After the completion of the final lesson, participants could answer the remaining four sections of the BES and peruse the results.

It is of note that an additional and unexpected data source emerged during and after the evaluation sessions: some participants approached the researcher with informal and unprompted feedback. Despite exceeding the boundaries of the original data collection arrangement, these comments were anonymously recorded, because they were considered a valuable contribution to the cause of this study.

3.5.4 Data Screening

In the data analysis, it had to be taken into account that all participants were volunteers and their motivation varied. Despite the measures that were taken to maximise the participants' motivation to complete all lessons, some participants quit the evaluation session early. Interestingly, all 63 participants completed the initial learning style assessment. As a consequence of the drop-outs, the statistical analysis had to be carried out with an incomplete data set. A minimum inclusion criterion was chosen to achieve a balance between statistical meaningfulness and completeness of the data.

The minimum inclusion criterion for the analysis was set at three completed lessons, because a progression to this stage of the learning process was considered to demonstrate an active involvement of the learner and an adequate amount of interest in the topic. It was assumed that at this stage, a sufficient amount of interaction with the learning materials and respective mental processing had taken place to show an effect of the independent variable, if there was one. Participants with less than three completed lessons were excluded from the analysis, because it was assumed that they did not have a genuine interest in the topic and as such they would not actively process their answers to pre- and post-test questions and the feedback forms. This criterion left 27 participants for the analysis, compared to 63 participants originally. Statistics for both groups on gender, mean age and mean number of completed lessons are listed in Table 3-5. Of the 27 included participants, 12 participants completed 3 lessons, 2 participants completed 4 and 5 lessons respectively, and 13 participants completed all 7 lessons. The 27 participants completed a total of 136 lessons compared to a theoretical maximum of 189 lessons (7 lessons each). This is akin to a 72% completeness ratio for the data that were used for the analysis.

To further strengthen the analysis, data were also analysed for the 13 participants who completed all seven lessons. This group was referred to as "finished participants" and it was examined in two separate sections in the results chapter. The number of participants in this group was too small to warrant a full analysis as the main focus of the results chapter. In contrast, the group of 27 participants with a minimum of three lessons provided both the repeated measures and more statistical power due to more observations per cell. By looking at both sets of data as an additional perspective, a repetition of similar results for both groups strengthens the overall conclusion. However, some overlap between the two sets of data is acknowledged.

Table 3-5

Participant Statistics by Analysis Group for Gender, Age and Completed Lessons

Group	*n*	Gender	Age (*M*)	*SD*	Lessons (*M*)	*SD*
All participants	63	28 f / 35 m	24.92	6.20	2.71	2.50
Analysed participants	27	8 f / 19 m	26.15	8.11	5.04	1.97
Finished participants	13	4 f / 9 m	24.46	5.92	7.0	0.0

Learning gain data were filtered for wild guesses by eliminating all answers from the pre- and the post-test results where the answer time was three seconds or less. A close examination of the data and tests of the environment showed that in three seconds it was impossible for a learner to (1) wait for the question page to load, (2) read the question and (at least some of) the answers, (3) select the correct answer and finally (4) click the "continue" button. The cleaning procedure added to the validity of the results, by filtering out wild guesses, which mainly affected the pre-test results. To provide a comparison, learning gain means before the filtering process were provided as a note in the means table in the results chapter.

3.5.5 Analysis Procedure

The data of this study were drawn from a convenience sample and the statistical analysis was performed on a subset of this sample. As such, the sample was neither a simple nor a complex random sample of the population, because not every member of the population had an equal opportunity to be selected in the study (Ross, 2005, p. 5). Simple or complex random sampling would have been an excellent basis to allow for a generalisation of the results. In comparison, a convenience sample can be interpreted as a complete population (i.e., six intact classes of a complete multimedia course), rather than a random sample. Statistical significance testing for a sample containing a complete population can lead to errors in the interpretation of data and to an exaggeration of the found difference (Izard, 2001). This error was referred to as a "design effect" (Ross, 2005, p. 18). The effect was attributed to a greater homogeneity within the class due to common selective factors that influence the participants such as joint exposure to the same external influences (e.g., teachers), a shared socioeconomic background, or the selection process of the university.

Nevertheless, the data drawn from the convenience sample were assumed to be sufficiently representative of the population described in section 3.4.2 (p. 123) to allow a cautious generalisation. Paired-samples *t*-tests were used to examine statistical differences between the means of the dependent variables for the two conditions. Additionally, effect sizes were calculated, which indicate the magnitude of the difference between the conditions. In other words, the effect size designates the proportion of variance that is attributable to the independent variable. Effect size calculations can be applied if the convenience sample used in this study is interpreted as a complete population, rather than a random sample.

The qualitative component of the data analysis consisted of examining the comments that were collected through the lesson feedback forms (see section 3.4.3, p. 124). In order to identify common themes, comments were grouped into logical clusters and interpreted within their cluster. Furthermore, interconnections between quantitative and qualitative data were sought to establish whether the participants' comments corroborate or contradict the quantitative findings.

3.5.6 Effect Size Calculation

The use of effect sizes is becoming increasingly popular in psychological experimental designs (e.g., E. McKay, 2000; Mayer, 2003). The fifth edition of the APA publication manual (American Psychological Association, 2001) noted that in order to give the reader an idea about the importance of findings, it is "almost always necessary to include some index of effect size or strength of relationship" (p. 25), when reporting results. In his suggested amendments to APA guidelines, Thomson (2000) highlighted that reporting effect sizes has three major benefits: (1) it facilitates later meta-analyses that include the study, (2) it contributes to a research literature where specific study expectations can be formulated; and (3) it facilitates a judgement of how the study fits into an existing body of literature by expressing how similar or dissimilar results are compared with related studies.

A frequently used formula to calculate the effect size was proposed by Cohen (1988). Cohen defined his version of effect size (Cohen's *d*) as the difference between two means divided by the pooled standard deviation:

$$d = \frac{\text{mean}_1 - \text{mean}_2}{\sqrt{\left(\text{SD}_1^2 + \text{SD}_2^2\right)/2}}$$

In order to reflect the sense of magnitude of an effect and to facilitate interpretation, Cohen (1992) proposed a rule-of-thumb categorisation in "small" (0.2), "medium" (0.5) and "large" (0.8) effects. This categorisation was employed to report and discuss the results of this study.

Due to the nature of a repeated measures design, the two means that are compared stem from the same person. Therefore, the correlation between these means is rather high. The correlation reduces the standard error and, as a result, artificially inflates the visible effect. In order to compensate for this inflation, Dunlap, Cortina, Vaslow, and Burke (1996) convincingly argued that it is appropriate to use the following formula to calculate a corrected *d* for correlated data:

$$d = t_C\left[2(1-r)/n\right]^{1/2}$$

In this formula, t_C stands for the *t*-value of the correlated groups and *r* represents the correlation coefficient. Correlation coefficients and *t*-values are reported in the results chapter to facilitate meta-analyses.

3.5.7 Threats to Validity

External validity describes the extent to which findings can be generalised beyond the sample used in a study. Generally, experimental studies are limited by the parameters in which they took place. With regards to this study, the properties of the sample and the iWeaver environment were examined to identify potential threats to external validity. The sample consisted of 27 TAFE multimedia students, who completed three or more lessons of iWeaver. This sample was considered as sufficiently representative of the population (described in section 3.4.2, p. 123); an assumption that could be challenged. For example, a design effect (Ross, 2005, p. 18) may have occurred due to the convenience sampling, as explained before. This design effect may reduce the generalisability of results. Furthermore, the properties of iWeaver's learning topic (computer programming), its custom-developed media experiences and its learning tools might not compare well with other learning-style adaptive environments. In summary, the results of this study cannot be generalised in an unrestricted manner, which is discussed further under limitations in the final chapter.

Despite measures taken to increase the motivation of participants (see section 3.5.1, p. 130), motivation still seemed low for some participants during the evaluation. This occurrence may be partially due to the fact that the assessment results from iWeaver were not part of the final mark of the participants, which was explicitly stated in the plain language statement (see appendix, section C2). Additionally, comments during the iWeaver sessions indicated that some participants felt somewhat stressed about assignments. This feeling, combined with a low motivation, may have resulted in time-saving behaviour (e.g., skimming over assessment questions), early drop-outs and a reduction in the likelihood of participants trying out multiple media experiences. In particular, drop-outs can be a problem for data analyses and for the generalisation of results, as their absence might mean that a group with a common trait is underrepresented. For example, drop-outs could mainly consist of students with very low initial motivation or interest.

Internal validity means that one can state with confidence that the change under the treatment condition has been caused by the treatment and not by another confounding factor. An increase of internal validity can reduce external validity, because the more variables are controlled in an experiment, the less one can generalise the results. For example, the growth behaviour of bacteria is probably very different in a highly controlled laboratory environment compared to a kitchen surface in a household environment.

A commonly quoted threat to internal validity is the novelty effect (Binder, 1968). It occurs if the impact of a treatment is primarily due to the fact that it is new and exciting and not due to its hypothesised benefits. Typically, this effect fades over time as the novelty wears off. The novelty effect was unlikely to occur in the sample population, as the multimedia students were familiar with learning on a computer due to the nature of their course.

Confounding factors such as prior experience, interest or mood can cause unwanted variability. These factors can be manifold and it is impossible to control for all of them. To reduce confounding factors, a within-group design was chosen to reduce between-subject variability. Furthermore, pre- and post-tests for each lesson were implemented and potential confounding variables were measured in the sign-up form, so that they could be accounted for in the statistical analysis.

Experimental biases can equally occur for participants and for researchers. To reduce participant bias, participants were informed that the research was concerned with learning styles in general. The investigation of the impact of choice was not mentioned. To reduce researcher bias, the role of the researcher was restricted to technical support and interactions with participants were kept to a minimum during the evaluation sessions.

Another threat to internal validity is the carry-over effect (also called order, sequencing, or practice effect), which can occur in repeated measures designs. It means that the effect from one condition can carry over to the comparison condition. For example, if a participant feels confused by having a choice, there is chance that the confusion carries over to the following no choice lesson. However, as participants crossed multiple times between conditions, carry-over effects (if any) were expected to counterbalance each other.

iWeaver was a prototype environment and as such not 100% robust. For this reason, some students got stuck at certain stages and needed technical assistance. About once during every evaluation session the server needed to be restarted, which meant the students were interrupted in their learning process for two to three minutes and had to log out and back in again. Even though participants were advised at the start of sessions that technical problems may occur, these issues may have had an impact on their motivation. However, this impact would have equally applied to both learners under the choice and the no choice condition.

3.6 Summary

This chapter provided background information on the development of iWeaver. As such, the chapter gave an answer to the first research question on how an e-learning environment can adapt itself to accommodate individual learning styles.

First, the instructional design and the learning materials were discussed. Then, the BES was introduced together with considerations that were taken into account for its transfer from a paper-based to an online version, followed by an overview of how participants progress through the environment. Then, the user interface and navigation of iWeaver were explained and the usability considerations to balance distance between pages with cognitive overhead. Finally, iWeaver's approaches to accommodate perceptual and information processing preferences were presented. Perceptual preferences were accommodated with four media experiences: visual text, visual pictures, tactile-kinaesthetic, and auditory. Information processing preferences were accommodated by three learning tools: the try-it tool, note-taking tool, and the full-tree tool. Additionally, a glossary tool was provided.

The next subchapter covered the design and production of iWeaver. It started with a description of the system architecture. Next, the learner and content model were described. The learner model was based on the participants' initial learning style profile and finetuned with their progression through the environment. The adaptive behaviour of iWeaver consisted of varying the recommendations for choice lessons by changing the order of recommended experiences and the opacity of their icons. These adaptations were dependent on both implicit learner behaviour and explicit learner feedback. Next, the production of media experiences and learning tools was described. This section continued with justifications of development decisions and some of the problems that were encountered during the production process and their solutions.

The following subchapter explained the experimental design and procedure to answer the second research question, regarding the effect of media choice. The target audience of the evaluation was defined as computer-literate, with little or no prior programming experience and diverse learning styles. Next, the data collection instruments were listed. As a result of the pilot tests, several changes were made to iWeaver and to the experimental design. Next, the repeated measures design for the evaluation was explained and justified. The independent variable choice and the dependent variables enjoyment, progress, and motivation were described in detail. Next, the planned experimental procedure was explained by mapping the progression of a learner through the environment.

The final subchapter contained a report of the actual experimental evaluation, the statistical analysis approach and threats to the study's validity. The subchapter provided the demographic details of the 63 multimedia students who participated in the evaluation. Next, the location and equipment were described. Following, the statistical analysis approach was detailed. Due to the high number of drop-outs, a minimum inclusion criterion of three completed lessons was set for the analysis. This criterion left 27 of the original 63 participants to be analysed. Due to the repeated measures within-group design with one independent variable (choice), paired *t*-tests were used for the analysis, complemented by corrected effect size calculations. Finally, threats to the internal and external validity of the evaluation and their counter-measures were discussed. Threats to external validity included that a convenience sample was used, time-saving behaviour by the participants and drop-outs. Threats to internal validity included the novelty effect, confounding factors such as prior experience or interest, experimental biases, carry-over effects, and technical problems during the evaluation.

4 RESULTS AND DISCUSSION

4.1 Introduction

This chapter describes, analyses and discusses the collected quantitative and qualitative data. The independent variable choice was investigated in a within-group (paired-samples) analysis. When results of repeated measures *t*-tests are reported, significance levels of less than .05 are considered statistically significant.

In order to determine the magnitude of practical relevance of the results, effect sizes of differences were calculated in addition to statistical significance. As this study used a repeated measures design, effect sizes were computed with an adjustment to compensate for correlation as recommended by Dunlap et al. (1996). Effect sizes were classified as small (0.2), medium (0.5) and large (0.8), in accordance with Cohen's recommendation (1992).

First, this chapter states the overall distribution of perceptual styles for the participants. Then, the data are analysed to determine whether participants actually took advantage of having a choice. This description of the data is followed by a brief discussion. Next, mean differences between the two conditions are calculated. In an initial analysis, the influence of choice on the four dependent variables (learning gain, lesson enjoyment, perceived progress, and motivation) is detailed and then discussed.

As the initial analysis revealed a small negative effect of choice, two exploratory analyses are conducted in an attempt to localise the effect. To this end, participants are split into groups according to their level of interest in programming and Java and according to their experience with computers and the Internet. Results of these two analyses are presented and subsequently discussed.

Finally, to further strengthen the assessment by statistical analysis, interconnections between the quantitative results and the qualitative data are sought and discussed at the end of the chapter.

4.2 Revisited: Research Questions

The first research question asked in what ways an e-learning environment can adapt itself to accommodate individual learning styles. An answer to this question was developed through the literature review and put into practice by the design and construction of the iWeaver environment, as described in the previous chapter.

The second research question asked if it is more beneficial for participants to learn with a choice of media experiences, or to learn with only one media experience, matched for their most-preferred learning style. Benefit was measured objectively by assessing the learning gain and subjectively by asking participants about their perceived enjoyment, progress, and motivation. Is was expected that giving learners a choice of media experiences would have a positive effect (see section 2.6.3, p. 72) on all four dependent variables.

A potential side-effect of offering learners a choice between media experiences is that the evaluation of these data can also provide insights about the effects of matching and mismatching learners. Mismatches could only happen in choice lessons, meaning learners mismatched themselves voluntarily. This is contrary to other matching and mismatching studies, where learners were automatically mismatched by the experimental design (e.g., E. McKay, 2000; Militello & Ovcin, 2003).

4.3 Revisited: Dependent Variables

As explained previously (see section 3.4.6, p. 128), learning gain was measured objectively by deducting the pre-test results from post-test results for each lesson and then averaged for each condition (choice and no choice). With seven questions per lesson, a maximum learning gain of seven could be achieved if zero answers were correct in the pre-test and all seven answers were correct in the post-test. In contrast, the remaining three variables enjoyment, progress, and motivation were measured subjectively by asking the learner for feedback after each lesson with six-point Likert scales. In addition to quantitative measurements, learners could leave free-text comments through the feedback forms at the end of each lesson. Unprompted feedback was also recorded, but without context.

4.4 Description of the Data

This subchapter describes the raw results obtained from a first inspection of the data. The perceptual style distribution from the 27 participants of the analysis group was compared to the data of all 63 participants in order to investigate if the cut-off criterion (completion of the third lesson) may have introduced a bias to the results from a style perspective. Next, the choices learners executed in choice lessons are examined in detail.

4.4.1 Distribution of Perceptual Styles

The distribution of the four perceptual styles tactile-kinaesthetic (TK), visual pictures (VP), auditory (AD) and visual text (VT) is displayed in Figure 4-1. The light bars represent percentages for all 63 participants, whereas the dark bars represent percentages for the group of 27 participants used for the statistical analysis. It was interesting to note that 12 of all 63 (19%) participants expressed equivalent scores for multiple (two or three) most-preferred styles compared to 6 of 27 (22%) of the analysed participants. Correspondingly, the weight of "1" for these participants was distributed evenly across the affected styles to maintain the overall balance. For example, if a participant had even scores for the TK and VP style, 0.5 was added to each style in the statistic. The control style for multi-style participants was randomly selected from their most-preferred styles.

The resulting perceptual style distribution of all participants compared to the distribution of the analysed participants were similar. In both groups, the VT style was rare: only 1% of all participants expressed a VT style and none of the analysed participants. Similarly, only 5% of all participants expressed an AD style, compared to 6% of the analysed participants. The second most common perceptual style was VP with 38% of all participants and 36% of the analysed participants. Learners were most commonly assessed with TK as their most-preferred perceptual style: 56% of all participants, compared to 58% of the analysed participants. In summary, 94% of the participants in both groups expressed either TK or VP as their most-preferred style.

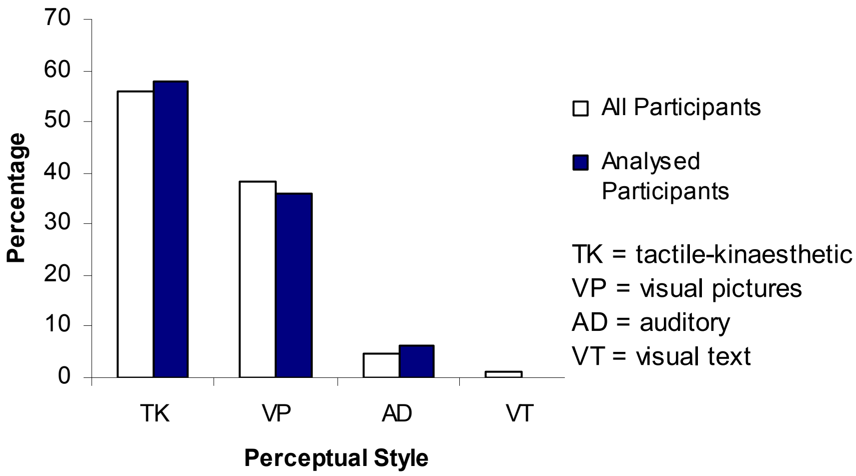


Figure 4-1. Distribution of perceptual styles for all participants compared to analysed participants.

4.4.2 Choices in Choice Lessons

As a first step in the analysis, the data were examined to determine whether the participants actually took advantage of the opportunity to select another media experience when they had a choice. The 27 analysed participants visited a total of 136 lessons. Of these participants, 12 participants started with the choice condition and 15 participants started with the no choice condition.

Figure 4-2 displays a breakdown of the choices that were executed in choice lessons. The first column shows the number of lessons in which a choice was given (67) and in which no choice was given (71). If no choice was given, participants were automatically exposed to materials matched for their control style.

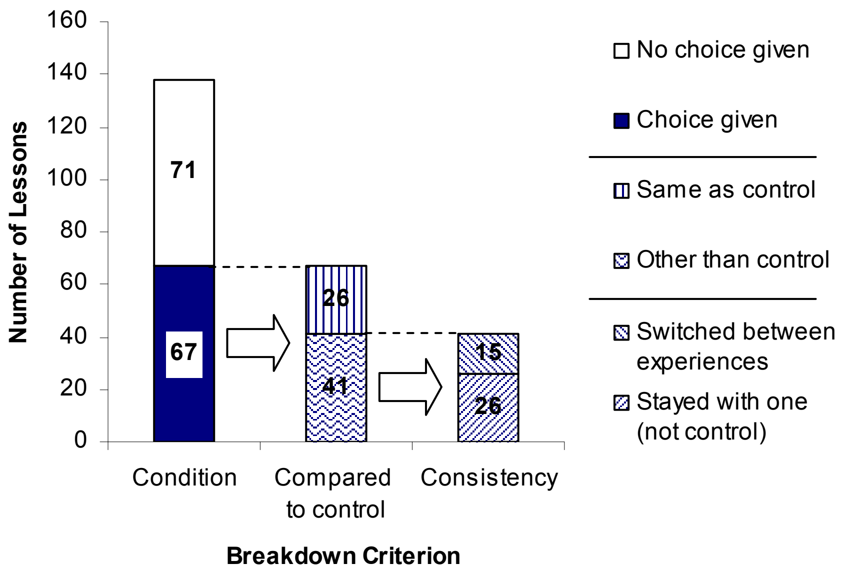


Figure 4-2. Breakdown of choices by "compared to control" and consistency.

As participants could freely switch between media experiences in choice lessons, a further breakdown at page impression level was conducted for the 67 choice lessons. Consequently, a total of 839 choice lesson page impressions were analysed. It should be noted that this analysis included every page impression, even sporadic visits, which could not be filtered out with the available data. The resulting pie chart is displayed in Figure 4-3. The chart shows that in choice lessons, participants chose the visual pictures media experience (41%) about twice as often as any of the other media experiences (16-22%). Notably, this distribution of choices is different to the overall distribution of perceptual styles as displayed in Figure 4-1 (see p. 143).

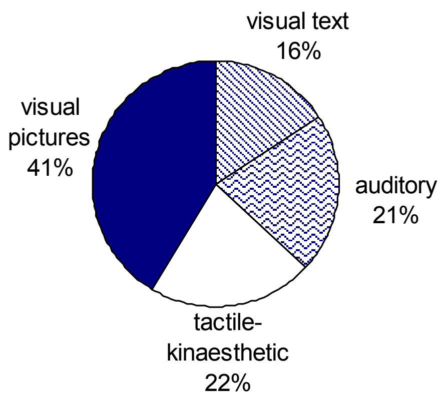


Figure 4-3. Breakdown of choices in choice lessons by media experience on a page impression level.

The 67 lessons in which participants had a choice were further broken down into two groups: “same as control” and “other than control” (see Figure 4-2, p. 144). In 26 choice lessons, participants selected the experience matched for their control style and stayed with it, even though there were other experiences available. In the remaining 41 choice lessons, participants selected another experience, not matched for their control style. These 41 lessons were further differentiated: in 26 lessons, participants simply stayed with the one experience they selected at the start of the lesson and did not switch. In the remaining 15 lessons, participants visited multiple experiences.

To gain insight into the relative amount of choice that participants executed during their learning experience, a simple model was devised to quantify choice as a score. Participants scored one point in each of the 41 lessons in which they deviated from their control style (see Figure 4-2, p. 144). This means they chose:

- mainly or solely mismatched experiences (28 lessons), or
- some mismatched experiences, but were mainly matched (10 lessons), or
- an experience different to their control style, but were still matched due to multiple most-preferred styles (3 lessons).

However, choice scores were not directly comparable, because the number of choice lessons varied per participant, due to alternating starting conditions and drop-outs. For example, a participant who completed all seven lessons and who started with a choice lesson, visited four choice lessons in total. By contrast, a participant who started with a no choice lesson could only visit up to three choice lessons. Therefore, the choice score was divided by the number of choice lessons a participant visited to calculate the “choice ratio”. Table 4-1 displays the breakdown of choice ratios for the 27 participants. 4 participants (15%) never deviated from their control style, whereas 12 participants (44%) always chose media experiences different to their control style when they had the chance. In total, the majority of participants (85%) took advantage of having a choice in one or more lessons during their learning experience.

Table 4-1

Executed Choice Ratio per Participant

Choice Ratio	Partici-pants[a]	%
1.00	12	44%
0.75	1	4%
0.67	3	11%
0.50	4	15%
0.33	2	7%
0.25	1	4%
0.00	4	15%

Note. Maximum possible choice ratio = 1.00. [a]$n = 27$.

4.4.3 Discussion

With regards to the perceptual styles distribution, it was interesting to note that 19% of all participants expressed multiple (two or three) most-preferred styles with equivalent scores for each style. Similarly, 22% of the participants in the analysis group expressed multiple most-preferred styles. This finding adds weight to the argument that classifying learners as having only one most-preferred style (e.g., Carver et al., 1996; Laroussi, 2001; Bajraktarevic & Fullick, 2003) is artificially restrictive and not advisable. It stands to reason to assume that learners with multiple most-preferred styles will benefit from choice. Unfortunately, there was insufficient data to statistically test this assumption, as only six learners expressed multiple most-preferred styles.

The style distributions for all 63 participants and the 27 analysed participants are very similar. As such it is unlikely that the cut-off criteria caused substantial bias for the results with regards to perceptual styles. Furthermore, it was interesting that almost all participants (94%) were initially assessed with either a visual pictures or a tactile-kinaesthetic perceptual style. Due to this skewed distribution, the results of this study mostly apply to learners with these predominant styles. This imbalance was surprising, as the target group of multimedia students was chosen with the particular aim in mind to achieve a balanced distribution across learning styles.

Several results in this subchapter indicate that participants were not choosing different media experiences as often as they could have. For example, in only 15 of 67 (22%) choice lessons, participants visited multiple experiences. Furthermore, 4 of 27 (15%) participants never chose a different experience at all. A possible explanations for this lack of deviation from the control style could be that the media selection bar was not prominent enough to encourage ongoing media choices. Another explanation could be that students were simply satisfied with the media experience for their control style and not interested in visiting other experiences. Even though the choices by some participants were equivalent to their control style, the fact that choices were available was still expected to have had an impact on the dependent variables for these learners.

Notwithstanding the lack of deviation of some participants, the majority of participants (85%) still took advantage of having a choice in one or more lessons during their learning experience. Additionally, the majority of choice lessons (61%) resulted in deviations from the control style and the breakdown of page impressions in those lessons also indicates that participants indeed executed choices. The visual pictures experience (41%) was visited twice as often as any other experience. Also, it was interesting to note that the visual text and auditory experiences accounted for 16% and 21% respectively of the page impressions. As such, the distribution of media experience choices in the choice lessons was vastly different from the overall perceptual style distribution for the participants. This indicates that offering participants a choice indeed made a difference to their learning experience compared to the no choice lessons. As such, the original within-group analysis approach to compare the two conditions choice/no choice with paired-samples *t*-tests was maintained.

4.5 Initial Analysis

In order to test for any differences between the choice and the no choice condition regarding the dependent variables (learning gain, enjoyment, progress, and motivation), mean and standard deviation calculations were performed. The results are listed in Table

4-2. Mean scores for learning gain and progress were slightly lower under the choice condition, whereas the scores for enjoyment and motivation were slightly higher.

Table 4-2

Mean Comparisons between Choice/No Choice Conditions in Initial Analysis

	Mean			*SD*	
Dependent variable[a]	C[b]	NC	Diff.	C	NC
Learning gain[c]	1.14	1.47	-0.33	1.49	1.71
Enjoyment	3.15	3.08	0.07	1.26	1.47
Progress	3.23	3.28	-0.05	1.23	1.45
Motivation	2.91	2.75	0.16	1.32	1.39

Note. Maximum possible learning gain = 7, Maximum possible enjoyment, progress, and motivation = 6. [a]$n = 27$. [b]C = Choice, NC = No Choice. [c]Before filtering wild guesses, the mean learning gain was 0.89 ($SD = 1.48$) for choice lessons and 1.12 ($SD = 1.54$) for no choice lessons.

In order to establish whether the data were normally distributed, Kolmogorov-Smirnov tests were conducted for the four dependent variables. The four tests revealed nonsignificant results. Accordingly, the data were considered normally distributed, which meant effect size calculations and analyses using paired-samples *t*-tests were warranted.

Next, effect sizes were calculated and a statistical analysis using paired-samples *t*-tests was conducted to investigate whether the influence of choice on the dependent variables was statistically significant. A two-tailed paired-samples *t*-test found no significant differences between the choice and the no choice condition for any of the four dependent variables. Corrected effect sizes were calculated and a small negative effect of choice on learning gain was revealed, whereas other effect sizes were negligible. Table 4-3 lists *p*-values, effect sizes and further statistical information.

Table 4-3

P-values and Effect Sizes for Choice Condition in Initial Analysis

Dependent variable[a]	t	r	p	d[b]
Learning gain	-1.39	0.71	.18	-0.20#
Enjoyment	0.40	0.84	.69	0.04
Progress	-0.31	0.80	.76	-0.04
Motivation	1.49	0.91	.15	0.12

Note. [b]corrected d, see p. 134. [a] $n = 27$. #$d \leq -0.20$.

4.5.1 Finished Participants

As explained in the last chapter (section 3.5.4, p. 132), 14 out of the 27 analysed participants quit the evaluation before completing all seven lessons. Therefore, the data were analysed as an incomplete set. To further probe the results of this analysis approach, only the data of the 13 participants with seven completed lessons were analysed as a complete set, whilst acknowledging some overlap of the data. Paired *t*-tests were carried out for this group and corrected effect sizes were calculated. For simplicity, only significant interactions and effect sizes exceeding 0.2 are reported. Full tables of mean scores, *p*-values and effect sizes can be found in the appendix (Table B-1 and Table B-2).

Two-tailed paired-samples *t*-test revealed no significant differences between choice and the dependent variables, but a small negative effect was detected for the influence of choice on learning gain ($d = -0.25$).

4.5.2 Discussion

Mean scores indicate that the choice condition had a slightly negative influence on learning gain and progress, but a slightly positive influence on enjoyment and motivation. Even though the paired-samples *t*-tests between the choice and no choice condition revealed no significant differences for any of the dependent variables, a small negative effect was found for the choice/learning gain interaction. An analysis of the data of finished participants revealed a similar result. This was surprising, as this outcome directly contradicted the original hypothesis: choice was believed to positively affect the dependent variables, but conversely, choice seemed to have a negative effect or no effect.

The slight negative impact of choice gave rise to the suspicion that a further exploration of the data might reveal additional insights by localising the effect. Following this, the sign-up data (see appendix, Figure C-1 for the sign-up form) of participants were included into the analysis to add further detail to the participant profiles. The added detail allowed the analysis of subgroups with certain dichotomous traits.

4.6 Exploratory Analysis

The aim of the exploratory analysis was to determine whether the influence of choice on the dependent variables was localised to participants with certain traits. As a first step, the sign-up data were investigated to look for suitable criteria to subdivide the 27 participants. To this end, their sign-up data with regards to prior experience and interests were tested for normal distributions and correlations. Kolmogorov-Smirnov tests were carried out for the variables e-learning experience; computer experience; Internet experience; Java interest; programming interest; and, experience with five different programming paradigms. Significant results were found for e-learning experience and three of the five programming paradigms, which indicated that the distributions for these variables were not normal and thus unsuitable to be used to split the group. The scores for prior HTML and JavaScript experience were normally distributed, but as the focus of these experiences was too specific, they were not considered as splitting factors.

Correlations between the remaining four variables were calculated with a conservative significance threshold of .01. Consequently, two statistically significant correlations were revealed. There was a significant positive correlation between Internet experience and computer experience, $r(n{=}27) = .68$, $p < .001$, and a significant positive correlation between Java interest and programming interest, $r(n{=}27) = .80$, $p < .001$. In order to simplify the analysis, the correlated variable pairs were summed up to form only two variables: interest and experience. It should be noted that, despite measuring different concepts, there was a significant positive correlation at the .05 level between interest and experience, $r(n{=}27) = .40$, $p = .039$. Frequency distributions for the scores of the two variables are displayed in Figure 4-4 and Figure 4-5.

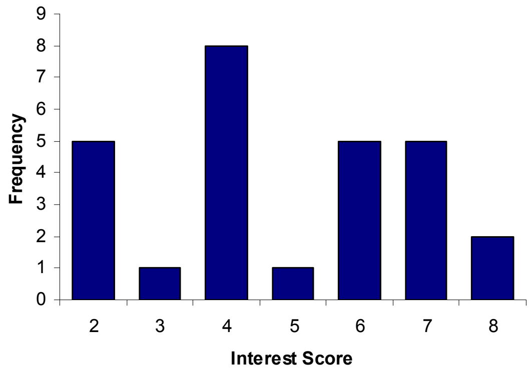


Figure 4-4. Interest score (Java interest + programming interest) score frequencies. Maximum score = 12.

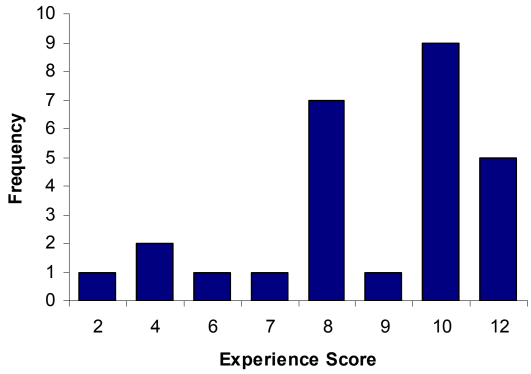


Figure 4-5. Experience (computer experience + Internet experience) score frequencies. Maximum score = 12.

Next, the group of 27 participants was divided into subgroups with high and low interest and experience. To split the group, a median split was used for interest scores (*Mdn* = 4), leading to a low interest subgroup with 14 participants and a high interest subgroup with 13 participants. However, a median split for experience scores (*Mdn* = 10) proved to be unsuitable, because the subgroups were considerably unbalanced with 22 participants in the low experience subgroup and only 5 participants in the high experience subgroup. To achieve more balanced subgroups, the group was split at an experience score of 9 (i.e., 1 below the median). As a result, the low experience subgroup consisted of 13 participants and the high experience subgroup of 14 participants.

Finally, the subgroups with differing levels of interest or experience were analysed with regards to differences between the choice/no choice conditions. Results of these analyses are presented in the next two sections and significant interactions are illustrated by line charts.

4.6.1 Interest

In order to test for any differences between the choice and the no choice condition regarding the dependent variables (learning gain, enjoyment, progress, and motivation), mean and standard deviation calculations were performed for the low interest (n = 14) and the high interest (n = 13) group. Results are listed in Table 4-4. It was found that in the low interest group, all mean results were higher under the choice condition. In contrast, is was found that in the high interest group, three out of four means were lower under the choice condition.

Table 4-4

Mean Comparisons Between Choice/No Choice Conditions in Low/High Interest Groups

	Low interest[b]					High interest[c]				
	Mean			*SD*		*Mean*			*SD*	
DV	C[a]	NC	Diff	C	NC	C	NC	Diff	C	NC
Learning gain	1.17	0.87	0.30	1.59	1.41	1.12	2.12	-1.00	1.44	1.82
Enjoyment	3.01	2.67	0.34	1.35	1.51	3.29	3.53	-0.24	1.19	1.33
Progress	2.96	2.84	0.12	1.40	1.53	3.52	3.76	-0.24	0.99	1.26
Motivation	2.67	2.52	0.15	1.56	1.56	3.18	2.99	0.19	1.01	1.18

Note. Maximum possible learning gain = 7, Maximum possible enjoyment, progress, and motivation = 6. [a]C = Choice, NC = No choice. [b]$n = 14$. [c]$n = 13$.

A two-tailed paired-samples *t*-test for the high interest group revealed a significant difference between the choice and the no choice condition for learning gain, $t(12) = -3.63$, $p = .003$. In other words, participants with high interest expressed a significantly lower learning gain when they had a choice compared to having only a single media experience. In comparison, the mean score of the low interest group was higher under the choice condition, but the difference was not statistically significant, $t(13) = 1.01$, $p = .33$. The other interactions in the high interest group and in the low interest group were also not statistically significant. The interaction between learning gain and choice for high and low interest is pictured in Figure 4-6.

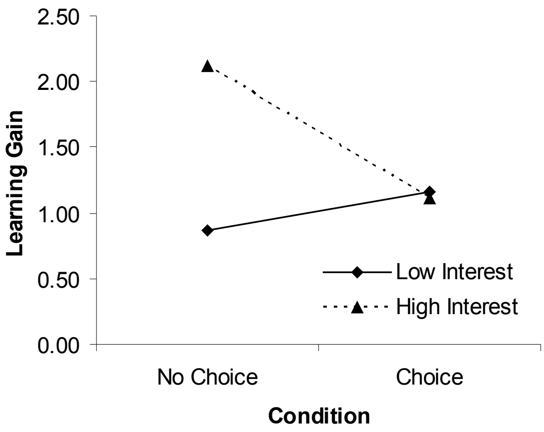


Figure 4-6. Interaction between learning gain and choice: Mean scores for the low and the high interest group.

Corrected effect sizes were calculated and are presented together with *p*-values and further statistical information in Table 4-5. For the high interest group, a medium negative effect of choice on learning gain was revealed, as well as a small negative effect of choice on progress. For the low interest group, small positive effects of choice on learning gain and enjoyment were found. Other effect sizes were negligible.

Table 4-5

P-values and Effect Sizes for Choice Condition in Low/High Interest Groups

	– Low interest[a] –				– High interest[b] –			
Dep. variable	*t*	*r*	*p*	*d*[c]	*t*	*r*	*p*	*d*[c]
Learning gain	1.01	0.73	.33	0.20#	-3.63	0.84	.003**	-0.57##
Enjoyment	1.69	0.87	.11	0.23#	-1.05	0.81	.31	-0.18
Progress	0.65	0.89	.53	0.08	-0.82	0.59	.43	-0.21#
Motivation	1.25	0.96	.23	0.10	0.93	0.79	.37	0.17

Note. [c]corrected *d*, see p. 134. [a]$n = 14$. [b]$n = 13$. **$p < .01$. #$d \leq$ or ≥ 0.20. ##$d \leq -0.50$.

4.6.2 Experience

In order to test for any differences between the choice and the no choice condition regarding the dependent variables (learning gain, enjoyment, progress, and motivation), mean and standard deviation calculations were performed for the low experience (*n* = 13) and high experience (*n* = 14) group. The results are listed in Table 4-6. It was found that in the low experience group, the mean results for learning gain and motivation were higher under the choice condition and the mean results for progress slightly lower. In contrast, it was found that in the high experience group, mean results for learning gain were lower under the choice condition, but for enjoyment, mean results were slightly higher. There was no difference between the means for progress and motivation.

Table 4-6

Mean Comparisons Between Choice/No Choice Conditions in Low/High Experience Groups

	Low experience[b]					High experience[c]				
	Mean			*SD*		*Mean*			*SD*	
DV	C[a]	NC	Diff	C	NC	C	NC	Diff	C	NC
Learning gain	1.12	0.57	0.55	1.63	1.38	1.17	2.30	-1.13	1.40	1.59
Enjoyment	2.85	2.84	0.01	1.32	1.78	3.42	3.31	0.11	1.18	1.12
Progress	2.92	3.02	-0.10	1.24	1.72	3.52	3.52	0.00	1.18	1.17
Motivation	2.64	2.29	0.35	1.48	1.52	3.17	3.17	0.00	1.15	1.14

Note. Maximum possible learning gain = 7, Maximum possible enjoyment, progress, and motivation = 6. [a]C = Choice, NC = No choice. [b]*n* = 13. [c]*n* = 14.

A two-tailed paired-samples *t*-test for the high experience group revealed a significant difference between the choice and the no choice condition for learning gain, $t(13) = -4.60$, $p < .001$. In other words, for participants with high experience, choice had a statistically significant negative influence on learning gain. This interaction is pictured in Figure 4-7. Interactions between choice and enjoyment, progress or motivation were not significant in the high experience group.

A two-tailed paired-samples *t*-test for the low experience group revealed a significant difference between the choice and the no choice condition for learning gain, $t(12) = 2.28$, $p < .042$. A further significant difference was found for the effect of choice on motivation, $t(12) = 2.34$, $p < .037$. In other words, for participants with low experience, choice had a statistically significant positive influence on learning gain and motivation. This interaction is pictured in Figure 4-7 and Figure 4-8. Interactions between choice and enjoyment and progress were not significant in the low experience group.

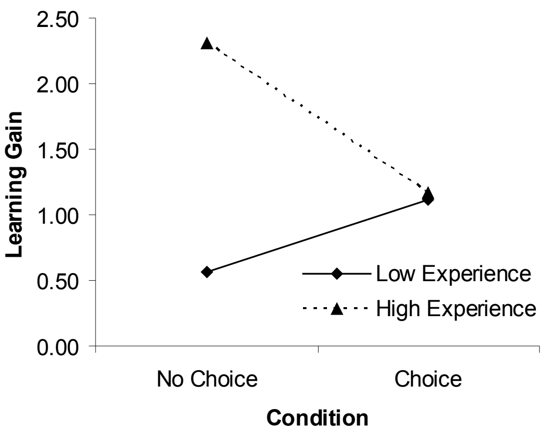


Figure 4-7. Interaction between learning gain and choice: Mean scores for the low and the high experience group.

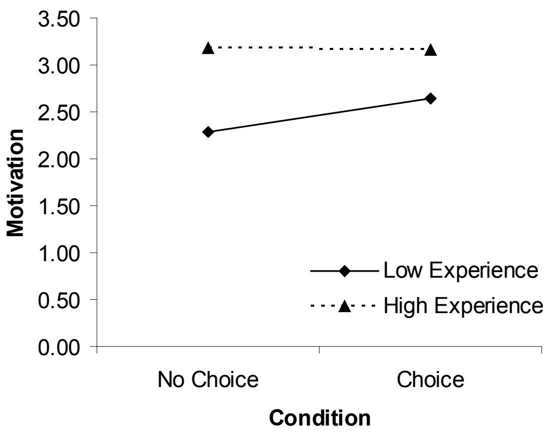


Figure 4-8. Interaction between motivation and choice: Mean scores for the low and the high experience group.

Corrected effect sizes were calculated and are presented in Table 4-7 together with *p*-values and further statistical information. For the high experience group, a medium negative effect of choice on learning gain was revealed. For the low experience group, small positive effects of choice on learning gain and motivation were evident. Other effect sizes were negligible.

Table 4-7

P-values and Effect Sizes for Choice Condition in Low/High Experience Groups

	– Low experience[a] –				– High experience[b] –			
DV	*t*	*r*	*p*	*d*[c]	*t*	*r*	*p*	*d*[c]
Learning gain	2.28	0.85	.042*	0.35#	-4.60	0.82	>.001**	-0.74##
Enjoyment	0.05	0.87	.96	0.01	0.56	0.81	.59	0.09
Progress	-0.32	0.74	.76	-0.06	-0.04	0.90	.97	-0.01
Motivation	2.34	0.93	.037*	0.23#	0.56	0.87	.97	0.08

Note. [c]corrected *d*, see p. 134. [a]$n = 13$. [b]$n = 14$. *$p < .05$. **$p < .01$. #$d \geq 0.20$. ##$d \leq -0.50$.

4.6.3 Finished Participants

To further probe the results of the exploratory analyses, only the data of the 13 participants with seven completed lessons were analysed as a complete set. First, the 13 participants were divided into two groups of high and low interest, then into two groups of high and low experience. Paired *t*-tests were carried out to compare groups and corrected effect sizes were calculated. For simplicity, only significant interactions and effect sizes exceeding 0.2 are reported in this section. Full tables of mean scores, *p*-values and effect sizes can be found in the appendix (Table B-3 to Table B-6).

A two-tailed paired-samples *t*-test for the high interest group ($n = 6$) revealed a significant difference between the choice and the no choice condition for learning gain ($t(5) = -5.41$, $p = .003$, $d = -0.98$). In other words, for participants with high interest, choice had a statistically significant negative influence on learning gain, with a large effect size. Interactions between choice and enjoyment, progress, and motivation were not significant in the high interest group, but a small negative effect of choice on enjoyment was calculated ($d = -0.22$). A two-tailed paired-samples *t*-test for the low interest group ($n = 7$) revealed no significant differences between choice and the dependent variables, but a small positive effect was detected for the influence of choice on learning gain ($d = 0.37$).

A two-tailed paired-samples *t*-test for the high experience group ($n = 7$) revealed a significant difference between the choice and the no choice condition for learning gain ($t(6) = -5.61$, $p = .001$, $d = -0.83$). In other words, for participants with high experience, choice had a statistically significant negative influence on learning gain, with a large effect size. Interactions between choice and enjoyment, progress, and motivation were not significant in the high experience group. A two-tailed paired-samples *t*-test for the low experience group ($n = 6$) revealed a significant difference between the choice and the no choice condition for learning gain, $t(5) = 2.70$, $p = .043$, $d = 0.54$. In other words, for participants with low experience, choice had a statistically significant positive influence on learning gain, with a medium effect size. Interactions between choice and enjoyment, progress, and motivation were not significant in the low experience group.

4.6.4 Discussion

Due to the exploratory nature of the analyses of the interest and experience subgroups, a Bonferroni correction was considered to conservatively adjust the significance threshold. This would have meant dividing the significance threshold by the number of comparisons carried out for each dependent variable. As five comparisons were carried out (one in the initial analysis and then four in the exploratory analyses), a conservative significance threshold would be .05 / 5 = .01. Measured at this level, the negative interaction of choice with learning gain for the high interest and the high experience group would still be statistically significant. On the other hand, the positive interaction of choice with learning gain and motivation for the low experience group would lose its statistical significance.

However, the practice of applying a Bonferroni correction is not universally supported (Perneger, 1998). Even though applying the correction reduces the chance of making a type I error (false positives) in hypothesis testing, it simultaneously increases the risk of making a type II error (false negatives). These and other problems with the Bonferroni correction are discussed by Perneger (1998). In accord with Perneger's recommendation, the correction was not applied, but instead all details and steps of the analyses were provided. As such, the decision about the practical significance of the provided results should be considered in light of the other evidence presented in this exegesis and is left to the reader.

It should be noted that the proposed explanations of results in this subchapter are speculative. Nevertheless, they are based on sound cognitive principles and they are to some extent supported the impressions conveyed by the qualitative data, presented in the next subchapter.

This exegesis attempted to establish that learning style is a flexible, rather than a static construct. A review of the literature (section 2.5.2, p. 42) revealed that there was considerable doubt in the field that learning styles are universally stable across tasks, situations, or time. For this reason, iWeaver departed from the stereotyping approach of other learning environments and gave learners a choice between media experiences. Choice was expected to positively influence the dependent variables, because it was meant to (1) empower learners by giving them more control over their learning experience (J. Kay, 2001), (2) promote cognitive flexibility (Spiro et al., 1992) and (3) provide multiple perspectives on the learning content (Ainsworth, 1999). However, the results gathered in the exploratory analysis indicate that the effect of choice largely depends on other variables, such as interest and experience of the participants.

The exploratory analysis of the low and high interest subgroups revealed differences for the effect of choice. In the high interest group, choice had a medium and statistically significant negative effect on learning gain and a small, nonsignificant negative effect on progress. In contrast, in the low interest group, choice had a small but not statistically significant positive effect on learning gain and enjoyment. An analysis of the data of finished participants revealed similar results for both interest groups.

One explanation for the negative effect of choice on high interest participants could be that these participants were likely to approach a lesson in a focused and highly goal-oriented fashion. Therefore, having a choice between multiple experiences could have been distracting or confusing for them by offering redundant information. This outcome supports the redundancy effect (Mayer, 2001, p. 147), which occurs when unnecessary, “nice-to-have” information has a detrimental effect on learning. It is conceivable that the focused learning approach of high interest students emphasised the redundancy effect, whilst overriding positive effects that were expected to occur, such as the promotion of cognitive flexibility (Spiro et al., 1992). A similar effect, that occurred when learners had too much choice, was observed by Carver et al. (1996).

Having a choice may have caused additional cognitive load (Chandler & Sweller, 1996) by asking students to make a decision. Current educational systems favour and reward the development of an executive thinking style (Cano-Garcia & Hughes, 2000, p. 417/425). According to Cano-Garcia and Hughes, executive thinkers adhere to existing rules and procedures and prefer prestructured or prefabricated approaches to problem solving. As such, they tend to see their role in a learning environment as rather passive and may not like to take responsibility for their learning process. By implication, the high interest learners may have adopted an executive thinking style in order to achieve academically. Therefore, the requirement to make a decision regarding which media representation to use could have had a confusing and distracting effect on them.

Similar to the interest subgroups, the analysis of the experience subgroups (experience with computers and the Internet) revealed differences for the effect of choice. In the high experience group, choice had a medium (approaching large) negative effect on learning gain, which was statistically significant. In the low experience group, small positive effects and statistically significant differences could be detected for the influence of choice on learning gain and motivation. An analysis of the data of finished participants revealed similar results for both experience groups.

Other authors have found nonsignificant effects of combining multiple media for learners with high experience in the respective knowledge area (Mayer & Gallini, 1990). Interestingly, the effect of having a choice between multiple media on high experience learners was significantly *negative* in the present study. It is conceivable that highly experienced learners trust decisions and recommendations of adaptive systems less than learners with little prior experience (discussed in section 2.6.2, p. 70). Therefore, participants with higher experience may have approached choice lessons with a more resistant attitude, which negatively affected their learning gain. Additionally, participants with substantial experience with computers and the Internet are likely to already have a reasonable idea which media they prefer to learn with. Consequently, they might have been missing the "cognitive comfort" (O. A. Roberts, 1999, p. 77) of a matched learning experience when they chose to mismatch themselves in some of the choice lessons.

The positive effect of choice on the low experience group indicates that these learners welcomed having a choice. However, increased motivation may have been partially caused by better post-test results. The potential influence of choice-supportive bias (Mather, Shafir, & Johnson, 2000) was considered as a confounding factor. Choice-supportive bias occurs when participants rate the option they chose more positively than rejected options (sometimes discounting evidence to the contrary), to protect themselves from the cognitive dissonance that would occur, would they regret forgoing an alternative option. Whilst choice-supportive bias may have had an impact on the rating of visited media experiences after each lesson, and as a result, on the adaptation mechanism, it is unlikely that it affected the objectively measured learning gain in post-tests.

Possible explanations for the increased learning gain for participants with low experience include that these participants may have felt reassured by having alternative learning options in case they did not understand a concept straight away. This explanation is in line with cognitive flexibility theory (Spiro et al., 1992) and the suspected positive effect of multiple external representations (Ainsworth, 1999). In addition, low experience learners may have been more likely to “drift” between preferences for different media experiences (Koychev, 2000), because their preferences are not yet as clearly defined as those of high experience learners. As such, having a choice would have been more motivating. Trying out different experiences may have led to “constructive friction” (Vermunt, 1992, as cited in Dekeyser, 2001, p. 100) caused by an incongruence between perceptual styles and instructional strategy, which contributed to the positive influence of choice on learning gain. Another explanation was offered by Mayer and Gallini (1990), who found that multimedia learning was more effective for learners with low experience in the respective knowledge area. The authors speculated that these learners are more likely to draw on the multimedia experiences to construct and reconstruct mental models, rather than relying on pre-existing models.

The positive effect of choice on low experience learners revealed in this study can to some extent be aligned with the results of Kelly (2005). Despite finding no conclusive effect for the level of control for learners, Kelly reported that low activity students learned better with mismatched learning resources. Similarly, the mismatching that occurred in choice lessons during the iWeaver evaluation, seemed to be only beneficial for low experience learners and, to a smaller degree, for learners with low interest. This gives rise to the suspicion that the effects of matching and mismatching media experiences with perceptual styles are complex and influenced by a number of confounding factors, which was also noted by Ford and Chen (2001).

4.7 Qualitative Data

Qualitative data were collected via the lesson feedback form (see appendix, Figure C-6), as described in the method chapter. In this form, learners were asked if there was anything else they would like to comment on. They could then provide feedback in an unrestricted text field. Additionally, participants provided unprompted feedback in the breaks and after the sessions.

In a screening process, seemingly irrelevant comments (e.g., "hello" or "good-bye"), very specific comments regarding the user interface or content issues, as well as excessively repetitive copy and pasted comments (one person commented "needs more interactivity" after every lesson) were omitted to avoid undue bias. The remaining 37 comments are collated in Table B-7 in the appendix. They comprise 8 unprompted verbal comments and 29 written comments that were provided via the feedback form at the end of a lesson.

Qualitative data were analysed with two aims in mind. The first aim was to determine whether the comments corroborate or contradict the more prominent findings from the quantitative analysis that choice has a detrimental effect on high experience learners and a beneficial effect on low experience learners. The second aim was to group comments into logical clusters in an effort to identify common themes that can be interpreted.

4.7.1 Choice Influence and Experience Level

The 37 comments were evaluated to determine whether they support or oppose the quantitative findings that choice has a detrimental effect on high experience learners and a beneficial influence on low experience learners. To this end, the comments needed to be viewed in their respective context within the learning environment. Therefore, comments were supplemented with the following information (see Table B-7 in the appendix):

- initial perceptual style(s) and control style of the participant,
- experience level,
- lesson number after which the comment was made, and
- lesson type after which the comment was made (i.e., choice or no choice).

Next, comments were evaluated by putting their context and connotation into perspective with the quantitative findings. It should be noted that a retrospective interpretation of the exact meaning of a comment can be difficult. Even though care was taken when a relationship was inferred between a comment and the choice/no choice conditions, that relationship may not have existed in reality. Ambiguous comments were not categorised.

Comments were considered supportive of the findings if high experience learners commented more positively after a no choice lesson and more negatively after a choice lesson. In the same way, comments were considered supportive if low experience learners commented more positively after a choice lesson and more negatively after a no choice lesson. For example, a comment with a negative connotation (e.g., "it [*sic*] a bit boring") expressed by a low experience learner after a no choice lesson, was considered supportive. Inversely, if a low experience learner commented negatively after a choice lesson (e.g., "…I didn't find it visually interesting and didnt [*sic*] respond to it well"), that comment was considered oppositional.

An evaluation according to these criteria revealed that 18 comments supported the quantitative findings to some extent, whereas 5 comments opposed them somewhat. Furthermore, 6 comments were either ambiguous or not relevant to the findings and 8 comments could not be evaluated, as they were given verbally and therefore their context was unknown.

This outcome indicates that the qualitative results support the quantitative results to a considerable degree. Learners with high prior experience (regarding computers and the Internet) commented more frequently positively after no choice lessons and negatively after choice lessons than the other way around (7 supporting vs. 4 non-supporting). Examples include comments such as "i did learn something" and "it was good..." after a no choice lesson and "starting to be to [*sic*] many new words to remember.." after a choice lesson. On the other hand, learners with low prior experience commented more frequently positively after choice lessons and negatively after no choice lessons than the other way around (11 supporting vs. 1 non-supporting). Examples include comments such as "the aduio [*sic*] would of work [*sic*] well here i think the visual is better for me than the audio" after a choice lesson and "… im [*sic*] not a coder i hate maths and i need pictures" after a no choice lesson.

4.7.2 Comment Clusters

The 37 comments were divided into six logical clusters: criticism (12 comments), support (7 comments), evidence for the impact of learning styles (8 comments), support for choice

(2 comments), opposition to choice (2 comments), and combining experiences (2 comments).

In the cluster with criticism, participants expressed their frustration with features of the environment and about their learning experience. Comments such as “im [*sic*] a bit bored...”, “it was frustrating to have to go tho [*sic*] the glossary” and “it need [*sic*] to be more interactive”, indicate that the interface can potentially be further enhanced through additional user testing. The comments also indicate that there may be residual instructional design issues that can be improved upon. The slight majority of negative comments can be explained by the theory that negative information weighs more heavily on the brain than positive information (e.g., Ito, Larsen, Smith, & Cacioppo, 1998). Therefore, it would be more likely for learners to remember and comment on what annoyed them, rather than what they liked.

In the cluster with general support, participants expressed positive feedback with regards to the environment and their learning experience. Learners praised certain aspects of the environment (“I like the décor … this is a good program”) and specifically expressed that they enjoyed learning with iWeaver (“This is great. I want to learn ActionScript this way, too.”). It was also interesting to note that several students enquired if they can continue working with the environment at home (“Can I log in from home to continue the session?”). Comments in this cluster are encouraging and point towards an acceptance and a certain enthusiasm towards the learning approach taken by the iWeaver environment.

In the cluster with comments pertaining to learning styles, participants requested specific changes or features for the learning environment, that can be explained by learning style theory. Examples such as “the layout of the information could be … colour coded for visual learners…” and “more textual examples” express that specific needs were not met by the media experiences. On the other hand, students also praised features of the environment: “I found the ‘try this’ part the most helpful and meaningful part of the experience … Without it the programing [*sic*] would have just been random words to me.“ Comments in this cluster indicate that learning styles had a distinct impact on the way participants approached and interacted with the media experiences and learning tools offered by iWeaver.

The cluster on support for choice encompasses comments in which participants expressed that they were happy to have choices ("I wanted the audio so I didn't have to read" and "I like getting different views of a topic"). In two comments, participants complained after no choice lessons that they would have liked to see more examples. Choice lessons would have most likely satisfied this need by providing different viewpoints of the topic.

However, there was also some opposition to choice with one participant commenting "I tried out different experiences, but the pictures worked best for me. I skipped some content, because I couldn't concentrate any longer". These comments indicate that choice had a negative impact by causing an overflow of information. Another learner commented "I knew I was a visual and auditory learner, so I didn't bother looking at the vistext or tactile components". This comment shows that this learner actively discounted exploring other experiences, which means that he (the learner was male) adopted a stereotypical line of thinking that is prevalent in several learning style theories (see p. 44). To encourage choice, it may be beneficial to not disclose participants' initially assessed styles before the interaction with the environment in future studies. Unfortunately, the two oppositional comments in this cluster were unprompted and thus no context was recorded. Therefore, it cannot be established whether these comments were made by learners in the high or low experience group. Nevertheless, these comments show that having a choice did not suit every learner.

In the final cluster on combined experiences, two comments were made that could inspire a new approach to developing learning-style adaptive environments. Two students expressed the wish to combine several experiences by commenting "it would be good if you could combine lets say the visual and the audion togher [*sic*]" and "it will be nice to integrate all the 4 [experiences] on the same page". In theory, it was easy and straightforward for learners to switch between experiences with the media experience bar (pictured earlier in Figure 3-4 on p. 100), but in practice it still took several seconds to render the page and transfer the data. This delay may have led to a perception that experiences were less inter-connected than they were intended to come across. Ideas on how to integrate multiple experiences in one page are discussed in the final chapter.

4.8 Summary

The aim of this chapter was to analyse the data to answer the research question if it is more beneficial for participants to learn with a choice of media experiences, or to learn with only one media experience, matched for their most-preferred learning style.

In an analysis of the perceptual style profiles of the participants, it was found that that 19% of all participants and 22% of the analysed participants expressed multiple (two or three) most-preferred perceptual styles. This finding adds weight to the argument that stereotyping learners by sorting them into “style drawers” is not an advisable practice. A similar message was conveyed by a comparison between the distribution of page impressions in choice lessons and the perceptual style distribution of participants, which showed substantial differences. Interestingly, almost all participants (94%) were assessed with either a visual pictures or a tactile-kinaesthetic perceptual style. Due to this skewed distribution, the results of this study mostly apply to learners with these predominant styles.

Next, it was investigated if participants took advantage of having a choice in choice lessons. Some results indicated that participants were not choosing different media experiences as often as they could have. Nevertheless, the majority of choice lessons (61%) resulted in deviations from the control style and the majority of participants (85%) took advantage of having a choice in one or more lessons during their learning experience.

Paired-samples *t*-tests between the choice and no choice condition revealed no significant differences for any of the dependent variables. However, a small negative effect was found for the interaction between choice and learning gain. This was a surprising result, as it directly contradicted the original hypothesis. To further investigate this result, an exploratory analysis was conducted by splitting the participants into groups of high and low interest (in programming and Java) and experience (with computers and the Internet), according to their sign-up data.

In the low interest group, no significant differences were revealed for any of the dependent variables. However, choice had a small positive effect on learning gain and enjoyment. Similarly for finished participants, choice had a medium positive effect on learning gain. In contrast, in the high interest group, choice had a statistically significant negative influence on learning gain with a medium effect size and a small negative effect on progress, which did not reach statistical significance. Similarly for finished participants, choice had a large negative, statistically significant effect on learning gain, and a small negative, nonsignificant effect on enjoyment. It was speculated that high interest learners are more susceptible to the redundancy effect (Mayer, 2001, p. 147), because they approach a lesson in a more focused manner. Having a choice may also have caused additional cognitive load (Chandler & Sweller, 1996) because learners have to make decisions. The additional load was suspected to have a greater impact on learners who express high interest and perform academically, because an unstructured learning process conflicts with the executive thinking style associated with these learners (Cano-Garcia & Hughes, 2000, p. 417/425).

In the low experience group, choice had a statistically significant positive influence on learning gain and motivation with small positive effect sizes. For finished participants, the influence on learning gain was also statistically significant with a medium effect size. These results indicate that low experience learners welcomed having a choice. However, it should be considered that increased motivation may have been partially caused by better post-test results. Possible explanations included that low experience participants felt reassured by having alternative learning options and that they were more likely to be open to other media experiences, which led to “constructive friction” (Vermunt, 1992, as cited in Dekeyser, 2001, p. 100) between perceptual style and instructional strategy. A similar positive influence of mismatching learners was observed by Kelly (2005). In the high experience group, choice had a statistically significant negative influence on learning gain with a medium (approaching large) effect size. For finished participants, the influence on learning gain was also statistically significant with a large effect size. It was speculated that highly experienced learners trust adaptive media less, which may lead to a more resistant attitude towards the choice condition. Furthermore, highly experienced learners may have their mind already set on a preferred medium. Consequently, a mismatch might more likely cause cognitive discomfort (O. A. Roberts, 1999, p. 77) for high experience learners compared to low experience learners.

Qualitative data were analysed to determine whether the participants’ comments corroborate or contradict the quantitative finding that choice had a detrimental effect on high experience learners and a beneficial effect on low experience learners. An evaluation of the comments revealed that 18 comments supported the finding to some extent, whereas 5 comments somewhat opposed it. In a second step, comments were grouped and interpreted within logical clusters. Several critical comments hinted at remaining instructional design issues, whereas supportive comments expressed a certain enthusiasm about learning with iWeaver. Comments with regards to learning styles indicated that styles seemed to have a distinct impact on the way participants approached and interacted with iWeaver. In support of choice, some students expressed they were happy to have different media experiences available or commented negatively after no choice lessons. On the other hand, choice appeared to have caused an overflow of information for at least one student. A stereotypical perception of one's own style seemed to have prevented at least one student from exploring alternative media experiences. Interestingly, two students expressed the wish to combine several experiences in one page, which was a feature not offered by iWeaver, but it represents a promising approach for future research.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter summarises the contributions of this project in relation to the research objectives. The significance and implications of the research findings are outlined, as well as their limitations. As a consequence of the findings and experiences collected in this project, recommendations for other researchers are provided for the methodology and direction of future studies.

5.2 Summary of Contributions

This exegesis has described the development and experimental evaluation of iWeaver, an adaptive e-learning environment that aims to address individual learning styles. The first research question asked how perceptual and information processing preferences can be accommodated in an e-learning environment. To this end, five main areas of investigation were reviewed: individualisation tendencies in learning paradigms, multimedia learning, e-learning, learning style theories and adaptive educational hypermedia. In light of the argument that there is a trend to acknowledge flexibility in learning styles, a comprehensive review of learning-style adaptive environments gave rise to the second research question. It asked if the static adaptation approach of existing learning-style adaptive environments can be improved by introducing the aspect of media choice, thus acknowledging flexibility in styles. In order to answer the first research question, the literature review included

- a justification for an individualised learning approach based on existing learning paradigms, information processing theories and the properties of e-learning,
- a review of major learning style models and a justification for the use of an adapted version of the Dunn and Dunn model (Rundle & Dunn, 2000), and
- a theoretical matching framework for perceptual and information processing preferences based on findings of previous studies.

In order to establish a theoretical basis to answer the second research question, the literature review contributed

- a substantiated proposal to view learning style as a context-dependent and flexible construct, rather than a stable construct,
- a critical review of nine existing learning-style adaptive environments, which established the gaps in existing research, and
- a summary of the potential benefits of providing learners with media choice.

The method chapter provided background information on the development of iWeaver. Consequently, this chapter gave an answer to the first research question on how an e-learning environment can adapt itself to accommodate individual learning styles. The main contributions of the method chapter included

- an application of the matching framework in a prototype environment that consists of custom-designed media experiences and learning tools that can be re-used in other contexts or research projects,
- an innovative, dynamic adaptation approach that takes style flexibility into account and provides guided recommendations, and
- an experimental methodology to determine the effect of media choice in a dynamically adaptive environment compared to a statically adapted environment.

Finally, iWeaver was experimentally evaluated with TAFE multimedia students to investigate the effect of media choice. Results were statistically analysed and discussed. The findings of the evaluation indicated that

- stereotyping learners as fixed styles is not an advisable practice,
- media choice has a negative effect on learning gain for participants with a high level of interest and prior experience, and
- media choice has a positive effect on learning gain and motivation for participants with a low experience level.

The general conclusion of these results is that even though the effect of choice was not comprehensive as expected, choice still seems beneficial for certain learners. As such, this project contributed to the discussion on the matching and mismatching of learning styles.

5.3 Significance and Implications

This study has contributed some weight to the argument that learning style should be seen as a flexible, rather than a stable construct. For example, 22% of the analysed participants expressed multiple most-preferred perceptual styles. Furthermore, the number of page impressions for each of the four media experiences was relatively evenly distributed in choice lessons and having a choice had a positive effect on low experience learners. These results add weight to the argument that stereotyping learners by sorting them into “style drawers” is not an advisable practice.

A choice of different media experiences was more beneficial for learners with low prior experience and detrimental for learners with high interest or experience. Executing a choice different to one’s control style implies a mismatch between initial preference and media experience. Therefore, the results indicate that both matching (cognitive comfort, see section 2.5.6, p. 58) and mismatching (constructive friction, see section 2.5.7, p. 64) have merit, but their value depends on the background of the learner. It seems only worthwhile to provide low experience learners with a choice of media experiences. On the other hand, learners with high interest and experience seem to benefit more from a statically adapted media experience without having a choice.

As a practical implication, it seems advisable to collect data on prior experience, interest, as well as the initial learning style distribution of the target audience *before* developing projects comparable to iWeaver (in terms of learning content, population, adaptive behaviour). For example, when contemplating the integration of multiple media experiences for the same learning content, a low level of prior experience would indicate that providing a choice is likely to be beneficial.

A more far reaching implication is related to the negative effect of choice on high interest/experience learners. This negative effect was surprising and contradicted expectations based on cognitive flexibility theory (Spiro et al., 1992) and learner control (J. Kay, 2001). It was speculated that this negative effect was related to a tendency in current educational systems to favour and reward the development of an executive thinking style (Cano-Garcia & Hughes, 2000, p. 417/425). According to Cano-Garcia and Hughes, executive thinkers tend to see their role in a learning environment as rather passive and may not like to take responsibility for their learning process. It is hypothesised that a shift to encourage a more active role of the learner would be likely to expand the positive influence of choice to a wider rage of learners.

A valid question to ask is whether it is worth the additional effort and development cost to offer learners a choice. To answer this question, effect sizes of the influence of choice can be examined. For the low experience learners of the main analysis group, there were statistically significant, small positive effects of choice on learning gain and motivation. Similarly for the low experience learners of the finished participants group, there was a statistically significant, medium positive effect of choice on learning gain. Considering that the adaptation mechanism only needed to be developed once (as opposed to the different versions of learning materials), the additional development effort seemed justified.

5.4 Limitations of the Research

A general limitation of this study was its small sample size with only 27 learners and with partially incomplete data, even though the additional analysis of the complete set of 13 learners corroborated the results. In addition, the data were collected from a convenience sample of multimedia students from intact classes. As Ross (2005, p. 8) noted, convenience samples can introduce a bias into sample estimates of population parameters. Thus the generalisability of the results obtained by this study may be limited.

Another limitation is the learning style model that was used in this project: an adapted version of the Dunn and Dunn model (Rundle & Dunn, 2000). Even though iWeaver considered both information processing and perceptual styles, the main focus of this study was on the accommodation of perceptual styles. The application of a different learning style model or other dimensions within the Dunn and Dunn model might yield different findings with regards to the impact of choice.

The distribution of initially assessed learning styles for the participants was strongly skewed. 94% of the participants were initially assessed with either a tactile-kinaesthetic or a visual pictures perceptual style. This means that the results mostly apply to learners with these predominant styles. Another effect of the skewed distribution was that there were only two participants with an auditory control style and no one with a visual text control style. Consequently, the media experiences matched for these styles were visited less frequently than other media experiences and as such, they were subjected to less scrutiny with regards to their adequacy for their respective styles.

Another limitation is the interpretation of the splitting variables that were used for the exploratory analysis. The perception of how much experience a participant has had with computers and the Internet may vary substantially for a different group of learners. The variables were measured in relatively broad self-assessment questions in the sign-up form and as such, the participants used their own criteria to quantify their experience. For example, they could have thought of the number of years they have worked with computers, their proficiency with standard office applications, or their programming experience. As the evaluation was carried out with first and second year multimedia students, it stands to reason to assume that their average experience with computers and the Internet was higher than that of students of a non-computer related course. Therefore, the differentiation between high and low experience or interest may be considerably different for students of other disciplines.

Despite the measures taken to assure the validity of pre- and post-tests, including expert verification and filtering of wild guesses, multiple choice tests are still a relatively coarse measure for the effect of a condition on learning gain. More innovative assessment approaches could be used in future studies to quantify successful learning. For example, Mayer (2001, p. 72; Moreno & Mayer, 2002) employed a panel of independent experts to assess the answers of students to problem-solving transfer tests in double-blind scenarios. Another assessment-related limitation in the experimental evaluation of iWeaver was that the subjective variables enjoyment, progress, and motivation might have been affected by revealing the post-test results. This potential interdependency could be counter-acted by not disclosing any post-test results. However, this measure contradicts basic instructional principles, such as immediate feedback and therefore, it would most likely be detrimental to the overall learning benefit for participants.

Generally, the effect of choice as demonstrated in this study may vary for different places, times, instructional content, and populations.

5.5 Areas and Directions for Future Research

This subchapter offers recommendations for future researchers who are interested in further investigating the benefits of media choice.

Improvements in the experimental design could corroborate the findings reported in this study and increase their external validity. Similar comparative studies could be carried out with a larger or a different population, other types of learning content, and a random sample of participants, rather than a convenience sample.

iWeaver proposed a new, dynamic approach to adaptive behaviour in learning style-responsive environments. Even though the source code was written specifically for the computer programming course that was used in the experimental evaluation, it is conceivable that with moderate programming effort, adapted versions of iWeaver can be created for other knowledge domains. It would also be possible to modify iWeaver to work as a plug-in for a larger learning management system. These systems usually allow learners to socially interact and collaborate, thus adding another important factor for a constructive learning experience (e.g., McConnell, 2000). Researchers interested in using the iWeaver source code should contact the author.

Future studies could focus more specifically on assessing the influence of prior experience (with computers and the Internet) and interest (in the knowledge domain) on the effect of choice. More accurate, valid and reliable measurement tools could be developed to assess experience and interest, and these tools could then be shared with other studies to facilitate comparable findings. Additionally, future studies could investigate whether there are more factors which also have an influence on the effect of choice. Possible candidates could be mood or stress level.

To emphasise the influence of choice, future studies could stimulate the execution of more choices for learners with low experience. In the present study, all participants were encouraged (verbally and through the design of the interface) to freely choose and switch between experiences. However, multiple experiences were only visited in 22% of the choice lessons and 15% of participants never chose an experience different to their control style. As the evaluation followed immediately after the learning style assessment, participants may have been inclined to let their assessment result guide their selection in choice lessons. One way to stimulate choice could be to separate the learning style assessment and the experimental evaluation, perhaps by a break of several weeks. As a result, learners may be more inclined to try out experiences they did not initially prefer, according to their profile. Another option to encourage choice could be to refine the presentation of experience recommendations. For example, all media experience icons could be displayed with equal opacity or in a non-hierarchical order. Furthermore, strategic choice prompts or a preview/thumbnail system could be integrated. Finally, from the perspective of the target population, a sample with more diverse learning style profiles would probably increase the amount of executed choices.

It appeared beneficial for learners with high experience and interest to not have a choice. Considering that 94% of the participants were initially assessed as either tactile-kinaesthetic or a visual pictures learners, it could be investigated if this skewed distribution is typical for multimedia students. Generally, an analysis of the learning style distribution of a target population is recommended before the design of future environments. This distribution may help to focus development efforts on experiences that are likely to be chosen. For example, offered experiences could be limited to only include the two most-preferred options. From a learner perspective, less experiences to choose from would reduce cognitive load (Chandler & Sweller, 1996), potential confusion (Carver et al., 1996) and redundancy (Mayer, 2001, p. 147). From a development perspective, less experiences would mean a reduction of cost and time. Two participants indicated that they would have liked to see multiple experiences combined on the same screen. One idea to accommodate this wish would be to embed and dyna-link (Ainsworth, 1999) the two most-preferred media experiences on the same content page.

Future research could employ a more sophisticated adaptation mechanism, such as an adaptive Bayesian modifier (Castillo et al., 2003), which uses a more detailed learner model. Additionally, a collaborative matching mechanism (Zukerman & Albrecht, 2001; Jameson, 2002) could be devised under the assumption that learners with comparable initial profiles have similar preferences under similar conditions. Collaborative matching was successfully used in other adaptive educational hypermedia environments, such as Arthur (Gilbert, 2000).

The development of four media experiences for the seven lessons of iWeaver took a substantial amount of time. Unfortunately, the motivation of the learners to engage with such an amount of content was relatively low, as indicated by the low number of participants who completed all lessons. To reduce the likelihood of drop-outs, participants could be paid or otherwise compensated for completing all lessons. A shorter session with less content to cover would also reduce the likelihood of drop-outs, development cost and time. In essence, it is recommended that future projects offer less instructional content and focus more on the validation of adaptive features. Smaller lessons with a specific focus are more likely to yield tenable results than larger or more lessons.

5.6 Final Conclusions

In summary, this exegesis compiled a snapshot of the current status quo of learning-style adaptive e-learning environments. As a result of a critical review of the learning styles literature and existing environments, a dynamic adaptation approach was suggested. This approach was implemented by creating an environment that provided learners with a choice of media experiences, rather than a static experience. Then, the environment was experimentally evaluated by comparing a choice with a no choice condition.

The findings presented in this exegesis suggest that the relationship between media choice and learning gain, enjoyment, perceived progress, and motivation is not as trivial as equating more choice with a comprehensive benefit for the learner. Conversely, the effect of choice appears to be strongly influenced by factors such as the level of prior experience with computers and the Internet and the level of interest in the topic that is facilitated.

An exploratory analysis of the data revealed that a choice of different media experiences was beneficial for learners with low experience (with computers and the Internet), but detrimental for learners with high experience or interest (in programming and Java).

As such, this study has contributed some weight to the argument that for certain groups of learners, it is constructive to view learning style as a flexible, rather than a stable construct.

To date, there has been limited research which examined the role of media choice in e-learning environments. It is hoped that the issues discussed in this exegesis, serve as heuristics to guide future research. The results of this future research can provide participants of adaptive e-learning environments with a more enjoyable, satisfying and effective learning experience.

REFERENCES

Due to the nature of this project, several of the resources that were drawn on were only available online. When publicly available web pages were used, their URLs are provided. It is characteristic for the Internet that these kinds of references tend to disappear after some time. Nonetheless, if this is the case, it might still be possible to retrieve the reference through a website named the "Internet Archive" (http://www.archive.org).

15 Seconds Discussion List. (2001). *The truth about Access*. Retrieved 15 April 2006, from http://www.15seconds.com/Issue/010514.htm

ACCC. (2006). *Snapshot of broadband deployment as at 31 March 2006*. Retrieved 24 June 2006, from http://www.accc.gov.au/content/index.phtml/itemId/693170

Ainsworth, S. E. (1999). A functional taxonomy of multiple representations. *Computers and Education, 33*(2/3), 131-152.

Alpert, S. R., Karat, J., Karat, C.-M., Brodie, C., & Vergo, J. G. (2003). User attitudes regarding a user-adaptive eCommerce web site. *User Modeling and User-Adapted Interaction, 13*(4), 373-396.

Alty, J. L. (1991). *Multimedia - What is it and how do we exploit it?* Paper presented at the HCI'91 - People and Computers VI: Usability Now!, Edinburgh, Scotland.

American Psychological Association. (2001). *Publication manual of the American Psychological Association* (5th ed.). Washington, DC: American Psychological Association.

Archer, S. N., Robilliard, D. L., Skene, D. J., Smits, M., Williams, A., Arendt, J., et al. (2003). A length polymorphism in the circadian clock gene Per3 is linked to delayed sleep phase syndrome and extreme diurnal preference. *Sleep, 26*(4), 413-415.

Arens, Y., Hovy, E. H., & Vossers, M. (1993). On the knowledge underlying multimedia presentations. In M. T. Maybury (Ed.), *Intelligent multimedia interfaces* (pp. 280-306). Menlo Park (USA), Cambridge (USA), London (England): AAAI Press/The MIT Press.

AT&T Labs. (2002). *AT&T Natural Voices - Demos (Interactive)*. Retrieved 1 August 2003, from http://www.naturalvoices.att.com/demos/#

Ausubel, D. P. (1968). *Educational psychology, a cognitive view*. New York: Holt Rinehart and Winston.

Bajraktarevic, N., & Fullick, P. (2003, 20 May). *ILASH: Incorporating learning strategies in hypermedia.* Paper presented at the Workshop on Adaptive Hypermedia and Adaptive Web-Based Systems (AH2003), Twelfth International World Wide Web Conference, Budapest, Hungary.

Bajraktarevic, N., Hall, W., & Fullick, P. (2003, 20-24 May). *Incorporating learning styles in hypermedia environment: Empirical evaluation.* Paper presented at the Workshop on Adaptive Hypermedia and Adaptive Web-Based Systems as part of the Twelfth International World Wide Web Conference, Budapest, Hungary.

Bell, M., Bush, D., Nicholson, P., O'Brien, D., & Tran, T. (2002, March 2002). *Universities online - A survey of online education and services in Australia*. Retrieved 16 September 2003, from http://www.dest.gov.au/highered/occpaper/02a/02_a.pdf

Bentlage, U. (2000, 02.03.2000). *Studium online - Deutschlands Universitäten müssen sich sputen*. Retrieved 16 September 2003, from http://www.presseportal.de/story.htx?nr=117631

Binder, A. (1968). Operation of a novelty principle in transfer of response. *Journal of Experimental Psychology, 77*(2), 347-350.

Blackboard Inc. (2004). *Blackboard Academic Suite*. Retrieved 15 July 2004, from http://www.blackboard.com/

Bloom, B. S. (1984). The 2 sigma problem: The search for methods of group instruction as effective as one-to-one tutoring. *Educational Researcher, 13*(6), 4-16.

Boettcher, J. V., & Conrad, R.-M. (1999). *Faculty guide for moving teaching and learning to the web*. Mission Viejo, CA: League for Innovation in the Community College.

Bollen, J. (1999). Cognitive complexity vs. connectivity: Efficiency analysis of hypertext networks. In F. Heylighen, J. Bollen & A. Riegler (Eds.), *The evolution of complexity* (pp. 345-368). Dordrecht: Kluwer Academic Publishers.

Bontcheva, K. (2002). The impact of empirical studies on the design of an adaptive hypertext generation system. In S. Reich, M. Tzagarakis & P. De Bra (Eds.), *Hypermedia: Openness, Structural Awareness, and Adaptivity, International Workshops OHS-7, SC-3, and AH-3, Aarhus, Denmark, August 14-18, 2001. Revised Papers* (pp. 201-214). Berlin, Heidelberg: Springer-Verlag.

Bourges-Waldegg, P., Moreno, L., & Rojano, T. (2000, 4-7 January). *The role of usability on the implementation and evaluation of educational technology.* Paper presented at the International Conference on System Sciences 2000, Hawaii.

Brewer, W. F., & Treyens, J. C. (1981). Role of schemata in memory for places. *Cognitive Psychology, 13*, 207-230.

Brown, E., Cristea, A., Stewart, C., & Brailsford, T. (2005). Patterns in authoring of adaptive educational hypermedia: A taxonomy of learning styles. *Educational Technology & Society, 8*(3), 77-90.

Bruer, J. T. (1997). Education and the brain: A bridge too far. *Educational Researcher, 26*(8), 4-16.

Bruner, J. S. (1968). *Toward a theory of instruction*. New York: Norton.

Brusilovsky, P. (1996). Methods and techniques of adaptive hypermedia. *User Modeling and User-Adapted Interaction, 6*(2-3), 87-129.

Brusilovsky, P. (2000). *Adaptive hypermedia: From intelligent tutoring systems to web-based education.* Paper presented at the Intelligent Tutoring Systems, 5th International Conference, ITS 2000, Montréal, Canada.

Brusilovsky, P. (2001). Adaptive hypermedia. *User Modeling and User-Adapted Interaction, 11*(1/2), 87-110.

Butler, J. B., & Mautz, R. D. J. (1996). Multimedia presentations and learning: A laboratory experiment. *Issues in Accounting Education, 11*(2), 259-269.

Cano-Garcia, F., & Hughes, E. H. (2000). Learning and thinking styles: An analysis of their interrelationship and influence on academic achievement. *Educational Psychology, 20*(4), 413-427.

Carberry, S. (2001). Techniques for plan recognition. *User Modeling and User-Adapted Interaction, 11*(1/2), 31-48.

Carver, C. A., Richard, A. H., & Edward, L. (1996, June 17-22). *Enhancing student learning by incorporating learning styles into adaptive hypermedia.* Paper presented at the ED-MEDIA 96, Boston, MA, USA.

Castillo, G., Gama, J., & Breda, A. M. (2003, 22-26 June). *Adaptive Bayes for a student modeling prediction task based on learning styles.* Paper presented at the International Conference on User Modeling (UM'2003), Johnstown, PA, U.S.A.

Chandler, P., & Sweller, J. (1996). Cognitive load while learning to use a computer program. *Applied Cognitive Psychology, 10*(2), 151-170.

Chin, D. N. (2001). Empirical evaluation of user models and user-adapted systems. *User Modeling and User-Adapted Interaction, 11*(1/2), 181-194.

Chomsky, N. (1972). *Language and mind* (Enl. ed.). New York: Harcourt Brace Jovanovich.

Clark, J. M., & Paivio, A. (1991). Dual coding theory and education. *Educational Psychology Review, 3*(3), 149-170.

Clark, R. E. (1983). Reconsidering research on learning from media. *Review of Educational Research, 53*(4), 445-459.

Clark, R. E. (1994). Media will never influence learning. *Educational Technology, Research and Development, 42*(2), 21-29.

Coffield, F., Moseley, D., Hall, E., & Ecclestone, K. (2004). Learning styles and pedagogy in post-16 learning: A systematic and critical review. Wiltshire: Learning and Skills Research Centre.

Cognition. (2004). In *Encyclopædia Britannica Online*. Retrieved August 14 2004, from http://www.britannica.com/ebc/article?eu=386397

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed. ed.). Hillsdale, N.J: L. Erlbaum Associates.

Cohen, J. (1992). A power primer. *Psychological Bulletin, 112*(1), 155-159.

Cohen, J. (1994). The earth is round (p <.05). *American Psychologist, 49*(12), 997-1003.

Cohen, P. A., Kulik, J. A., & Kulik, C. C. (1982). Educational outcomes of tutoring: A meta-analysis of findings. *American Educational Research Journal, 19*, 237-248.

Conklin, J. (1987). Hypertext: An introduction and survey. *IEEE Computer, 20*(9), 17-41.

Conlan, O. (2000). *Novel components for supporting adaptivity in education systems - Model-based integration approach.* Paper presented at the Eight International Conference on Multimedia, Marina del Rey, California, United States.

Connell, M. W. (2004, April). *A response to John Bruer's "Bridge Too Far": Linking neuroscience to education via computational neuroscience.* Paper presented at the Neuroscience and Education SIG at the American Educational Research Association Annual Conference, San Diego, CA, USA.

Cooper, G. (1990). Cognitive load theory as an aid for instructional design. *Australian Journal of Educational Technology, 6*(2), 108-113.

Corso, D. D., & Ovcin, E. (2004). The 3DE environment for the design and development of customised educational packages. In M. Kelleher, A. Haldane & E. Kruizinga (Eds.), *Researching technology for tomorrow's learning: Insights from the European community*. Bilthoven, Netherlands: CIBIT Consultants/Educators.

Corso, D. D., Ovcin, E., Morrone, G., Gianesini, D., Salojarvi, S., & Kvist, T. (2001). *3DE: An environment for the development of learner-centered custom educational packages.* Paper presented at the 31st ASEE/IEEE Frontiers in Education Conference, Reno, Nevada.

Corso, D. D., Ovcin, E., Morrone, G., Gianesini, D., Salojarvi, S., & Kvist, T. (2002). *The 3DE custom course compiler: An engine to assemble custom web courses.* Paper presented at the 32nd ASEE/IEEE Frontiers in Education Conference, Boston, MA, USA.

Cronbach, L. J., & Snow, R. E. (1977). *Aptitudes and instructional methods: A handbook for research on interactions*. New York: Irvington Publishers: distributed by Halsted Press.

Curry, L. (1983). An organization of learning styles theory and constructs. In *Learning style in continuing medical education* (pp. 115-131). Ottawa: Canadian Medical Association.

Curry, L. (1990). A critique of the research on learning styles. *Educational Leadership, 48*(Oct), 50-55.

Curry, L. (2000). Review of learning style, studying approach, and instructional preference research in medical education. In R. J. Riding & S. Rayner (Eds.), *Cognitive styles* (pp. 239-276). Stamford, CT: Ablex Publishing Corp.

DBTools Software. (2006). *DBTools Manager Professional*. Retrieved 3 May 2006, from http://www.dbtools.com.br/EN/dbmanagerpro/

De Bra, P. (2002). Adaptive educational hypermedia on the web. *Communications of the ACM, 45*(5), 60-61.

De Bra, P., & Stash, N. (2004). *Multimedia adaptation using AHA!* Paper presented at the ED-MEDIA 2004, Lugano, Switzerland.

DeBello, T. C. (1990). Comparison of eleven major learning styles models: Variables, appropriate populations, validity of instrumentation and the research behind them. *Journal of Reading, Writing, and Learning Disabilities, 6*, 203-222.

Dekeyser, H. M. (2001). Student preference for verbal, graphic or symbolic information in an independent learning environment for an applied statistics course. In J.-F. Rouet, J. Levonen & A. Biardeau (Eds.), *Multimedia learning: Cognitive and instructional issues* (1st ed., pp. 99-109). Amsterdam, New York: Pergamon.

Delahoussaye, M. (2002). The perfect learner: An expert debate on learning styles. *Training, 39*(5), 28-36.

Desmedt, E., & Valcke, M. (2004). Mapping the learning styles jungle. An overview of the literature based on citation analysis. *Educational Psychology Review, 24*(4), 445-464.

Dewey, J. (1972). *Experience and education*. New York: Collier. (Reprinted from the Kappa Delta Pi Lecture Series, by J. Dewey, 1963, New York: Collier).

Dieterich, H., Malinowski, U., Kühme, T., & Schneider-Hufschmidt, M. (1993). State of the art in adaptive user interfaces. In M. Schneider-Hufschmidt, T. Kuhme & U. Malinowski (Eds.), *Adaptive user interfaces: Principles and practice* (pp. 13 - 48). North Holland: Elsevier Science Publishers B.V.

DMReview. (2001). *The global outlook for personalization applications*. Retrieved 2 August 2004, from http://www.dmreview.com/article_sub.cfm?articleId=4005

Dufresne, A., & Turcotte, S. (1997). Cognitive style and its implications for navigation strategies. In B. du Boulay & R. Mizoguchi (Eds.), *Artificial intelligence in education: Knowledge and media in learning systems* (pp. 287-293). Amsterdam: IOS Press.

Dunlap, W. P., Cortina, J. M., Vaslow, J. B., & Burke, M. J. (1996). Meta-analysis of experiments with matched groups or repeated measures designs. *Psychological Methods, 1*(2), 170-177.

Dunn, R. (1984). Learning style: State of the science. *Theory Into Practice, 23*(1), 10-19.

Dunn, R., & Dunn, K. (1993). *Teaching secondary students through their individual learning styles: Practical approaches for grades 7-12*. Boston: Allyn and Bacon.

Dunn, R., Dunn, K., & Price, G. E. (1989). *Learning style inventory*. Lawrence, KS: Price Systems, Inc. (Original work published 1975)

Dunn, R., Dunn, K., & Price, G. E. (1990). *Productivity environmental preference survey*. Lawrence, KS: Price Systems, Inc. (Original work published 1979)

Dunn, R., Griggs, S. A., Olson, J., Gorman, B., & Beasley, M. (1995). A meta-analytic validation of the Dunn and Dunn model of learning-style preferences. *Journal of Educational Research, 88*(6), 353-362.

Dunn, R., Thies, A. P., & Honigsfeld, A. (2001). *Synthesis of the Dunn and Dunn learning-style model research: Analysis from a neuropsychological perspective*. [Monograph]. New York: St. John's University, Center for the Study of Learning and Teaching Styles.

Eghtedari, A. G. (2005). Measuring the benefits of adaptive traffic signal control: Case study of Mill Plain Boulevard, Vancouver, Washington. *Dissertation Abstracts International, 66*(07), 3842B. (UMI No. 3183749).

Eklund, J., & Brusilovsky, P. (1998). *The value of adaptivity in hypermedia learning environments: A short review of empirical evidence.* Paper presented at the Ninth ACM Conference on Hypertext and Hypermedia, Pittsburgh, USA.

Eklund, J., & Sinclair, K. (2000). An empirical appraisal of the effectiveness of adaptive interfaces for instructional systems. *Educational Technology & Society, 3*(4), 165-177.

Ericsson. (2004). *Ericsson survey shows tech savvy population and strong desire for broadband*. Retrieved 19 August 2004, from http://www.ericsson.com.au/press/2004/20040804_survey.shtml

Felder, R. M. (2005a). *Learning style inventory-FAQ*. Retrieved 12 November 2005, from http://www.ncsu.edu/felder-public/ILSdir/ILS-faq.htm#validation

Felder, R. M. (2005b). *What is known about the reliability and validity of the ILS?* Retrieved 15 September 2005, from http://www.ncsu.edu/felder-public/ILSdir/ILS-faq.htm#validation

Felder, R. M., & Silverman, L. K. (1988). Learning styles and teaching styles in engineering education. *Engineering Education, 78*(7), 674-681.

Felder, R. M., & Soloman, B. A. (1996). *Index of learning styles questionnaire*. Retrieved 17 September 2005, from http://www.engr.ncsu.edu/learningstyles/ilsweb.html

Ford, N., & Chen, S. Y. (2001). Matching/mismatching revisited: An empirical study of learning and teaching styles. *British Journal of Educational Technology, 32*(1), 5-22.

Gagné, R. M., Briggs, L. J., & Wager, W. W. (1992). *Principles of instructional design* (4th ed.). Fort Worth: Harcourt Brace Jovanovich College Publishers.

Gao, T., & Lehman, J. D. (2003). The effects of different levels of interaction on the achievement and motivational perceptions of college students in a web-based learning environment. *Journal of Interactive Learning Research, 14*(4), 367-386.

Gardner, H. (1993). *Frames of mind* (tenth-anniversary ed.). New York: BasicBooks. (Original work published 1983)

Gardner, H. (1996). Reflections on multiple intelligences: Myths and messages. *International Schools Journal, 15*(2), 8-22.

Gardner, H. (1999). *Intelligence reframed: Multiple intelligences for the 21st century*. New York: Basic Books.

Giere, T. d., & Burmeister, O. K. (2002, 25-27 November). *Universal usability: Accessibility considerations for aural renditions of tables in web sites.* Paper presented at the Human Factors Conference (HF 2002), Melbourne, Australia.

Gilbert, J. E. (2000). Arthur: An intelligent tutoring system with adaptive instruction. *Dissertation Abstracts International, 68*(08), 3787B. (UMI No. 3061805).

Gilbert, J. E., & Han, C. Y. (1999). Adapting instruction in search of 'a significant difference'. *Journal of Network and Computer Applications, 22*, 149-160.

Gilbert, J. E., & Han, C. Y. (2000). Researching adaptive instruction. In P. Brusilovsky, O. Stock & C. Strapparava (Eds.), *International Conference on Adaptive Hypermedia and Adaptive Web-Based Systems*. Trento, Italy: Springer-Verlag.

Gilbert, J. E., & Han, C. Y. (2002). Arthur: A personalized instructional system. *Journal of Computing in Higher Education, 14*(1), 113-129.

Glasersfeld, E. v. (1995). *Radical constructivism: A way of knowing and learning*. London: Falmer Press.

Greenagel, F. L. (2002). *The illusion of e-learning: Why we are missing out on the promise of technology*. Retrieved 16 September 2003, from http://www.league.org/publication/whitepapers/0802.html

Hacker, D. J. (1998). Metacognition: Definitions and empirical foundations. In D. J. Hacker, J. Dunlosky & A. C. Graesser (Eds.), *Metacognition in educational theory and practice*. Mahwah, NJ: Erlbaum.

Handal, B., & Herrington, A. (2004). On being dependent or independent in computer based learning environments. *e-Journal of Instructional Science and Technology, 7*(2).

Harris, P. (2003, February 2003). *IDC again leads e-learning's cheering section*. Retrieved 16 September 2003, from http://www.learningcircuits.org/2003/feb2003/newsbytes.html#1

Harris, R. N., Dwyer, W. O., & Leeming, F. C. (2003). Are learning styles relevant in web-based instruction? *Journal of Educational Computing Research, 29*(1), 13-28.

Hayes, J., & Allinson, C. W. (1993). Matching learning style and instructional strategy: An application of the person-environment interaction paradigm. *Perceptual and Motor Skills, 76*, 63-79.

Hix, D., & Hartson, H. R. (1993). *Developing user interfaces: Ensuring usability through product & process*. New York: J. Wiley.

Hodges, R. B., & Evans, J. R. (1983). Effect of three instructional strategies with juvenile delinquents of differing learning styles. *Journal of Offender Counseling Services and Rehabilitation, 7*(3-4), 57-65.

Holzinger, A. (2000). *Basiswissen Multimedia Band 2: Lernen. Kognitive Grundlagen multimedialer Informationssysteme*. Würzburg: Vogel.

Hughes, J. N. (1992). Review of the learning style inventory. In J. J. Kramer & J. C. Conoley (Eds.), *The eleventh mental measurements yearbook*. Highland Park, N.J.: Gryphon Press.

IEEE. (2000, November 28). *Draft standard for learning technology - Public and private information (PAPI) for learners (PAPI learner)*. Retrieved October 16 2002, from http://ltsc.ieee.org/wg2/papi_learner_07_main.pdf

Ito, T. A., Larsen, J. T., Smith, N. K., & Cacioppo, J. T. (1998). Negative information weighs more heavily on the brain: The negativity bias in evaluative categorizations. *Journal of Personality and Social Psychology, 75*(4), 887-900.

Izard, J. (2001, 1 June). *Consultancies and research projects in Asian countries.* Paper presented at the Research Conference for Postgraduate Students and RMIT Staff, Melbourne, Australia.

Jackson, C. (2005). The neuropsychological model of learning and its application to business, education, training and clinical psychology: Cymeon Research.

James, W. B., & Blank, W. E. (1993). Review and critique of available learning-style instruments for adults. In D. Flannery (Ed.), *Applying cognitive learning styles* (pp. 47-58). San Francisco: Jossey-Bass.

Jameson, A. (2002). *AI techniques for personalized recommendation - Tutorial presented at AAAI 2002*. Retrieved 15 July 2005, from http://dfki.de/~jameson/aaai02-tutorial

Johnson, S. D., Aragon, S. R., Shaik, N., & Palma-Rivas, N. (2000). Comparative analysis of learner satisfaction and learning outcomes in online and face-to-face learning environments. *Journal of Interactive Learning Research, 11*(1), 29-49.

Jung, C. G. (1966). *Modern man in search of a soul* (W. S. Dell & C. F. Baynes, Trans.). London: Routledge & Kegan Paul. (Original work published 1933)

Jung, C. G. (1976). *Psychological types* (H. G. Baynes, Trans., Rev. ed.). Princeton, N.J: Princeton University Press. (Original work published 1921)

Kaiser, J. (1998). Review of the productivity environmental preference survey. In J. C. Impara & B. S. Plake (Eds.), *The thirteenth mental measurements yearbook* (pp. 787-788). Highland Park, N.J.: Gryphon Press.

Karagiannidis, C., & Sampson, D. (2004). *Adaptation rules relating learning styles research and learning objects meta-data.* Paper presented at the Workshop on Individual Differences in Adaptive Hypermedia, 3rd International Conference on Adaptive Hypermedia and Adaptive Web-based Systems (AH2004), Eindhoven, Netherlands.

Kastens, K. A., Kaplan, D., & Christine-Blick, K. (2001). Development and evaluation of "where are we" map-skills software and curriculum. *Journal of Geoscience Education, 49*(3), 249-266.

Katayama, A. D., Shambaugh, R. N., & Doctor, T. (2005). Promoting knowledge transfer with electronic note taking. *Teaching of Psychology, 32*(2), 129-131.

Kavale, K. A., & Forness, S. R. (1987). Substance over style: Assessing the efficacy of modality testing and teaching. *Exceptional Children, 54*(3), 228-239.

Kay, H., Dodd, B., & Sime, M. E. (1968). *Teaching machines and programmed instruction*. Harmondsworth: Penguin.

Kay, J. (2001). Learner control. *User Modeling and User-Adapted Interaction, 11*(1/2), 111-127.

Kelly, D. (2005). *On the dynamic multiple intelligence informed personalization of the learning environment.* Unpublished doctoral dissertation (available online at https://www.cs.tcd.ie/crite/publications/sources/DeclanKellyPhd.pdf), University of Dublin, Trinity College, Dublin.

Kelly, D., & Tangney, B. (2004, 23-26 August). *Evaluating presentation strategy and choice in an adaptive multiple intelligence based tutoring system.* Paper presented at the Workshop on Individual Differences in Adaptive Hypermedia as part of the 3rd International Conference on Adaptive Hypermedia and Adaptive Web-based Systems, Eindhoven University of Technology, Netherlands.

Kelly, D., & Tangney, B. (2005). Matching and mismatching learning with multiple intelligence based content. In S. Weibelzahl & D. Kelly (Eds.), *Proceedings of the Twelveth International Conference on Artificial Intelligence in Education, AIED'05* (pp. 354-361). Amsterdam: IOS Press.

Kemnitz, K. B.-B., Astrid. (2003). *LearnTEC 2003 - Final report*. Karlsruhe, Germany: Karlsruhe Trade Fair and Congress Company.

Kentridge, R. (n.d.). *A hypertext history of instructional design*. Retrieved 12 September 2004, from http://www.coe.uh.edu/courses/cuin6373/idhistory/programmed_instruction.html

Kerres, M. (2002). Bunter, besser, billiger? Zum Mehrwert digitaler Medien in der Bildung. *it+ti - Informationstechnik und Technische Informatik, 44*(4), 187-192.

Knebel, E. (2001). *The use and effect of distance education in healthcare: What do we know?* Retrieved 20 April 2004, from http://www.qaproject.org/pdf/distlrnissue.pdf

Knowles, M. S. (1968). Androgogy, not pedagogy. *Adult Leadership, 16*(10), 350-386.

Knowles, M. S., & Associates. (1984). *Andragogy in action. Applying modern principles of adult education*. San Francisco: Jossey Bass.

Koedinger, K. R., Anderson, J. R., Hadley, W. H., & Mark, M. (1997). Intelligent tutoring goes to school in the big city. *International Journal of Artificial Intelligence in Education, 8*, 30-43.

Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development*. Englewood Cliffs, N.J.: Prentice-Hall.

Kolb, D. A., Boyatzis, R. E., & Mainemelis, C. (2001). Experiential learning theory: Previous research and new directions. In R. J. Sternberg & L.-F. Zhang (Eds.), *Perspectives on thinking, learning and cognitive styles* (pp. 227-247). London: Lawrence Erlbaum Associates.

Kölling, M., & Rosenberg, J. (2001). *Guidelines for teaching object orientation with Java.* Paper presented at the 6th Annual Conference on Innovation and Technology in Computer Science Education, Canterbury, United Kingdom.

Kono, Y., Ikeda, M., & Mizoguchi, R. (1994). THEMIS: a non-monotonic inductive student modeling system. *Artificial Intelligence in Education, 5*(3), 371-413.

Koumi, J. (1994). Media comparison and deployment: a practitioner's view. *British Journal of Educational Technology, 25*(1), 41-57.

Kovalchick, A., & Dawson, K. (2002). *Component display theory*. Retrieved 15 May 2006, from http://opencontent.org/docs/cdt.pdf

Koychev, I. (2000, 20-25 August). *Gradual forgetting for adaptation to concept drift.* Paper presented at the European Conference on Artificial Intelligence Workshop "Current Issues in Spatio-Temporal Reasoning", Berlin, Germany.

Kozamernik, F. (2002). *Media streaming over the Internet - An overview of delivery technologies*. Retrieved 22 September 2003, from http://www.ebu.ch/en/technical/trev/trev_292-kozamernik.pdf

Kozma, R. B. (1991). Learning with media. *Review of Educational Research, 61*(2), 179-211.

Kozma, R. B. (1994). Will media influence learning? Reframing the debate. *Educational Technology Research and Development, 42*(2), 7-19.

Kyllonen, P. C., & Shute, V. J. (1989). A taxonomy of learning skills. In P. L. Ackerman, R. H. Sternberg & R. Glaser (Eds.), *Learning and individual differences: Advances in theory and research* (pp. 117-163). New York: W. H. Freeman.

Laroussi, M. (2001). *Conception et réalisation de système didactique hypermédia adaptatif: CAMELEON.* Unpublished doctoral dissertation (available online at http://wwwis.win.tue.nl/ah/thesis/laroussi.pdf), Manouba University, Manouba, Tunisia.

Laroussi, M., & Benahmed, M. (1998). *Providing an adaptive learning through the web case of CAMELEON: Computer aided medium for learning on networks.* Paper presented at the Fourth International Conference on Computer Aided Learning and Instruction in Science and Engineering (CALISCE), Chalmers University of Technology, Goeteborg, Sweden.

Leahy, W., Chandler, P., & Sweller, J. (2003). When auditory presentations should and should not be a component of multimedia instruction. *Applied Cognitive Psychology, 17*(4), 401 - 418.

Learning. (2000). In *The American heritage dictionary of the English language*. Retrieved 14 September 2004, from http://dictionary.reference.com/search?q=learning

Learning. (2004). In *Encyclopædia Britannica Online*. Retrieved 13 September 2004, from http://www.britannica.com/ebc/article?tocId=9369902

Lefkowitz, R. F. (2001). Effects of traditional versus learning-style presentation of course content in medical/legal issues in health care on the achievement and attitudes of college students. *Dissertation Abstracts International, 63*(01), 69A. (UMI No. 3041187).

Lefrançois, G. R. (2000). *Theories of human learning: What the old man said* (4th ed.). Belmont, CA: Wadsworth.

Lewthwaite, B. (1999). The productivity environmental preference survey and building excellence: A statistical comparison of two adult learning-style diagnostic instruments. *Dissertation Abstracts International, 60*(12), 4396 (UMI No. 9956087).

Liao, Y.-K. C. (1999). Effects of hypermedia on students' achievement: A meta-analysis. *Journal of Educational Multimedia and Hypermedia, 8*(3), 255-277.

Lim, S. (2001, 05.12.2001). *IDC says Asia/Pacific corporate eLearning adoption hampered by user resistance*. Retrieved 16 September 2002, from http://www.idc.com.sg/Press/2001/AP-PR-eLearning.htm

Lockee, B. B., Burton, J. K., & Cross, L. H. (1999). No comparison: Distance education finds a new use for 'no significant difference'. *Educational Technology, Research and Development, 47*(3), 33-42.

Lovelace, M. K. (2005). Meta-analysis of experimental research based on the Dunn and Dunn model. *Journal of Educational Research, 98*(3), 176-183.

Lowe, R. K. (2003). Animation and learning: Selective processing of information in dynamic graphics. *Learning and Instruction, 13*(2), 157-176.

Martinez, M. (2001). Key design considerations for personalized learning on the web. *Educational Technology & Society, 4*(1), 26-40.

Martinez, M., & Bunderson, C. V. (2000). Building interactive world wide web (web) learning environments to match and support individual learning differences. *Journal of Interactive Learning Research, 11*(2), 163-195.

Martini, M. (1986). An analysis of the relationship(s) between and among computer-assisted instruction, learning style perceptual preferences, attitudes, and the science achievement. *Dissertation Abstracts International, 47*(03), 877A. (UMI No. 8605106).

Maslog-Levis, K. (2005). *Australia soon to be wireless savvy: Telsyte*. Retrieved 25 May 2005, from http://www.zdnet.com.au/news/communications/0,2000061791,39183157,00.htm

Massy, J. (2002). *Quality and eLearning in Europe - Summary report 2002*. Retrieved 16 September 2002, from http://www.elearningage.co.uk/docs/qualitysummary.pdf

Mather, M., Shafir, E., & Johnson, M. K. (2000). Misremembrance of options past: Source monitoring and choice. *Psychological Science, 11*(2), 132-138.

Matlin, M. W. (2002). *Cognition* (5th ed.). Fort Worth ; London: Harcourt College Publishers.

Mautone, P. D., & Mayer, R. E. (2001). Signaling as a cognitive guide in multimedia learning. *Educational Psychology, 93*(2), 377-389.

Mayer, R. E. (2001). *Multimedia learning*. Cambridge, U.K. ; New York: Cambridge University Press.

Mayer, R. E. (2003). The promise of multimedia learning: using the same instructional design methods across different media. *Learning and Instruction, 13*(2), 125-139.

Mayer, R. E., & Gallini, J. K. (1990). When is an illustration worth ten thousand words? *Educational Psychology, 82*(4), 715-726.

Mayer, R. E., & Sims, V. K. (1994). For whom is a picture worth a thousand words? Extensions of a dual-coding theory of multimedia learning. *Educational Psychology, 86*(3), 389-401.

McCarthy, B. (1990). Using the 4MAT system to bring learning styles to schools. *Educational Leadership, 48*(2), 31-37.

McConnell, D. (2000). *Implementing Computer Supported Cooperative Learning*: Routledge (UK).

McGrenere, J. (2002). The design and evaluation of multiple interfaces: A solution for complex software. *Dissertation Abstracts International, 63*(06), 2901. (UMI No. NQ69118).

McGrenere, J., Baecker, R. M., & Booth, K. S. (2002, April 20-25). *An evaluation of a multiple interface design solution for bloated software.* Paper presented at the Computer Human Interaction (CHI 2002), Minneapolis, Minnesota, USA.

McKay, E. (2000). *Instructional strategies integrating cognitive style construct: A meta-knowledge processing model.* Unpublished doctoral dissertation, Deakin University, Geelong, Australia.

McKay, M. T., Fischler, I., & Dunn, B. R. (2003). Cognitive style and recall of text: An EEG analysis. *Learning and Individual Differences, 14*(2003), 1-21.

McKenna, F. P. (1990). Learning implications of field dependence-independence: Cognitive style versus cognitive ability. *Applied Cognitive Psychology, 4*, 425-437.

Merisotis, J. P. (1999). The "what's-the-difference?" debate. *Academe, 85*(5), 47-51.

Merriam, S. B. (2001). Andragogy and self-directed learning: Pillars of adult learning theory. In S. B. Merriam (Ed.), *The new update on adult learning theory* (pp. 3-13). San Francisco: Jossey-Bass.

Merrill, D. C., Reiser, B. J., Merrill, S. K., & Landes, S. (1995). Tutoring: Guided learning by doing. *Cognition and instruction, 13*(3), 315-372.

Merrill, M. D. (1994). *Instructional design theory*. Englewood Cliffs, N.J.: Educational Technology Publications.

Michas, I. C., & Berry, D. C. (2000). Learning a procedural task: effectiveness of multimedia presentations. *Applied Cognitive Psychology, 14*(6), 555 - 575.

Militello, S., & Ovcin, E. (2003). *3DE system assessment and evaluation*: 3DE Project Deliverable.

Mioduser, D., Nachmias, R., Lahav, O., & Oren, A. (2000). Web-based learning environments: Current pedagogical and technological state. *Journal of Research on Computing in Education, 33*(1), 55-76.

Monaghan, P., & Stenning, K. (1998). *Effects of representational modality and thinking style on learning to solve reasoning problems.* Paper presented at the 20th Annual Meeting of the Cognitive Science Society of America, Madison Wisconsin.

Moreno, R., & Mayer, R. E. (2002). Verbal redundancy in multimedia learning: When reading helps listening. *Educational Psychology, 94*(1), 156-163.

Multimedia. (2000). In *The American heritage dictionary of the English language*. Retrieved 19 July 2004, from http://dictionary.reference.com/search?q=multimedia

Murray, T. (1999). Authoring intelligent tutoring systems: An analysis of the state of the art. *International Journal of Artificial Intelligence in Education, 10*, 98-129.

Myers, I. B. (1978). *Myers-Briggs type indicator*. Palo Alto, CA: Consulting Psychologists Press.

MySQL AB. (2006). *MySQL migration toolkit*. Retrieved 3 May 2006, from http://dev.mysql.com/doc/migration-toolkit/en/

Najjar, L. J. (1996). *The effects of multimedia and elaborative encoding on learning* (No. GIT-GVU-96-05). Atlanta, Georgia, USA: Georgia Institute of Technology, Graphics, Visualization & Usability Center.

Nelson, B., Dunn, R. S., Griggs, S. A., Primavera, L., Fitzpatrick, M., Bacilious, Z., et al. (1993). Effects of learning-style intervention on college students' retention and achievement. *Journal of College Student Development, 34*(5), 364–369.

Nielsen, J. (1993). Iterative user interface design. *IEEE Computer, 26*(11), 32-41.

Nielsen, J. (1994). Heuristic evaluation. In J. Nielsen & R. L. Mack (Eds.), *Usability inspection methods* (pp. 25-64). New York: John Wiley & Sons.

Nievergelt, J., & Weydert, J. (1980). Sites, modes and trails: Telling the user of an interactive system where he is, what he can do, and how to get to places. In R. A. Guedj, P. J. W. ten Hagen, F. R. A. Hopgood, H. A. Tucker & D. A. Duce (Eds.), *Methodology of interaction* (pp. 327-338). Amsterdam: North Holland Publishing.

Norman, D. A. (1990). *The design of everyday things* (Doubleday/Currency ed.). New York: Doubleday. (Original work published 1988: The psychology of everyday things)

OECD. (2002). *Measuring the information economy*. Retrieved 21 March 2005, from http://www.oecd.org/sti/measuring-infoeconomy

O'Hare, L. E. (2004). Effects of traditional versus learning-style presentations of course content in nursing on the achievement and attitudes of baccalaureate nursing students. *Dissertation Abstracts International, 65*(05), 1650A. (UMI No. 3135472).

Olson, T. M., & Wisher, R. A. (2002). The effectiveness of web-based instruction: An initial inquiry. *The International Review of Research in Open and Distance Learning, 3*(3).

O'Neil, H. (2003, 11 August 2003). *What works in distance learning*. Retrieved 16 September 2003, from http://www.adlnet.org/screens/shares/dsp_displayfile.cfm?fileid=874

Paivio, A. (1986). *Mental representation: A dual coding approach*. Oxford: Oxford University Press.

Papanikolaou, K. A., Grigoriadou, M., Kornilakis, H., & Magoulas, G. D. (2002). INSPIRE: An intelligent system for personalized instruction in a remote environment. In S. Reich, M. Tzagarakis & P. De Bra (Eds.), *Hypermedia: Openness, Structural Awareness, and Adaptivity, International Workshops OHS-7, SC-3, and AH-3, Aarhus, Denmark, August 14-18, 2001. Revised Papers* (pp. 215-225). Berlin, Heidelberg: Springer-Verlag.

Papanikolaou, K. A., Grigoriadou, M., Kornilakis, H., & Magoulas, G. D. (2003). Personalizing the interaction in a web-based educational hypermedia system: The case of INSPIRE. *User Modeling and User-Adapted Interaction, 13*(3), 213-267.

Pask, G. (1988). Learning strategies, teaching strategies, and conceptual or learning style. In R. R. Schmeck (Ed.), *Learning strategies and learning styles* (pp. 83-100). New York: Plenum Press.

Paulsen, M. F. (2002). Online education systems in Scandinavian and Australian universities: A comparative study. *International Review of Research in Open and Distance Learning, 3*(1).

Pearl, J. (1988). *Probabilistic reasoning in intelligent systems: Networks of plausible inference*. San Mateo, Calif.: Morgan Kaufmann Publishers.

Perneger, T. V. (1998). What's wrong with Bonferroni adjustments. *British Medical Journal, 316*(7139), 1236-1238.

Phipps, R., & Merisotis, J. (1999). *What's the difference? A review of contemporary research on the effectiveness of distance learning in higher education.* Retrieved 23 May 2003, 2003, from http://www.ihep.com/Pubs/PDF/Difference.pdf

Pollock, E., Chandler, P., & Sweller, J. (2002). Assimilating complex information. *Learning and Instruction, 12*, 61–86.

Polson, P. G., Lewis, C., Rieman, J., & Wharton, C. (1992). Cognitive walkthroughs: A method for theory-based evaluation of user interfaces,. *International Journal of Man-Machine Studies, 36*(5), 741-773.

Reeves, T. (1996). *ITForum posting string 16-61*. Retrieved 03 May 2003, from http://itech1.coe.uga.edu/itforum/paper16/16-61.html

Regian, J. W., Seidel, R., Schuler, J., & Radtke, P. (1996). *Functional area analysis of intelligent computer-assisted instruction*. Brooks Air Force Base, Texas: Training and Personnel Systems Science and Technology Evaluation and Management Committee.

Reliability (statistics). (2006, 16 June). In *Wikipedia, the free encyclopedia*. Retrieved 22 June 2006, from http://en.wikipedia.org/w/index.php?title=Reliability_%28statistics%29&oldid=58931898

Revell, P. (2005). *Each to their own*. Retrieved 10 January 2006, from http://education.guardian.co.uk/egweekly/story/0,,1495514,00.html

Rich, E. (1979). Building and exploiting user models. *Dissertation Abstracts International, 40*(05), 2273. (UMI No. 7925024).

Riding, R. J. (1991). *Cognitive styles analysis*. Birmingham: Learning and Training Technology.

Riding, R. J. (2000). Cognitive style: A review. In R. J. Riding & S. Rayner (Eds.), *Cognitive styles* (pp. 315-344). Stamford, CT: Ablex Publishing Corp.

Riding, R. J., & Douglas, G. (1993). The effect of cognitive style and mode of presentation on learning performance. *British Journal of Educational Psychology, 63*, 297-307.

Riding, R. J., & Pearson, F. (1994). The relationship between cognitive style and intelligence. *Educational Psychology, 14*(4), 413-425.

Riding, R. J., & Rayner, S. (1998). *Cognitive styles and learning strategies: Understanding style differences in learning and behaviour*. London: D. Fulton Publishers.

RMIT University. (2002). *Policy and procedures for higher degrees by research*. Retrieved 5 April 2005, from http://www.rmit.edu.au/higher-degrees

RMIT University. (2006a). *Advanced diploma of arts (multimedia) - Program information*. Retrieved 22 April 2006, from http://www.rmit.edu.au/browse;ID=b13ddrv3cxecz

RMIT University. (2006b). *Policy and programs committee minutes*. Retrieved 20 Oct 2006, from http://mams.rmit.edu.au/nkf2xppi88rjz.pdf

Roberts, A. V., Dunn, R., Holtschnieder, D., Klavas, A., Miles, B., & Quinn, P. (2000). Effects of tactual kinesthetic instructional resources on the social studies achievement and attitude test scores and short- and long-term memory of suburban fourth-grade students. *National Forum of Special Education Journal, 9E*, 13-22.

Roberts, O. A. (1999). Investigating the construct validities of the learning styles inventory and the learning styles profile: A latent trait structural equation model. *Dissertation Abstracts International, 60*(10), 3638A. (UMI No. 9948783).

Rogers, P. L. (2001). Traditions to transformations: The forced evolution of higher education. *Educational Technology Review, 9*(1), 47-60.

Rosenberg, M. J. (2001). *E-learning: Strategies for delivering knowledge in the digital age*. New York: McGraw-Hill.

Ross, K. N. (2005). *Sample design for educational survey research*. Retrieved 27 June 2006, from http://www.sacmeq.org/training.htm

Rovai, A. P. (2002). A preliminary look at the structural differences of higher education classroom communities in traditional and ALN courses. *Journal of Asynchronous Learning Networks, 6*(1), 41-56.

Rozecki, T. (1998). Review of the productivity environmental preference survey. In J. C. Impara & B. S. Plake (Eds.), *The thirteenth mental measurements yearbook* (pp. 788-790). Highland Park, N.J.: Gryphon Press.

Rundle, S. M., & Dunn, R. (2000). *The guide to individual excellence: A self directed guide to learning and performance solutions*. New York: Performance Concepts International.

Russell, T. L. (1999). *The no significant difference phenomenon as reported in 355 research reports, summaries and papers: A comparative research annotated bibliography on technology for distance education*: North Carolina State University: Office of Instructional Telecommunications.

Russell, T. L. (2002). *The "no significant difference phenomenon"*. Retrieved 19 March 2005, from http://www.nosignificantdifference.org/

Sandberg, J., & Andriessen, J. (1997). *Where is AI and how about education?* Paper presented at the 8th World Conference on Artificial Intelligence in Education (AI-ED 97), Kobe, Japan.

Sarasin, L. C. (1998). *Learning style perspectives: Impact in the classroom*. Madison, WI: Atwood Publishing.

Schnotz, W., & Bannert, M. (2003). Construction and interference in learning from multiple representation. *Learning and Instruction, 13*(2), 141-156.

Schnotz, W., & Lowe, R. (2003). External and internal representations in multimedia learning. *Learning and Instruction, 13*(2), 117-123.

Schutte, J. G. (1996). *Virtual teaching in higher education: The new intellectual superhighway or just another traffic jam?* Retrieved 16 September 2003, from http://www.csun.edu/sociology/virexp.htm

Seaton, A. (2002). Reforming the hidden curriculum: The key abilities model and four curricular forms. *Curriculum Perspectives, April*, 9-15.

Seaton, A. (2005). A dynamic view of knowledge: Constructing a more intelligent humanity. *Gyan [Knowledge]: A Journal of Education, 1*(2), 64-70.

Shin, E. C., Schallert, D. L., & Savenye, W. C. (1994). Effects of learner control, advisement, and prior knowledge on young students' learning in a hypertext environment. *Educational Technology Research and Development, 42*, 33-46.

Shute, V. J., & Gluck, K. A. (1996). Individual differences in patterns of spontaneous online tool use. *Journal of the Learning Sciences, 5*(4), 329-355.

Simonite, T. (2007, 5 January 2007). *Emotion-aware teaching software tracks student attention*. Retrieved 6 January, 2007, from http://www.newscientisttech.com/article.ns?id=dn10894

Skinner, B. F. (1969). *Contingencies of reinforcement: A theoretical analysis*. New York: Appleton-Century-Crofts.

Snow, R. E. (1989). Aptitude-treatment interaction as a framework for research on individual differences in learning. In P. L. Ackerman, R. J. Sternberg & R. Glaser (Eds.), *Learning and individual differences: Advances in theory and research* (pp. 13-60). New York: W.H. Freeman.

Snyder, A. W., Mulcahy, E., Taylor, J. L., Mitchell, D. J., Sachev, P., & Gandevia, S. C. (2003). Savant-like skills exposed in normal people by suppressing the left frontotemporal lobe. *Journal of Integrative Neuroscience, 2*(2), 149-158.

Solomon, A. (2003). *Applying nails to blackboard.* Paper presented at the Fifth Australasian Computing Education Conference (ACE2003), Adelaide, Australia.

Specht, M. (1998). *Empirical evaluation of adaptive annotation in hypermedia.* Paper presented at the ED-MEDIA / ED-TELECOM 98, Freiburg, Germany.

Speech synthesis. (2006, 16 June). In *Wikipedia, the free encyclopedia*. Retrieved 22 June 2006, from http://en.wikipedia.org/w/index.php?title=Speech_synthesis&oldid=61550606

Spiro, R. J., Feltovich, P. J., Jacobson, M. J., & Coulson, R. L. (1992). Cognitive flexibility, constructivism and hypertext: Random access instruction for advanced knowledge acquisition in ill-structured domains. In T. Duffy & D. Jonassen (Eds.), *Constructivism and the technology of instruction*. Hillsdale, NJ: Erlbaum.

St Hill, R. (2000). *Modal preference in a teaching strategy.* Paper presented at the Effective Teaching and Learning at University Conference, Duchesne College, University of Queensland, Australia.

Stash, N., Cristea, A., & Bra, P. D. (2004, 17-22 May 2004). *Authoring of learning styles in adaptive hypermedia: Problems and solutions.* Paper presented at the 13th International World Wide Web Conference, New York, USA.

Stern, M. K. (2001). Using adaptive hypermedia and machine learning to create intelligent web-based courses. *Dissertation Abstracts International, 62*(10), 4638B. (UMI No. 3027261).

Sternberg, R. J., & Grigorenko, E. L. (2001). A capsule history of theory and research on styles. In R. J. Sternberg & L.-f. Zhang (Eds.), *Perspectives on thinking, learning and cognitive styles* (pp. 1-21). London: Lawrence Erlbaum Associates.

Stokas, P. (2002). *Which is the best low-bitrate audio compression algorithm?* Retrieved 23 September 2003, from http://ekei.com/audio/

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science, 12*(2), 257-285.

Thies, A. P. (1999-2000). The neuropsychology of learning styles. *National Forum of Applied Educational Research Journal, 13*(1), 50-62.

Thompson, B. (2000). *A suggested revision to the forthcoming 5th edition of the APA publication manual*. Retrieved 15 September, 2006, from http://www.coe.tamu.edu/~bthompson/apaeffec.htm

Tolman, E. C., & Honzik, C. H. (1930). 'Insight' in rats. *University of California Publications in Psychology, 4*, 215-232.

Transcranial magnetic stimulation. (2006, 16 June). In *Wikipedia, the free encyclopedia*. Retrieved 25 June 2006, from http://en.wikipedia.org/w/index.php?title=Transcranial_magnetic_stimulation&oldid=60051802

Truong, N., Bancroft, P., & Roe, P. (2002). *ELP-A web environment for learning to program.* Paper presented at the Australasian Society for Computers in Learning in Tertiary Education (ASCILITE) Conference, Auckland, New Zealand.

Truong, N., Bancroft, P., & Roe, P. (2005). *Learning to program through the web.* Paper presented at the 10th annual SIGCSE conference on Innovation and Technology in Computer Science Education (ITiCSE), Capacrica, Portugal.

Tucker, S. (2001). Distance education: better, worse, or as good as traditional education? *Online Journal of Distance Learning Administration, 4*(4).

Valley, K. (1997). Learning styles and courseware design. *Association for Learning Technology Journal, 5*(2), 42-51.

Vekiri, I. (2002). What is the value of graphical displays in learning? *Educational Psychology Review, 14*(3), 261-312.

W3C. (2001, August 7). *Synchronized multimedia integration language (SMIL 2.0) W3C recommendation.* Retrieved October 14, 2002, 2002, from http://www.w3.org/TR/smil20/

Wadsworth, B. J. (1989). *Piaget's theory of cognitive and affective development* (4th ed.): New York: Longman.

Wang, M. (2002, June 10). *Morten's JavaScript tree menu*. Retrieved October 20, 2002, from http://www.treemenu.com

Watson, J. S. (1972). Smiling, cooing, and 'the game'. *Merrill-Palmer Quarterly, 18*, 323-339.

WebCT Inc. (2004). *WebCT campus edition - Course management system*. Retrieved 15 July 2004, from http://webct.com/

Weibelzahl, S. (2005). Problems and pitfalls in the evaluation of adaptive systems. In S. Y. Chen & G. D. Magoulas (Eds.), *Adaptable and adaptive hypermedia systems* (pp. 285-299). Brunel University, UK; University of London, UK: IRM Press.

West, C., Farmer, J. A., & Wolff, P. M. (1991). Introduction to cognitive science and instructional design. In *Instructional design: Implications from cognitive science* (pp. 1-35). Englewood Cliffs, NJ: Prentice Hall.

Whirlpool Broadband Multimedia. (2003). *Broadband choice - Plan search*. Retrieved 3 Dec 2003, from http://bc.whirlpool.net.au/bc-plan.cfm

Widmer, G., & Kubat, M. (1996). Learning in the presence of concept drift and hidden contexts. *Machine Learning, 23*(1), 69-101.

Wisher, R. A., & Curnow, C. K. (1999). Perceptions and effects of image transmissions during Internet-based training. *American Journal of Distance Education, 13*(3), 37-51.

Witkin, H. A., Moore, C. A., Goodenough, D. R., & Cox, P. W. (1977). Field dependent and field independent cognitive styles and their educational implications. *Review of Educational Research, 47*(1), 1-64.

Woolf, B. P., Beck, J., Eliot, C., & Stern, M. (2001). Growth and maturity of intelligent tutoring systems: A status report. In K. D. Forbus & P. J. Feltovich (Eds.), *Smart machines in education*. Cambridge, Massachusetts and London, England: MIT Press.

Yates, G. C. R. (2000). Applying learning style research in the classroom: Some cautions and the way ahead. In R. J. Riding & S. Rayner (Eds.), *Cognitive styles* (pp. 347-364). Stamford, CT: Ablex Publishing Corp.

Zaslow, J. (2002, Nov 26). If TiVo thinks you are gay, here's how to set it straight --- amazon.com knows you, too, based on what you buy; why all the cartoons? *Wall Street Journal,* p. A.1.

Zirkle, C. (2001). *Instructional quality in web-based learning: Some suggestions for success.* Paper presented at the Annual Technology Enhanced Learning and Research (TELR) Conference, Ohio State University, U.S.A.

Zukerman, I., & Albrecht, D. W. (2001). Predictive statistical models for user modeling. *User Modeling and User-Adapted Interaction, 11*(1-2), 5-18.

APPENDIX

A. Additional Information on Project Materials

A1. Learning Content Structure

Table A-1

Learning Content: Lesson Titles

Lesson	Sub-Lessons
1 Programming Terminology	Syntax and Semantics
	Compiler versus Interpreter
2 Language Basics	Separators and Operators
	Blocks
3 Variables and Data Types	Declaring Variables
	Data Types of Variables
4 Primitive Data Types	Integral Numbers
	Floating-Point Numbers
	Logical Values
	Operations on Primitive Data Types
5 Decisive Statements	If-Statement
	Switch-Statement
6 Looping Statements	While-Loop
	Do-While-Loop
	For-Loop
7 Reference Data Types	Arrays

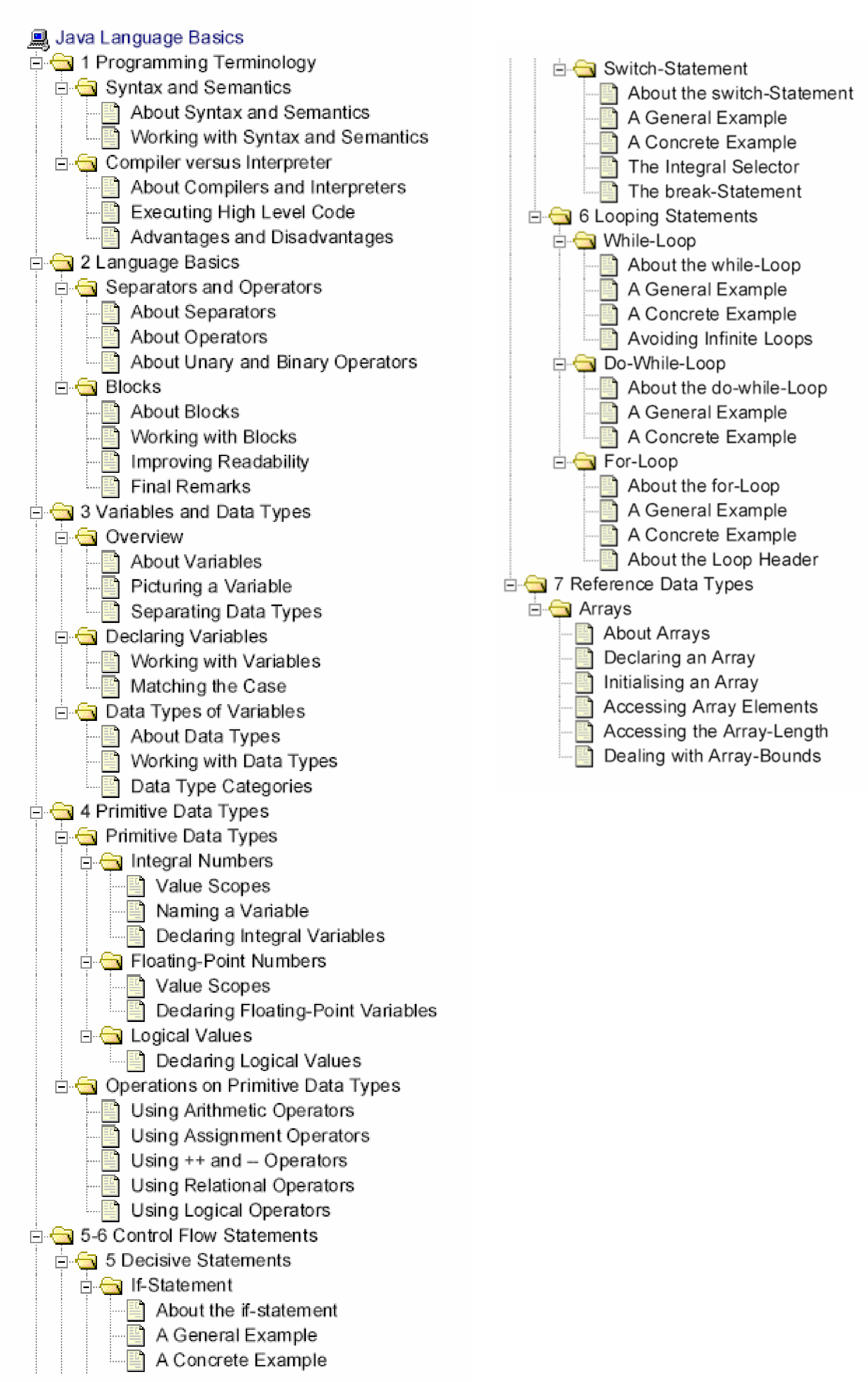


Figure A-1. Full-tree view of iWeaver's learning content.

A2. Approval Letters

tele-akademie
fachhochschule furtwangen

Permission

The tele-akademie, the distance education department of the University of Applied Sciences Furtwangen gives Christian Wolf permission to use and translate the content of the modules of its online Java Course for the purpose of his research project "Development of an Adaptive Online Learning Environment".
The copyrights of the tele-akademie are not affected by this permission which also excludes multiple use or any commercial usage of the material by Christian Wolf or third parties.

Furtwangen, den 20. November 2001

Dr. Thomas Jechle
Studienleiter

PERFORMANCE CONCEPTS
INTERNATIONAL LIMITED

AGREEMENT

Performance Concepts Int'l, Ltd. and Christian Wolf
1 November 2003

Company:	Performance Concepts Int'l, Ltd.	**Person**:	Christian Wolf
Contact:	Susan M. Rundle	**Contact**:	Ph.D. (Education) Candidate 3rd year
Address:	1 Wintergreen Hill Road	**Address**:	RMIT University 485 Station Street
City:	Danbury	**City**:	Carlton North
State:	Connecticut **Zip**: 06811-4243	**State**:	VIC 3054, Australia
Phone:	+203.743.5743	**Phone**:	+61 (3) 9380 9421

This document outlines the Agreement between **Performance Concepts International, Ltd. (PCI)** and **Christian Wolf**.

This Agreement is subject to the following terms and conditions:

1) PCI shall accord Christian Wolf permission to use the Building Excellence (BE) Survey for the sole purpose of his Ph.D. research project *Development of an Adaptive Online Learning Environment*.
2) PCI shall accord Christian Wolf permission to use the Guide to Individual Excellence Workbook (GIE) for the sole purpose of his Ph.D. research project *Development of an Adaptive Online Learning Environment*.
3) Christian Wolf shall not create, at any time now or in the future, a derivative work of BE, GIE, or the *Development of an Adaptive Online Learning Environment*.
4) Christian Wolf shall not use, at any time now or in the future, BE, GIE, or the *Development of an Adaptive Online Learning Environment* in any commercial endeavor.
5) Christian Wolf shall not provide access to BE, GIE, or the *Development of an Adaptive Online Learning Environment* to any third party for commercial or any other use.
6) Christian Wolf shall provide the source code, upon completion, to PCI as per e-mail dated 19 June 2002.

Signatures

Christian Wolf	Susan M. Rundle, President and CEO
Signature: C. Wolf	Signature: Susan M. Rundle
Date: 20/11/2003	Date: 29/11/03

B. Additional Results Tables

B1. Tables for Initial Analysis (Finished Participants)

Table B-1

Mean Comparisons between Choice/No Choice Conditions in Initial Analysis (Finished Participants)

	Mean			*SD*	
Dependent variable[a]	C[b]	NC	Diff.	C	NC
Learning gain	1.06	1.47	-0.41	1.47	1.80
Enjoyment	3.11	3.17	-0.06	1.48	1.68
Progress	3.24	3.28	-0.03	1.44	1.71
Motivation	3.05	3.05	0.00	1.55	1.68

Note. Maximum possible learning gain = 7, Maximum possible enjoyment, progress, and motivation = 6. [a]$n = 13$. [b]C = Choice, NC = No Choice.

Table B-2

P-values and Effect Sizes for Choice Condition in Initial Analysis (Finished Participants)

Dependent variable[a]	*t*	*r*	*p*	*d*[b]
Learning gain	-1.06	0.65	.31	-0.25#
Enjoyment	-0.30	0.89	.77	-0.04
Progress	-0.18	0.93	.86	-0.02
Motivation	0.0	0.96	1.0	0.0

Note. [b]corrected *d*, see p. 134. [a] $n = 13$. #$d \leq -0.20$.

B2. Tables for Exploratory Analysis (Finished Participants)

Table B-3

Mean Comparisons Between Choice/No Choice Conditions in Low/High Interest Groups (Finished Participants)

	Low interest[b]					High interest[c]				
	Mean			*SD*		*Mean*			*SD*	
Dep. var.	C[a]	NC	Diff	C	NC	C	NC	Diff	C	NC
Learning gain	1.12	0.52	0.60	1.67	1.39	1.0	2.58	-1.58	1.36	1.64
Enjoyment	3.01	2.85	0.16	1.59	1.99	3.22	3.56	-0.34	1.49	1.29
Progress	3.06	2.96	0.10	1.62	1.97	3.46	3.64	-0.18	1.30	1.45
Motivation	2.90	2.82	0.08	1.85	1.98	3.22	3.32	-0.10	1.25	1.38

Note. Maximum possible learning gain = 7, Maximum possible enjoyment, progress, and motivation = 6. [a]C = Choice, NC = No choice. [b]$n = 7$. [c]$n = 6$.

Table B-4

P-values and Effect Sizes for Choice Condition in Low/High Interest Groups (Finished Participants)

	– Low interest[a] –				– High interest[b] –			
Dep. variable	*t*	*r*	*p*	*d*[c]	*t*	*r*	*p*	*d*[c]
Learning gain	1.63	0.82	0.16	0.37#	-5.41	0.90	.003**	-0.98###
Enjoyment	0.50	0.90	0.63	0.08	-1.49	0.93	.20	-0.22#
Progress	0.30	0.91	0.78	0.05	-1.32	0.98	.24	-0.12
Motivation	0.52	0.98	0.63	0.04	-0.42	0.91	.69	-0.07

Note. [c]corrected d, see p. 134. [a]$n = 7$. [b]$n = 6$. **$p < .01$. #$d \leq -0.20$. ###$d \leq -0.80$.

Table B-5

Mean Comparisons Between Choice/No Choice Conditions in Low/High Experience Groups (Finished Participants)

	Low experience[b]					High experience[c]				
	Mean			*SD*		*Mean*			*SD*	
DV	C[a]	NC	Diff	C	NC	C	NC	Diff	C	NC
Learning gain	1.42	0.57	0.85	1.62	1.52	0.76	2.25	-1.49	1.39	1.73
Enjoyment	2.68	2.49	0.19	1.45	1.92	3.48	3.76	-0.28	1.51	1.3
Progress	2.74	2.63	0.11	1.51	1.92	3.68	3.83	-0.15	1.32	1.42
Motivation	2.56	2.46	0.10	1.75	1.90	3.48	3.56	-0.08	1.33	1.41

Note. Maximum possible learning gain = 7, Maximum possible enjoyment, progress, and motivation = 6. [a]C = Choice, NC = No choice. [b]$n = 6$. [c]$n = 7$.

Table B-6

P-values and Effect Sizes for Choice Condition in Low/High Experience Groups (Finished Participants)

	– Low experience[a] –				– High experience[b] –			
DV	*t*	*r*	*p*	*d*[c]	*t*	*r*	*p*	*d*[c]
Learning gain	2.702	0.882	.043*	0.54##	-5.62	0.92	.001**	-0.83###
Enjoyment	0.495	0.873	.64	0.10	-1.47	0.94	.19	-0.19
Progress	0.294	0.880	.78	0.06	-1.31	0.98	.24	-0.11
Motivation	0.510	0.970	.63	0.05	-0.43	0.93	.69	-0.06

Note. [c]corrected *d*, see p. 134. [a]$n = 6$. [b]$n = 7$. *$p < .05$. **$p < .01$. ##$d \geq 0.50$. ###$d \leq -0.80$.

B3. Qualitative Data

Table B-7

Qualitative Feedback from the Participants (Clustered and Contextualised)

Id	XP	Style(s)	#	C/NC	QR	Comment [*sic*]
						Criticism
7	L	**AD**/VP/TK	1	NC	Y	"it a bit boring"
7	L	**AD**/VP/TK	3	NC	Y	"there is two much information between test your brain fells overloaded…"
7	L	**AD**/VP/TK	5	NC	Y	"im a bit bored i think its the design of the interface"
14	H	VP	1	C (VP)	X	"this is not the learning style for me i need human contact, and high visual elements."
26	L	TK/**VP**	4	C (AD)	X	"It was frustrating to have to go tho the glossary so often."
26	L	TK/**VP**	1	C (VP+)	N	"…i didn't find it visually interesting and didnt respond to it well"
31	L	TK	1	NC	Y	"i dont understand"
31	L	TK	3	NC	Y	"i still dont understand"
39	H	TK	4	C (AD)	Y	"it need to be more interactive"
39	H	TK	5	NC	X	"the interface … needs more work …"
52	H	TK	3	C (TK+)	Y	"starting to be to many new words to remember.."
59	L	AD	1	NC	Y	"can' stand this shit"

Table B-7 (continued)

Id	XP	Style(s)	#	C/NC	QR	Comment [*sic*]
						Support
4	H	VP	2	NC	Y	"Well, this is a good program ... I think this program would be useful for me when Im in the right frame of mind to learn java"
9	H	VP	2	C (VP)	N	"I like the décor … this is a good program…"
15	H	TK	1	NC	Y	"i did learn something"
45	H	TK	7	NC	Y	"It was good. Would like to have understood how the code could be applied more. As in a visual outcome. Otherwise good. … Well done."
–	–	–	–	–	–	"I normally don't like learning on a computer, but I enjoyed this."
–	–	–	–	–	–	"This is great. I want to learn ActionScript this way, too."
–	–	–	–	–	–	"Can I log in from home to continue the session?"
						Evidence of learning styles impact
7	L	**AD**/VP/TK	3	NC	Y	"… im not a coder i hate maths and i need pictures"
15	H	TK	1	NC	N	"more pictures"
25	H	TK	1	NC	N	"more textual examples"
26	L	TK/**VP**	1	C (VP+)	X	"the layout of the information could be … colour coded for visual learners…"
39	H	TK	5	NC	Y	"…i would like to learn in this way i think its something that works better than listening to a lecture"
40	L	TK	1	C (VP)	X	"I found the 'try this' part the most helpful and meaningful part of the experience … Without it the programing would have just been random words to me."
45	H	TK	1	NC	X	"I found the intro learning test too long & too much text is offputting for visual learners"
–	–	–	–	–	–	"The Try-it button is great for tactile people like me"

Table B-7 (continued)

Id	XP	Style(s)	#	C/NC	QR	Comment [*sic*]
						Support for choice
7	L	**AD**/VP/TK	6	C (VP)	Y	"the aduio would of work well here i think the visual is better for me than the audio"
26	L	TK/**VP**	5	NC	Y	"… More examples [could be] used (for what situation it would be used in)"
32	L	TK/**VP**	1	C (AD)	Y	"i wanted the audio so i didn't have to read."
51	H	VP	1	NC	N	"more reallife examples…"
–	–	–	–	–	–	"I like getting different views of a topic."
–	–	–	–	–	–	"In some chapters, I was missing a choice. I thought it would be there all the time."
						Opposition to Choice
–	–	–	–	–	–	"I tried out different experiences, but the pictures worked best for me. I skipped some content, because I couldn't concentrate any longer."
–	–	–	–	–	–	"I knew I was a visual and auditory learner, so I didn't bother looking at the vistext or tactile components."
						Combined experiences
7	L	**AD**/VP/TK	5	NC	Y	"it would be good if you could combine lets say the visual and the audion togher"
51	H	VP	2	C (VP+)	Y	"it will be nice to integrate all the 4 [experiences] at the same page."

Notes. The Id column contains the user id, which is random and anonymous. The XP column indicates the level of experience with computers and the Internet (L=2-9, H=10-12, max=12). The style column specifies the initially assessed learning style. If a person was assessed with multiple most-preferred styles, the randomly selected control style is printed in boldface. # indicates the lesson after which the comment was made. C/NC designates whether it was a choice or no choice lesson. For choice lessons, the chosen style is provided in brackets. An added + denotes that multiple other styles were visited. The QR column indicates whether the comment in the given context supports (Y) or opposes (N) the quantitative results of the exploratory analysis (section 4.6, p. 150) or if it is unrelated (X). The "– " symbol denotes that the comment was manually recorded after a session without specifying the learner/user id and therefore without context details.

C. Ethics Documentation

C1. Approval Letters

Tel: +613 9925.4919
Fax: +613 9925 4916
fiona.nolan@rmit.edu.au

RMIT UNIVERSITY
FACULTY OF ART, DESIGN AND COMMUNICATION

City Campus
GPO Box 2476V
Melbourne 3001
Victoria Australia

Tel +61 3 9925 2173
Fax +61 3 9925 3728

30 November 2001

Mr C Wolf
485 Station St
Carlton North 3054

SUBJECT: **Ethics Classification for Research Project**

The Faculty's Human Research Ethics Sub-Committee, at its meeting of 7 November 2001, considered you ethics application for your research project.

The Committee classified the program as **No Risk**.

Please note that, if there should be any change in the design of your research you are asked to notify the Committee immediately.

Yours sincerely,

Fiona Nolan

Fiona Nolan
Secretary of Faculty Human Research Ethics Sub-Committee

Cc Robyn Blake, Senior Supervisor, School of Creative Media

C:\FRGSC\ethics approval.doc - 1 -

RMIT University

Design and Social Context Portfolio

Building 8
360 Swanston Street
Melbourne VIC 3000
Australia

GPO Box 2476V
Melbourne VIC 3001
Australia

Tel.+61 3 9925 2226
Fax +61 3 9663 2891
• www.rmit.edu.au

HRESC
HF:HP
Building 220.2.36
Bundoora West Campus

19 January 2007

Mr Christian Wolf
485 Station Street
Carlton North

Dear Christian

Re: Human Research Ethics Amendment Approval

The Design and Social Context Human Research Ethics Sub-Committee received your request for an amendment to your ethics application.

The new title has been registered:
Development of a Web-Based Adaptive Learning Environment Using Interactive Multimedia to Address Individual Learning Style"

We acknowledge the change to:
Participant Source
To use first and second year students of the Advanced Diploma of Multimedia (ADoM), RMIT TAFE, and that participation is voluntary.
Change of Location
That workshop classes will be held in the ADoM multimedia labs, RMIT. Not as previously stated in the home environment.
Change to Data Collection Instruments
The use of the Building Excellence Survey (BES) (Rundle & Dunn, 2000)

I am pleased to advise that the committee has approved your application as level 2-risk classification.

You are reminded that an Annual/Final report is required to be submitted by 1st of December each year for the duration of the approval period. This report is available from: URL: http://www.rmit.edu.au/rd/hrec_apply

Should you have any queries regarding your ethics application please seek advice from the Chair of the sub-committee Assoc. Prof. Heather Fehring on 9925 7840, heather.fehring@rmit.edu.au or contact me on (03) 9925 7877 or email heather.porter@rmit.edu.au

I wish you well in your research.

Yours sincerely

HPorter.

Heather Porter
Secretary
Design and Social Context
Human Research Ethics Sub-Committee
Operational Unit - Bundoora

Advanced Diploma of Multimedia

RMIT UNIVERSITY
School of Creative Media

Wednesday, 14 June 2006

To Whom It May Concern:

This is to state that I am in full support of Christian Wolf's PhD project and the involvement of the students of the Advanced Diploma of Arts (Multimedia).

[redacted]
Program Coordinator
Advanced Diploma of Arts (Multimedia)
School of Creative Media
RMIT University

Phone: [redacted]

C2. Plain Language Statement

My name is Christian Wolf and I am completing a PhD titled “Development of a Web-Based Adaptive Learning Environment Using Interactive Multimedia to Address Individual Learning Styles” in the School of Education, Portfolio of Design and Social Context at RMIT University.

Thank you for your interest and participation in this research project. Its purpose is to investigate how educational materials can be “translated” into interactive multimedia content and how this content can be adapted to your individual learning preferences in an online environment.

The total duration of the experiment is about 150 minutes. This should allow plenty of time to have your learning preferences assessed and to complete the e-learning course. This course is titled “An Introduction to Java”, which consists of seven short chapters. To access the course, you need to fill in a short online sign-up form. In the process of the course, you will experience online learning content in different formats of media and you can use different learning tools.

Before each chapter, you will be tested for prior knowledge in a short multiple-choice test. After each chapter, there will be a short follow-up test to determine what you have learned. Your results in these tests are used for research purposes only and will not have any impact on your TAFE course mark. Please do not consult any learning materials for the tests, as it would distort the outcome of this experiment. Between chapters, you will also be asked for feedback with regards to your current motivation and satisfaction. For example: How do you feel about your learning progress? (Very Satisfied … Very Dissatisfied).

Your sign up information, test and survey answers, and your navigation choices will be recorded in a database. This database will be kept on a secure, password-protected computer at all times. After the project is completed, your personal details will be deleted and there will be no association between your name or email address and the collected data. No one will spam you as a result of your participation in this experiment.

Participation in this project is entirely voluntary and you may withdraw consent to participate and discontinue participation at any time. All data will be used for research purposes only. The results of this study may appear in future scientific publications, but your anonymity is assured. Your participation in this project is very much appreciated. It will greatly contribute to the future development of online learning environments.

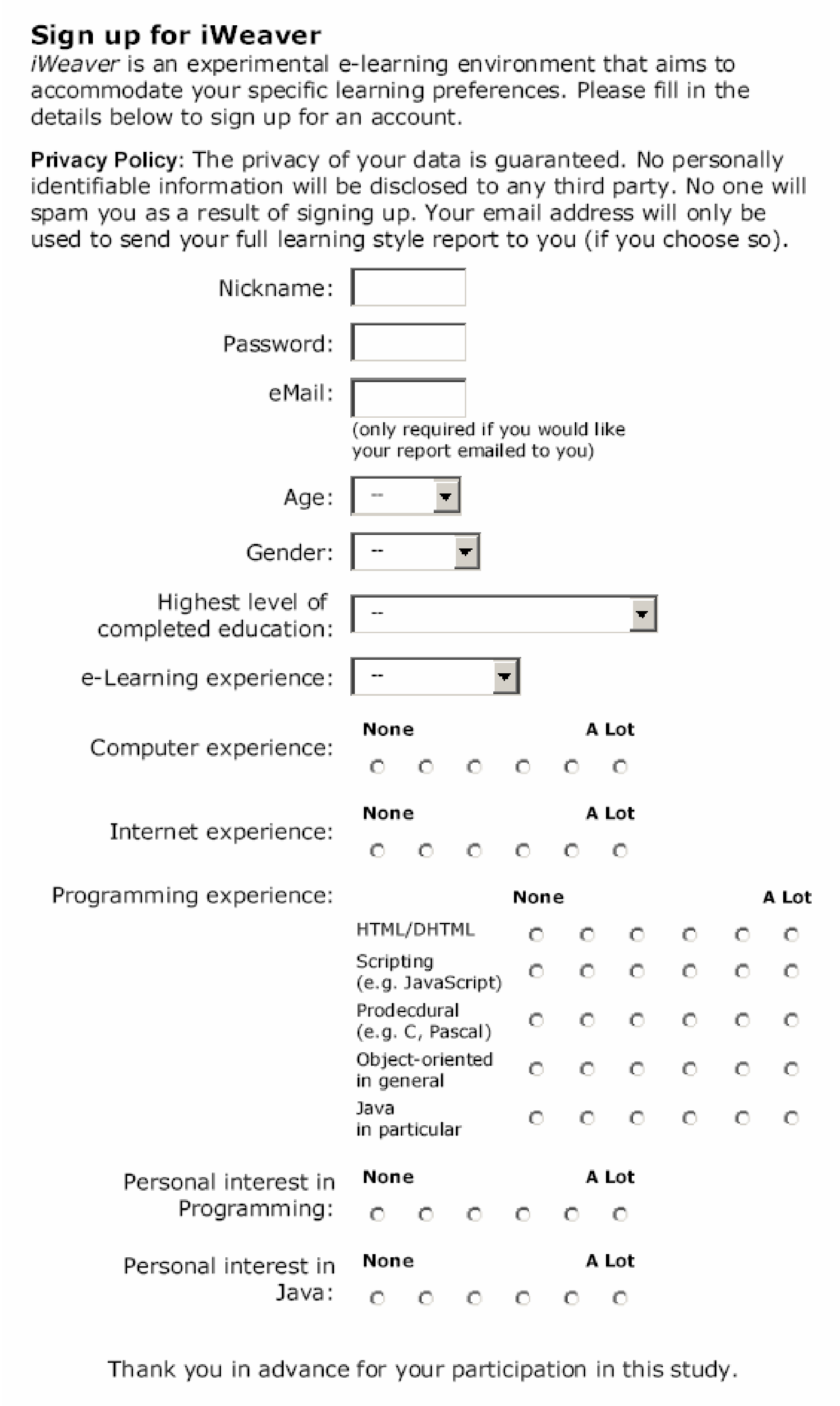
You are encouraged to ask for clarification at any time of any aspect that concerns you. If you have any further questions about the project, please don't hesitate to contact me or my supervisor.

Best regards,

Christian Wolf	Supervised by:	Dr. Andrew Seaton	Dr. Anthony Owens
Principal Investigator			
PhD by Project (Education) Candidate		RMIT University	RMIT University
Computer Scientist (Media and Computer Science)			
chris@adaptive-learning.net		andrew.seaton@rmit.edu.au	tony.owens@rmit.edu.au

Any complaints about your participation in this project may be directed to the Secretary, RMIT Human Research Ethics Committee, University Secretariat, RMIT, GPO Box 2476V, Melbourne, 3001. The telephone number is (03) 9925 1745. Details of the complaints procedure are available from http://www.rmit.edu.au/rd/hrec

C3. Data Collection Instruments



Sign up for iWeaver

iWeaver is an experimental e-learning environment that aims to accommodate your specific learning preferences. Please fill in the details below to sign up for an account.

Privacy Policy: The privacy of your data is guaranteed. No personally identifiable information will be disclosed to any third party. No one will spam you as a result of signing up. Your email address will only be used to send your full learning style report to you (if you choose so).

Nickname:

Password:

eMail:
(only required if you would like your report emailed to you)

Age: --

Gender: --

Highest level of completed education: --

e-Learning experience: --

Computer experience: **None** ○ ○ ○ ○ ○ ○ **A Lot**

Internet experience: **None** ○ ○ ○ ○ ○ ○ **A Lot**

Programming experience:

	None					**A Lot**
HTML/DHTML	○	○	○	○	○	○
Scripting (e.g. JavaScript)	○	○	○	○	○	○
Prodecdural (e.g. C, Pascal)	○	○	○	○	○	○
Object-oriented in general	○	○	○	○	○	○
Java in particular	○	○	○	○	○	○

Personal interest in Programming: **None** ○ ○ ○ ○ ○ ○ **A Lot**

Personal interest in Java: **None** ○ ○ ○ ○ ○ ○ **A Lot**

Thank you in advance for your participation in this study.

Figure C-1. Sign-Up Form for iWeaver.

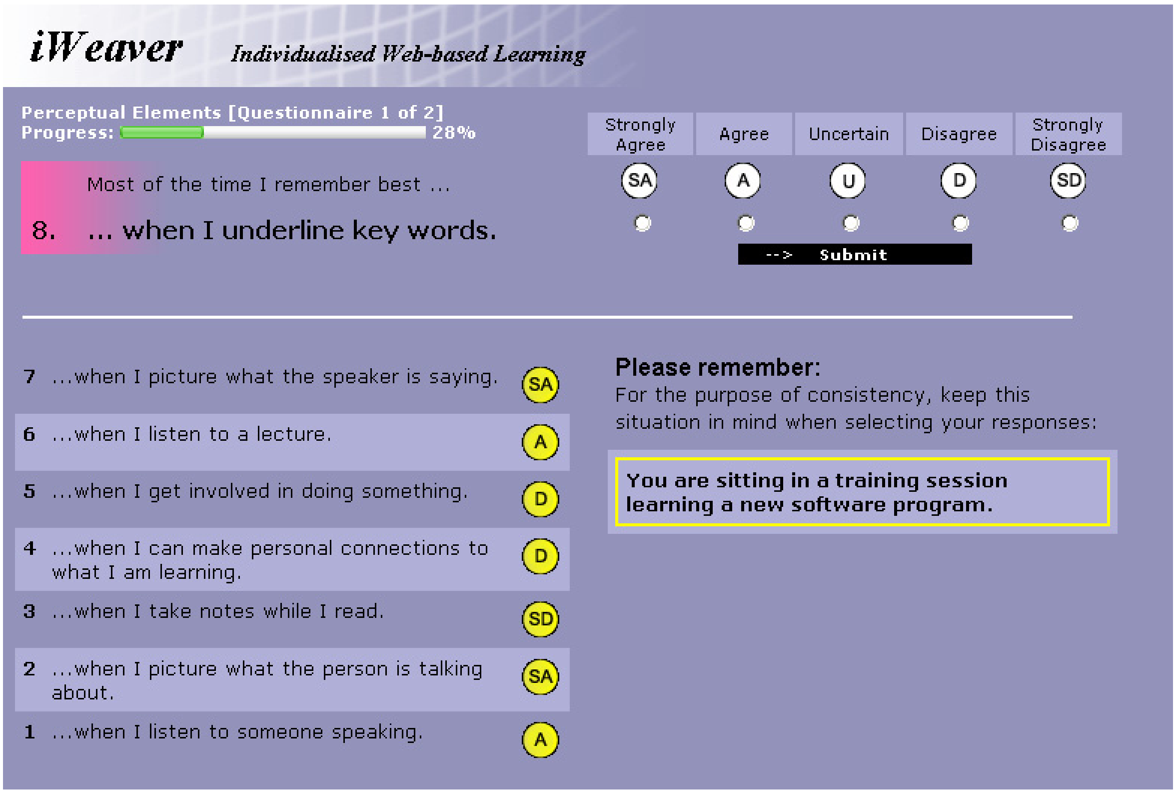


Figure C-2. Building Excellence Survey: Sample Questions.

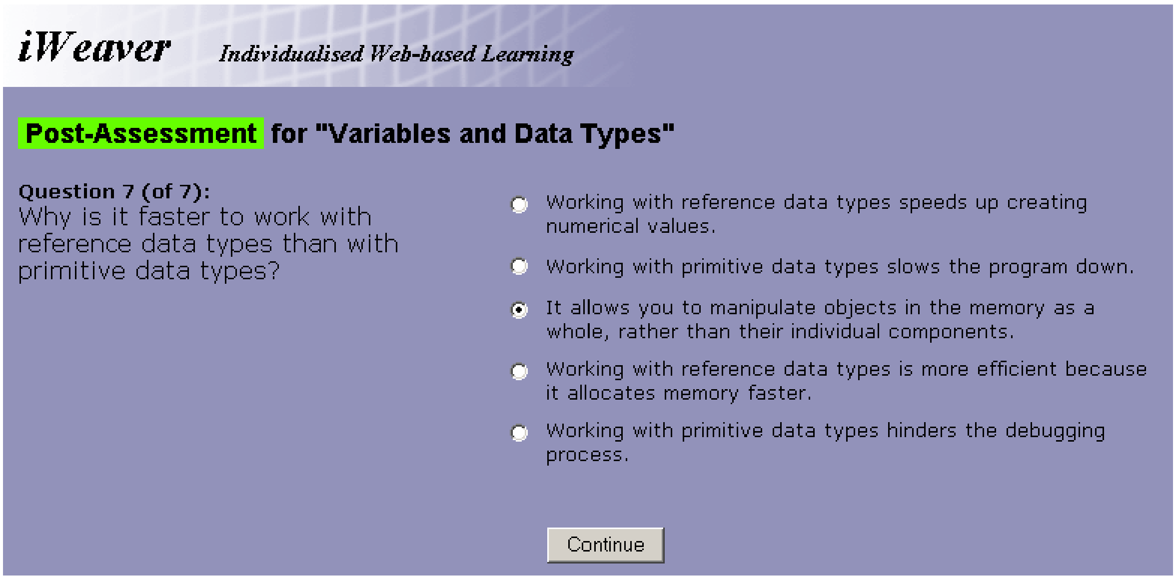


Figure C-3. Post-Test Question: Example 1.

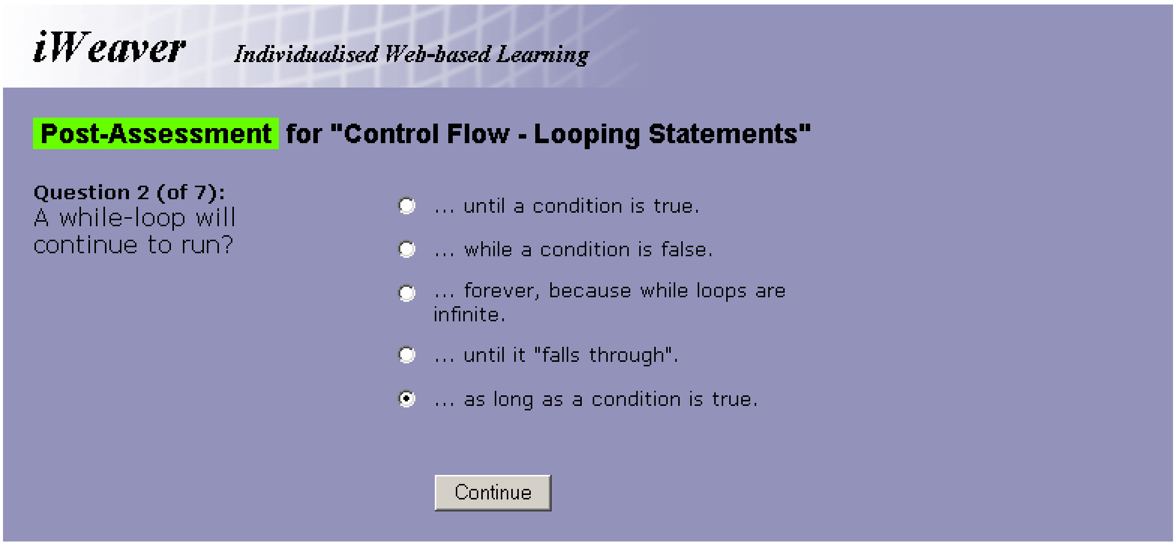


Figure C-4. Post-Test Question: Example 2.

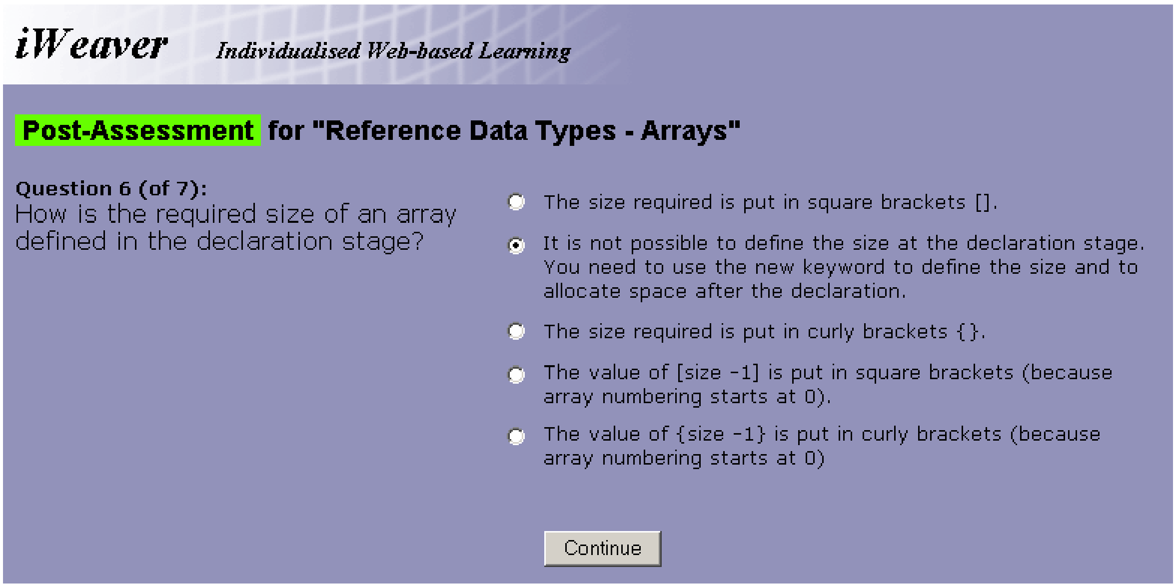
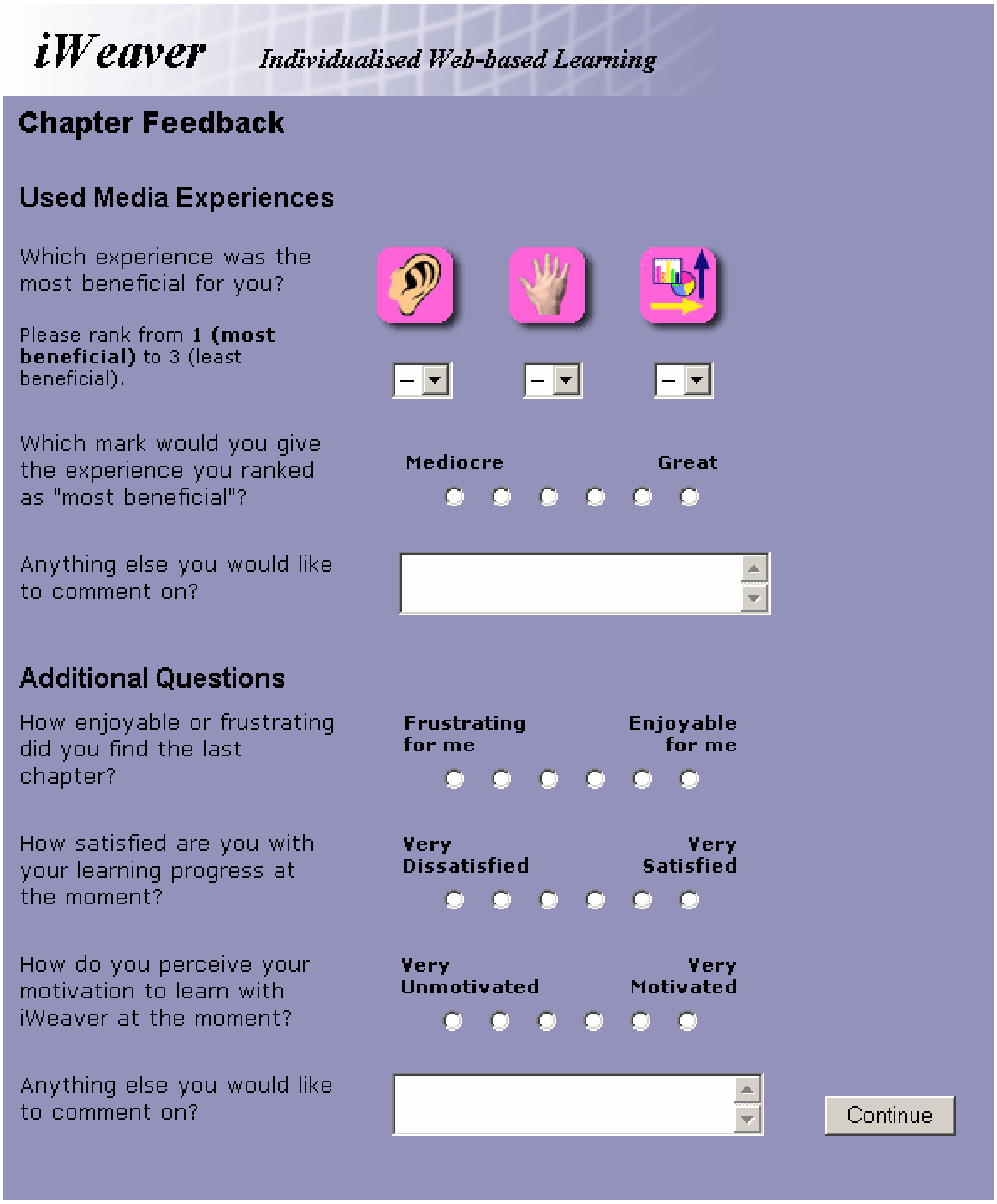


Figure C-5. Post-Test Question: Example 3.



iWeaver *Individualised Web-based Learning*

Chapter Feedback

Used Media Experiences

Which experience was the most beneficial for you?

Please rank from **1 (most beneficial)** to 3 (least beneficial).

– – –

Which mark would you give the experience you ranked as "most beneficial"?

Mediocre **Great**

Anything else you would like to comment on?

Additional Questions

How enjoyable or frustrating did you find the last chapter?

Frustrating for me **Enjoyable for me**

How satisfied are you with your learning progress at the moment?

Very Dissatisfied **Very Satisfied**

How do you perceive your motivation to learn with iWeaver at the moment?

Very Unmotivated **Very Motivated**

Anything else you would like to comment on?

Continue

Figure C-6. Complete Lesson Feedback Form (Choice Condition).

C4. Interpretation of Learning Style Assessment (Excerpt)

Remarks by the Researcher

It is important to note that this report gives an indication of your preferences and probable tendencies only. Therefore, it should not be used to make decisions with regards to your general life, profession, work requirements or career goals.

Each section of this report is structured as follows: First, a preference element is introduced in an brief overview. Then, your personal preference score for that element is printed, followed by a short interpretation of your score and some recommended strategies. In order to keep this report concise, a full interpretation and strategy recommendation is only printed if your preference level for an element is moderate or strong.

The current report covers the perceptual and psychological dimension only. Your preferences in these two elements import for this research project, because the environment will attempt to adapt to them. Nevertheless, if you are interested in a ***full report on all six dimensions***, you will have the option to answer the questionnaires for the remaining four dimensions at the end of the course. You will then get a full personal learning style report that can be either printed or emailed to you.

The Guide to Individual Excellence — Short Report

Part 1 — Perceptual Elements

Perceptual Elements

The perceptual elements are a set of biological (nature) preferences:

1. *Auditory Strength* — hearing and listening
2. *Visual Picture Strength* — creating mental images and viewing pictures
3. *Visual Text Strength* — reading material
4. *Tactile Kinaesthetic Strength* — hands-on, physical interaction
5. *Internal Kinaesthetic Strength* — verbalizing and engaging in discussions

The Importance of the Perceptual Strengths

The perceptual elements are a collection of senses (also known as modalities). The modalities affect the way we learn information and retain it. As a rule when we think of senses, we think of the five with which we are most familiar: seeing, hearing, smelling, tasting, and touching. Within the context of learning, however, you can view senses from an even broader perspective—one that focuses on the most efficient way for an individual to remember new material.

Perceptual preference seems to be biologically determined. Consequently, individuals have limited control over their preference.

Auditory Strength: An Overview

The auditory modality refers to the sense of hearing and listening. People who have an auditory strength typically learn and remember best when they hear the information first; e.g., when they listen to a lecture, a presentation or a discussion. Much of what we do every day (*voice mail, telephone conversations, a presentation, lecture, conversation, or discussion*) centres around listening. Consequently, understanding your predominant perceptual strength is crucial to learning and performance.

Your Personal Preference — Auditory (more preferred) = 15 [out of 50]

You acquire and retain more by using your auditory preference, which means that you are most responsive to verbal rather than written communication. You remember more when you listen to someone speak rather than by reading documents or taking notes. You may talk or read to yourself, which is good, because it reinforces what you heard. You also may prefer telephone conversations rather than e-mail.

Recommended Strategies — *select those you believe will work best for you*.

- Record meetings, lectures, or presentations in order to listen to them again.
- Ask people to use voice mail rather than e-mail.
- Read memos and information out loud.
- Repeat to yourself (aloud or internally) the information you just heard.
- Listen to someone summarize a lengthy document.
- Listen to books on tape.

Visual Pictures Strength: An Overview

The visual modality refers to the sense of seeing. People who have a visual strength often say "show me" since they learn and remember best when they see and read the information first. There are two types of visual strengths — pictures and text.

Visual Pictures: People who prefer the visual picture modality learn and remember best when they can refer to pictures, illustrations, flowcharts or graphs. If visual materials are unavailable, individuals create their own images either on paper or in their minds.

Your Personal Preference — Visual Pictures (more preferred) = 25 [out of 50]

You acquire and retain information best by using your visual picture preference. You remember more through visual thinking and tend to create mental images. You might say that your mind works like a web browser in that your visual thinking process moves from one image to the next making connections along the way. […]