

Ontological Approach for Developing an Adaptive E-Learning System Based on Learning Styles for Students with Dyslexia

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*This doctoral thesis is dedicated to
my parents Yaquob & Hamedah
my loving husband Khaled
my daughter Sarah*

Abstract

Learning management systems (LMS), such as WebCT, Blackboard, and Moodle, are commonly employed in modern educational settings. However, while these applications have proven their worth, they do not typically take the individual needs of students into consideration, especially those with learning difficulties. Furthermore, research into the value adaptive e-learning systems can offer students with learning difficulties is lacking.

This thesis aims to address gaps in existing research by examining the use of an adaptive e-learning system that can adapt to the needs of students with learning disabilities (LD). The research conducted in this thesis focused on dyslexia because there are various forms of dyslexia and, as such, it cannot be categorised as a single condition that can be served by one specific e-learning system.

Following an extensive literature review, three models by which the characteristics of students with dyslexia could be taken into consideration within an adaptive LMS were formulated: a consensus-based model of dyslexia signs and symptoms, which includes consideration of reading, writing, memory, mathematics and speaking difficulties; a comprehensive listing of the existing assistive technologies that can be employed to assist dyslexic students in their educational process mapped according to dyslexia symptoms; and a learning styles model that was based on the Felder-Silverman learning style model that establish relationships between dyslexia type and learning styles.

The three models were subsequently incorporated into the Dyslexia Adaptive E-Learning (DAEL) Framework, which specified the design requirements by which an e-learning technology that can facilitate dyslexic student's learning can be developed. The proposed framework was validated using a quality assessment approach.

This thesis proposes an innovative semantic approach to dynamically generate personalised learning materials in the form of the Adaptive E-Learning Management System (DAELMS). The DAELMS is an ontology-based engine that composes and adapts learning experiences according to learner's dyslexia type and learning styles. This novel approach aims to improve flexibility, extensibility and reusability of systems, while offering a pedagogically effective and satisfactory learning experience for learners with dyslexia. The evaluation of the system revealed that the proposed concept successfully supported students learning in general and students with dyslexia specifically. It is anticipated that this research will pave the way for the development of advanced adaptive learning systems that can support the needs of multiple learners and learning disability types.

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Abbreviations

Abbreviation	Meaning
ABTs	Abstract Tasks
AEHS	Adaptive Educational Hypermedia System
AHS	Adaptive Hypermedia Systems
AI	Artificial Intelligence
ATs	Assistive Technologies
BDA	British Dyslexia Association
B/S	Browser/Server
C/S	Client/Server
CSS	Cascade Style Sheet
DAEL	Dyslexia Adaptive E-Learning System
DAELMS	Dyslexia Adaptive E-Learning Management System
DATs	Dyslexia Assistive Technologies Model
DDA	Disability Discrimination Act
DED	Disability Equality Act
DRA	Disability Right Advocate
DRC	Disability Rights Commission
DSCM	Dyslexia Symptoms and Classification Model
E-Learning	Electronic Learning
FIPA	Foundation for Intelligent Physical Agents
FSLSM	Felder-Silverman learning style
FTF	Face to Face
GUI	Graphical User Interface
HESA	Higher Education Statistical Agency
HTML	Hyper Text Markup Language
IDA	International Dyslexia Association
IIS	Intelligent Information System
IT	Information Technology
IS	Information System
JISC	Joint Information Systems Committee
JS	JavaScript
KB	Knowledge Base
KG	Knowledge Gain
KIF	Knowledge Interchange Format
LD	Learning Disability
LMS	Learning Management System
LOs	Learning Objects
LSI	Learning Styles Inventory
LSQ	Learning Style Questionnaire
M-Learning	Mobile Learning
MVC	Model-View-Controller
ODAEL	Ontology of Dyslexia Adaptive E-Learning
OIL	Ontology Inference Layer
OWL	Ontology Web Language
OWL DL	Ontology Web Language Description Logic
RDF	Resource Description Framework
SpLD	Specific Learning Difficulty
SUE	Systematic Usability Evaluation
TAM	Technology Acceptance Model
TeL	Technology-enhanced Learning
VLE	Virtual Learning Environment
WAI	Web Accessibility Initiative
XOL	Ontology Exchange Language
XML	eXtensible Markup Language

Peer Reviewed Publications and Contributions

Conference Contributions

Papers

- Alsobhi, A., Khan, N. & Rahanu, H. 2015, Personalised learning materials based on dyslexia types: ontological approach, In *Proceedings of the 19th International Conference on Knowledge-Based and Intelligent Information & Engineering Systems (KES 2015)*, Singapore. *Procedia Computer Science*, 60(2015), 113 – 121. Published by Elsevier B.V. **Accepted**
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- Alsobhi, A., Khan, N. & Rahanu, H. 2015, DAEL Framework A New Adaptive E-learning Framework for Students with Dyslexia, in *Proceedings of the International Conference On Computational Science, (ICCS 2015)*, Reykjavík, Iceland. *Procedia Computer Science*, 51(2015), 1947 – 1956. Published by Elsevier B.V. **Accepted**
- Alsobhi, A., Khan, N. & Rahanu, H. 2014, Toward Linking Dyslexia Types and Symptoms to The Available Assistive Technologies, in *Proceedings of the 14th IEEE International Conference Advance Learning Technologies (ICALT 2014)*, Athens, Greece. **Accepted**
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Posters

- Alsobhi, A., Khan, N. & Rahanu, H. 2015, An Attempt to Link Dyslexia Types and Symptoms to the Current Assistive Learning Technologies, in *Proceedings of the 8th Saudi Students Scientific Conference (SSSC 2015)*, London, United Kingdom. **Accepted**

Journal Contributions

- Alsobhi, A., Khan, N. & Rahanu, H. 2015, Implementation process of DAELMS: Ontology-based Adaptive E-Learning System Based on Learning Style for Student with Dyslexia, *Computer and Education*. Published by Elsevier B.V. **Submitted**

Chapter 1 Introduction

1.1. Overview

Digital technologies have pervaded every area of modern life as we know it, and education is no exception. The availability of applications, software and devices that are designed to facilitate teaching and learning has had a significant impact on the process by which people acquire new knowledge and skills. As a result of the wide-scale availability of the Internet and the proliferation of low-priced computer devices in UK, students can now directly access a vast array of multimedia content that can enhance their learning and development. However, while such technologies are promising, they are also evolving at a rapid pace, and this presents both educators and students with a number of significant challenges. There is now a fundamental need to establish a systematic mechanism by which the effect that technology offerings have on learning outcomes can be identified. The research¹ described in this thesis examined the impact that the use of technology in the classroom setting had on educational outcomes with a specific focus on students with dyslexia. This chapter is organised as follows. Sections (1.2) and (1.3) present a literature review of the existing research that has examined dyslexia, the various forms it takes and the application of technology in educational settings. Section (1.4) then presents a distinct research problem and outlines the rationale behind the research, its aims and objectives and the specific questions it seeks to answer. Section (1.5) provides an overview of the topics of the thesis.

1.2. The Application of Technology in Educational Settings

As a result of the proliferation of technology-based learning interventions, a wide variety of terminology has become commonplace and terms such as online learning, virtual learning platforms and electronic learning (e-learning) are now in standard use. Nicholas (2003) described online learning as a form of education that takes place exclusively in a virtual world with no use of physical learning resources. He differentiated this from e-learning, which he specified involves the use of technological offerings to extend or supplement the learning process. Nicholas' view of e-learning differed slightly from that of Guri-Rosenblit and Gros (2011), who employed the term to describe any general utilisation of electronic tools or materials in learning environments. According to Guri-Rosenblit and Gros, there are many different forms of e-learning including Internet-mediated learning, web-based learning and mobile device-based learning. According to this definition, online learning is considered as a form of e-learning. Heinze and Procter (2004) examined the concept of blended learning and described it as an educational approach that combines several models, teaching and learning methods and educational formats (Heinze & Procter, 2004). Mobile learning, on the other hand, is more specific and involves the use of mobile and wireless technologies to facilitate e-learning

¹ This chapter is based on the following peer-reviewed paper:

Alsobhi, A. & Abeyasinghe, G. 2013, An Evaluation of Accessibility of E-Learning for Dyslexic Students, in *Proceedings of the CTIT International Conference on Current Trend on Information Technology (IEEE 2013)*, Dubai, UAE, ISBN 978-1-4799-2424-0.

interventions. Unlike e-learning, which is predominantly completed on a desktop computer, m-learning involves the use of mobile devices to access learning experiences. For the purposes of this thesis, the term *e-learning* will be employed to describe any form of learning that involves the use of technology to enhance learning experiences, be it by desktop or mobile device, through technology alone or in combination with additional resources.

According to Pretorius et al. (2015), higher education has undergone a significant amount of change in recent years, and such changes have had a direct impact on how students learn and develop. One specific change can be observed in the move from predominantly teacher-centred to more student-centred models. According to Harden and Crosby (2000), in the past teachers typically employed a unidirectional approach in which they shared their knowledge with the members of their class with very little opportunity for student interaction or feedback. O'Malley and McGraw (1999) described such an approach as the *sage on the stage*. Conversely, Nihuka and Voogt (2012), state that even in the past the educational experts have recognised the value of allowing students to take an active role in their own learning and development and, as such, they are more readily encouraged to ask questions and interact with the teacher in a two-way teaching and learning process. According to some educational experts, such an approach enhances the quality of learning experiences and provides students with a deeper knowledge and understanding (Newble & Cannon, 1995). Following this approach students have more direct involvement in their own learning and often have an opportunity to adopt a learning approach that is most closely aligned with their needs and preferred learning style.

Education and curriculums are in a continual state of change and evolution. This presents contemporary teachers with a large number of challenges (Lim, 2015). In addition to keeping abreast of what subjects they need to teach, when, and to what degree, teachers also need to maintain up-to-date knowledge of the latest developments in pedagogical understanding and develop methods of putting these into practice to optimise the learning experiences they provide to their students. There are currently wide varieties of e-learning systems available including games, chat interfaces, websites, web-based classrooms, forums, online databases and electronic teacher networks. Each of these has their own distinct advantages and potential to enhance student's learning outcomes. It is the teacher's role to identify and assess the various e-learning systems that are available and to identify methods by which these can be employed to meet the diverse needs of the student population. Through doing so, teachers will develop a more effective learning system that takes into consideration learner's individual abilities and requirements while also taking full advantage of the resources that are available. Section (3.3.2) describes the notion of personalised e-learning in more depth, and considers methods by which this can be employed in the classroom.

1.2.1 Personalised e-learning approaches based on adaptive technologies

E-learning systems need to be flexible and adaptable for two main reasons. First, a large number of different students who all have their own unique needs and requirements use e-learning systems. Second, learners typically interact with e-learning systems independently of the teacher and, therefore, do not have immediate access to personalised assistance (Brusilovsky, 1999). As a result of these two issues, a significant amount of attention in recent

years has been directed at developing e-learning systems that incorporate methods of personalising learning experiences according to learner needs and preferences (Baylari & Montazer, 2009; Brusilovsky, 1999; Brusilovsky & Peylo, 2003; Chen et al., 2006; Chen, 2008; Henze et al., 2004; Jeong et al., 2012; Jovanovic et al., 2009; Milosevic et al., 2006; Trella et al., 2005).

One area, in which there is significant promise for developing e-learning systems that are capable of meeting the needs of diverse learners, is semantic web technologies. Ontologies, in particular, hold great promise because they allow formal and explicit conceptualisation (Gruber, 1993). That is, they allow the development of an abstract exemplification of a concept through facilitating the process by which the main ideas supporting the phenomenon are identified and forming links between these ideas (Chi, 2009).

In combination with reasoning approaches, ontologies have been proven to represent high quality, cost-effective educational systems because they are fully flexible and can be readily adapted to the needs of diverse learners (Gruber, 1993). A further advantage of ontologies is that they incorporate inference mechanisms that can provide learners with an opportunity to engage in practical reasoning activities (Berners-Lee et al., 2001). This thesis aims to identify the key components of an e-learning system that will be required to deliver adaptive and personalised learning systems that effectively incorporate ontological and semantic capabilities. The focus of the research will be on students who suffer from dyslexia. A distinct effort will be made to develop a flexible model that employs effective adaptive strategies that can adjust according to a learner's unique learning needs and the type of dyslexia that he or she has. The key focus of this research will be on the development of personalised e-learning systems for students with dyslexia. The next section will provide an overview of dyslexia and how it influences students' learning approaches.

1.3. A Basic Overview of Dyslexia

The word 'dyslexia' is derived from the Greek language, with "dys" meaning difficulty and "lexia" meaning language (Ott, 1997). The definition of dyslexia that will be applied within this thesis is that provided by the British Dyslexia Association (BDA) (2007):

Dyslexia is a specific learning difficulty that mainly affects the development of literacy and language related skills. It is likely to be present at birth and to be life-long in its effects. It is characterised by difficulties with phonological processing, rapid naming, working memory, processing speed, and the automatic development of skills that may not match up to an individual's other cognitive abilities. It tends to be resistant to conventional teaching methods, but its effect can be mitigated by appropriately specific intervention, including the application of information technology and supportive counselling.

According to research by Tinklin, Riddell, and Wilson (2004), twice as many students disclosed that there were dyslexics in 1999/2000 than those who specified they were dyslexics in 1995/1996. This is not necessarily an indication that dyslexia is on the rise, but is likely to be more indicative that more students are being actively encouraged to disclose their dyslexia than

ever before, and that some of the stigma associated with the condition has been removed in more recent years. Further statistics that were published by the Higher Education Statistics Agency (HESA, 2015), revealed that the majority of students who revealed that they had learning disabilities were male. This is unsurprising given the fact that research has proven that males are more likely to have dyslexia than females and that the majority of disabled students declared over that period were men (Tinklin, Riddell, & Wilson 2004). While dyslexia does have the potential to impede learning, it is by no means an indication of intellectual and creative capability. Notable sufferers of dyslexia include Albert Einstein, Leonardo da Vinci, Walt Disney, Thomas Edison, Isaac Newton, Steve Jobs and Pablo Picasso. Every one of these remarkable men were described as lazy and unskilled in their school days as a result of their learning differences; however, they all went on to make a significant contribution to society despite their disadvantage (Sekovanić, Vukovac, & Podbojec 2012). Indeed, research has revealed that dyslexia by no means renders an individual incompetent. On the contrary, individuals who have dyslexia have been proven to possess advanced intuition, creativity, perception, visualisation, and originality (Sekovanić, Vukovac, & Podbojec 2012).

Today, teachers have a much better understanding of dyslexia and of the teaching interventions that can be employed to help students who suffer from this condition. However, such students continue to encounter many challenges in their quest to access learning experiences that are aligned with their needs and capabilities. One reason for this is that many educational systems are not equipped for students who have dyslexia. This is true in the UK, despite the fact that the UK is widely regarded as having one of the most comprehensive legislative support networks for dyslexic people among all European countries, as evidenced by a number of formal enactments including the Disability Discrimination Act 1995 (DDA), the Disability Equality Duty 2006 (DED), Equality Act (2010), and the Special Educational Needs and Disability Act 2002 (SENDA). If dyslexic students are offered learning experiences that are comparative to those available to their peers and, therefore, the guidelines of the various legislative frameworks are adhered to, they have every potential to achieve academic and career success.

Research by Woodfine, Nunes, and Wright (2008) revealed that learning experiences that involve real-time text-based activities, such as those associated with the use of online chat and conference facilities could put students who have dyslexia at a distinct disadvantage to their peers. The issues that people with dyslexia experience when interacting with e-learning systems extends beyond accessibility and design issues alone, and incorporates many other factors. However, while some of these issues are readily acknowledged, there is a lack of existing research in the field, and academics lack a solid understanding of the problems that students who suffer from dyslexia experience when attempting to interact in collaborative learning environments. It is potentially because of this gap in understanding that many of the technologies that have been introduced into contemporary classrooms with the intention of facilitating the learning experiences of students with dyslexia have fallen short. This thesis will make a concerted effort to identify the reasons as to why current offerings are limited and to present recommendations as to how future technologies can be improved.

Dyslexia is a very complicated and multifaceted condition that affects sufferers in many different ways. Rarely, two people with dyslexia will typically encounter the same symptoms. This basic

fact is at the core of this current research. As the nature and impact of a student's dyslexia symptoms will vary from individual to individual, it is very difficult to develop a standard learning system that is capable of meeting the needs of all dyslexia sufferers. As such, to provide effective learning interventions, educators need to develop learning experiences for the dyslexic students they teach on a case-by-case basis. In light of the disadvantages associated with such an approach and the current lack of formal research into the use of e-learning systems with students who suffer from dyslexia, this study aimed to explore dyslexic students' interactions with e-learning systems in depth with the intention of forwarding recommendations for future technological applications.

As outlined above, dyslexia manifests itself in many different ways, and it is, therefore, exceptionally difficult to categorise dyslexia. However, some broad subtypes of dyslexia have been identified (Carlson, 1998). One of the fundamental reasons as to why e-learning applications may not be as effective for dyslexic students as they are for standard learners, can be attributed to the fact that technology developers have not taken into account the different types of dyslexia. At present, the technologies that are available are very generic and do not offer any means of differentiating learning experiences according to the needs of the user. As such, there is a need for developers to create more flexible and adaptable systems that can adjust to the type of dyslexia that a student has. As dyslexic students may differ in terms of the symptoms that they exhibit, it is useful to consider dyslexia in terms of the three broad categories defined by Ingram (1964): *(1) visio-spatial difficulties (2) speech sound difficulties and (3) correlating difficulties.*

The next section will define the main research problem of this thesis.

1.4. Research Problem

In recent years, the use of hardware and software applications in the classroom has significantly evolved, and the availability of technological learning interventions and information and communication technologies (ICTs) has had a noticeable impact on learning inputs and outputs. It is acknowledged that e-learning systems have changed approaches to learning and teaching, however the extent to which these shifts have been positive remain unclear. In fact, some research, such as that by Woodfine, Nunes, and Wright (2008), has indicated that e-learning interventions in the classroom actually have a negative impact on learning outcomes especially for dyslexic learners.

The increased use of ICTs by means of assistive technologies (ATs) have provided mechanisms through which students who have disabilities can access some of the learning experiences that are available to their peers. For example, chat-based programs have provided deaf children with a chance to communicate with others, text-to-speech tools have allowed children who are blind to access the content of books and stories, and word processing applications and their accompanying grammar and spelling checks have helped dyslexic students to overcome their disabilities. One explanation for the rise in popularity of ATs in recent years can be attributed to the Equality Act of 2010, which mandates that all education providers

are required to ensure that the provision of all educational experiences do not discriminate against any students for any reason.

While ATs have undoubtedly provided a mechanism by which learners with disabilities can access some of the learning experiences that are available to their peers, not all technologies are created equal when it comes to students' differing needs. Furthermore, the use of some technical tools, such as synchronised communication, may provide unfair disadvantage for some students. In light of these issues, it is extremely important that effort is invested in identifying effective learning systems and these are used to their optimal potential to facilitate all learners to achieve a satisfactory level of learning and development. To make this possible, the next generation of e-learning technologies need to be more adaptable and flexible than their predecessors, which typically employ a one-size-fits-all approach to education that does not offer any real opportunity to differentiate learning experiences according to a student's abilities, learning preferences and existing capabilities. As opposed to delivering standard generic content to all students, the e-learning systems of the future need to incorporate differentiation strategies through which the content of the lesson and the way it is presented is aligned with the user's needs. To make this happen, it is first important to develop an explicit analysis of what they needs are, subsequently to develop a curriculum that is aligned with a solid set of educational requirements. As opposed to trying to force a learner to adapt to a curriculum, and risk that they will fail trying, the e-learning systems of the future should be flexible and adaptable in accordance with the learner's distinct needs.

Over the last fifteen years, the number of self-proclaimed disabled students has increased from 5.4% in 2003/2004 to 8.0% in 2012/2013. According to figures released by the Higher Education Statistical Agency (HESA) in 2015, a total of 77,795 UK students were regarded as having a disability in the 2013/14 academic year, of which 37,710 had a specific learning disability like dyslexia. Furthermore, between the 2007/2008 and 2013/2014 academic years, the percentage of learners in the UK education system who had a specific learning disability, such as dyslexia, increased by 0.5%. These figures indicate that the number of students in the system who have recognised learning difficulties is on the rise, but what has been done to meet the needs of these students in terms of e-learning systems? How many of these students are being provided with the access to the e-learning technologies they need to thrive in the school setting?

While existing research has considered the functionality of e-learning systems (Ituma, 2011), there is a lack of reliable studies that have examined the extent to which disabled students, such as those with dyslexia, are able to use and access these technologies. Although standards by which accessibility via technical specifications and interface design were outlined in the Web Accessibility Intuitive (WAI) guidelines, these apply only to conventional web applications and no formal research has examined the extent to which existing e-learning systems meet these standards.

The following subsections will examine the rationale that underpins this research and will provide further information about the research objectives, questions and scope, and the contribution it can make to improving educational outcomes for dyslexic students.

1.4.1 Research rationale

To date, a large amount of research has been conducted that aims to assess the extent to which so-called universally accessible systems are capable of meeting the needs of a variety of different user groups (Goette, et al., 2006; Keates, 2006). However, learning disabilities are extremely complex and multifaceted and, as such, it is extremely difficult to develop a standard system that is capable of meeting the unique and varied needs of a wide range of disabled users (Maybury, 2001). Before it is possible to even attempt this complex task, it is important to develop a solid understanding of the e-learning requirements that a specific set of disabled users have. One subgroup of such users that is widely regarded as being at a disadvantage when attempting to employ conventional e-learning applications is students who suffer from dyslexia. The very nature of dyslexia entails that the interface operations that are a standard element of the majority of e-learning systems, such as data entry fields and navigation systems, are very difficult for dyslexic students to use.

According to the British Dyslexia Association (2015), approximately 10% of the student population in the United Kingdom have dyslexia and, of those that do, 4% have a severe form of the condition. As a result of laws, as listed in Section (1.3), above, dyslexic students now have legal rights to access the support they need to live a full life, and these statutory rights are applicable in the educational setting. As such, an investigation into how existing e-learning systems can be adjusted to meet the needs of disabled users is not only justified, it is necessary.

Despite the legal recognition of the need to support disadvantaged learners, very little existing research has examined how e-learning systems can be modified to meet the needs and requirements of dyslexic learners. As the application of e-learning systems is becoming increasingly common in the classroom setting, especially those that are web based, there is a distinct need to investigate how a strong framework can be developed that is capable of supporting the learning needs of dyslexic students. To this end, the design, development and evaluation of the Dyslexia Adaptive E-Learning framework for students with dyslexia will be discussed in this thesis.

1.4.2 Research questions

The aim of this research is to examine how e-learning systems can be adapted to meet the needs of dyslexic students. To achieve this, the research will identify the main criteria used to determine accessibility and will build an adaptive framework for student with dyslexia. In order to provide more adaptive and personalised learning the research linked the learning style with dyslexia difficulty type and proposed an ontological approach accordingly. Afterwards, a set of presentation, hypermediality, accessibility and user experience attributes will be identified in order to design the e-learning system based on the proposed framework. Accordingly, the focus of this thesis is on the following research questions:

- Research question one (RQ1): In comparison to traditional e-learning system, do dyslexic students exhibit any significant differences in their learning outcomes when engaging with an adaptive e-learning system?

- Research question two (RQ2): From the point of view of students with dyslexia, what key elements will an e-learning system need to offer in order to be sufficiently adaptive?
- Research question three (RQ3): What is dyslexia? How is it manifest? What learning difficulties do students with dyslexia typically encounter?
- Research question four (RQ4): How can systems that offer more personalised and flexible learning experiences based on dyslexia types and learning styles be utilised to enhance the learning outcomes of dyslexic students?

These research questions underpinned the research and guided the methodology and discussion.

1.4.3 Research aims

This research had three specific aims:

- Aim One (RA1): To develop a thorough understanding of dyslexia, the different types of dyslexia, the various ways in which the condition manifests itself in learning difficulties, and existing theories pertaining to optimising the learning outcomes of students who have this condition.
- Aim Two (RA2): To apply the comprehensive understanding of dyslexia that was developed during the first stage of the research to develop a stringent set of guidelines by which a model that informs the development of e-learning applications can be developed. This framework could then guide further research with individuals who have dyslexia and the teachers and other professionals who interact with them in an educational setting.
- Aim Three (RA3): To apply the outcomes of the research and analysis to inform the development of an e-learning system that is able to accommodate for different dyslexia difficulty types, while fully taking into account their sensitivities, experiences and goals.

1.4.4 Research objectives

The research objectives of this thesis underpinned the overall aims as described above and were as follows:

- Research Objective One (RO1): To develop a comprehensive overview of dyslexia in terms of how it is defined and classified.
- Research Objective Two (RO2): To identify dyslexia theories.
- Research Objective Three (RO3): To identify the learning styles that individuals of each type of dyslexia are most likely to exhibit.
- Research Objective Four (RO4): To develop a framework by which dyslexia types and symptoms can be aligned with learning styles and needs.
- Research Objective Five (RO5): To assess the aspects of e-learning technologies that can enhance or undermine a dyslexic student's ability to interact with an e-learning system.
- Research Objective Six (RO6): To develop an ICT based framework for e-learning systems to improve the accessibility for students with dyslexia.

- Research Objective Seven (RO7): To develop an approach to e-learning that facilitates flexible learning experiences that are tailored to the preferred learning style of the student and the type of dyslexia that they have.
- Research Objective Eight (RO8): To create a flexible and adaptive e-learning system that is based on the defined ontology-based approach.
- Research Objective Nine (RO9): To test the system in a practical setting with a student who has dyslexia in order to determine its efficacy in achieving its objectives.

Table 1.1 Mapping the research questions, aims and objectives

Research Questions	Research Aims	Research Objectives
• RQ3 • RQ4	RA1	• RO1 • RO2 • RO3 • RO4
• RQ1 • RQ2	RA2	• RO5 • RO6 • RO7
• RQ4	RA3	• RO8 • RO9

1.4.5 Research scope

Although the scope of this research was limited to students with dyslexia, it is anticipated that the framework and ontological approach that were developed as a result of this study will be of use to all students with learning disabilities. It will also be of use to people who are involved in designing and delivering learning experiences to students who have a variety of forms of learning disabilities. Specifically, it will be extremely useful to developers who are interested in creating e-learning applications that can meet the needs of dyslexic users. In doing so, the people referred to above will be able to fulfil their legal and moral duties to ensure equality in the provision of educational experiences for students with disabilities.

1.4.6 Research contribution

This thesis represents an ontological approach to develop an adaptive e-learning system that is capable of adapting to the knowledge level and learning style of students with dyslexia. The research will make a valuable contribution to the education and technology fields in the following ways:

- 1) The development of a **Dyslexia Classification Model (DCM)** that can be employed to identify an individual's symptoms and represents the relationships between the dyslexia classification and symptoms. This model will provide a basic checklist by which dyslexia can be diagnosed, and the type of dyslexia that an individual has can be subsequently assessed (Chapter 5, Section 5.2.1).
- 2) The development of a **Dyslexia Assistive Technologies Model (DATs)** that identifies the types of assistive technologies that can be employed to facilitate the learning experiences of dyslexic students in accordance to their dyslexia type and classification as defined by the DCM (Chapter 5, Section 5.2.2).

- 3) The creation of a **Dyslexia and Learning Styles Model (DLSM)** that employs the outputs of existing research in the area of dyslexia and learning style to map dyslexia types to the four dimensions of the Felder-Silverman learning style model. The DLSM can then be employed to develop a further model that adequately captures adaptivity needs (Chapter 5, Section 5.3).
- 4) The development of a **Dyslexia Adaptive E-Learning (DAEL) Framework** that consists of a clear and focused set of design requirements that should govern the subsequent development of any e-learning technologies that facilitate dyslexic student's learning (Chapter 6).
- 5) The application of **Ontology Dyslexia Adaptive E-Learning (ODAEL)** an ontological approach to system design that facilitates the delivery of personalised learning experiences that are aligned with students' learning styles and dyslexia type (Chapter 8).
- 6) The design of a **Dyslexia Adaptive E-Learning Management System (DAELMS)**. This extensive research will culminate in the design of a fully adaptive e-learning application that delivers personalised learning materials that are aligned with an individual's preferred learning style and the type of dyslexia they have (Chapter 9).
- 7) DAELMS offers **Adaptation** features, which are primarily defined in according to the content of the learning experience and the characteristics of the users. Each user has his or her own profile, and this profile contains key data relating to important characteristics, such as learning style and the matching dyslexia type, that are represented by a set of attributes. Likewise, there is a set of attributes available that relate specifically to content; for example, knowledge level, learning style, etc. As such, Adaptation approaches match the user to content attributes. A further key feature of Adaptation is that it can be applied to a group of users who share similar profiles in such a manner that it adjusts content according to a group of users as opposed to an individual user. The adaption occurs at the levels of course structure, course content, navigation, and communication tools (Chapter 10, Section 10.4).
- 8) Published articles: Six conference papers and a conference poster have been published as outputs of this research (see Appendix A).

The next section provides an overview of the content of this thesis.

1.5. Research Outline

This thesis describes a number of significant educational concepts including electronic learning, learning difficulties, dyslexia, type of dyslexia, learning styles, adaptive technology, ontologies and personalised learning experiences. Every one of these topics has important implications for the overall research objectives and aims. The thesis consists of twelve chapters in total, and these are organised as follows.

Chapter 1 describes the aims and objective of the research together with the methodology that will be employed to answer the research questions. Chapter one also contains an outline of the problem definition and an overview of the content of the thesis.

Chapter 2 contains a comprehensive literature review of existing research that has examined dyslexia and considers some of the issues researchers and theorists have encountered when attempting to define and classify the nature of dyslexia, the type it takes, and the implications that it has for learners. A key focus will be placed on understanding how different type of dyslexia can result in variations in a learner's preferred learning style.

Chapter 3 concentrates on e-learning technologies and specifically considers adaptive hypermedia. It examines the concept of adaptivity and the various technologies that are currently available for use in e-learning systems. Chapter three also considers the existing assistive technologies and learning management systems that are employed in contemporary classrooms to facilitate learning experiences for students who have dyslexia. The chapter concludes by reviewing the potential that semantic web technologies have for personalising e-learning approaches and places a specific focus on the benefits of ontology in delivering adaptive experiences.

Chapter 4 presents the appropriate research methodology for this study. The research methods quantitative and qualitative are presented as possible choices. It describes the methodological justification and topic challenges as well.

Chapter 5 describes three important frameworks that have important implications for this research. These are as follows:

- Dyslexia Symptoms and Classification Model (DSCM). This is employed to define the relationship between the type of dyslexia that an individual has and the symptoms he or she will typically exhibit;
- Dyslexia Assistive Technologies Model (DATs): The DATs model serves to establish a link between the type of dyslexia and the assistive e-learning technologies that are available.
- Dyslexia and Learning Styles Model (DLSM): The DLSM model serves to establish a link between the dimensions of the Felder-Silverman Learning Style Model and the dyslexia type.

Chapter 6 describes the development of a new framework that is designed to facilitate the learning processes of students who have dyslexia.

Chapter 7 tests the effectiveness of the proposed framework and examines the resulting data and qualitative information in depth. The validation processes are examined from two perspectives. First, the findings are compared with those outlined in existing research studies and theories. Following that, the ways in which the effectiveness of the DAEL framework are assessed are considered. The outputs of the two different approaches are employed to understand the extent to which the DAEL framework is more effective than a standard e-learning approach.

Chapter 8 defines an ontological model that is referred to as ODAEL and provides an overview of the process by which this model was designed and developed. An overview of the model together with sample screenshots of a prototype, is provided.

Chapter 9 provides an in-depth overview of the architecture of the proposed application and presents a generic methodology and architecture for creating a DAELMS that adapts to individual learning styles based on their dyslexia type.

Chapter 10 tests the application of the ODAEL ontologies as a supportive application that facilitates the learning experiences of a student who has dyslexia. The chapter also reviews the adaptive technologies and components involved and how these are achieved through ontology that delivers a personalised learning approach.

Chapter 11 offers a comprehensive overview of the results of the evaluation. It describes the extent to which the learners involved in the research were happy with the proposed system and examines the specific ways in which the application of an adaptive system influences the learning experiences of dyslexic students. The chapter concludes by presenting a technical assessment of the application.

Chapter 12 examines the outputs of the research and presents a solid set of conclusions pertaining to the use of adaptive ontology-based e-learning experiences to facilitate the learning experiences of students who have dyslexia. The chapter concludes by summarising the main findings of the thesis and its limitations, before progressing to present recommendations as to how research in this domain should progress in the future.

1.6. Chapter One Summary

This introductory chapter defined the background upon which this research project was based and provided a broad overview of the research objectives, aims and methodology. The problem that the research sought to address was clearly defined, and the process by which the research questions will be answered was outlined. Finally, a summary of the content of the remainder of this thesis was presented. Chapter 2 provides a comprehensive literature review of dyslexia and its associated symptoms.

Chapter 2 Defining and Classifying Dyslexia, and Identifying the Associated Learning Styles

2.1. Introduction

Over a century ago, a German physician named Dr Kussmaul studied the case of a man of standard intelligence who was unable to learn to read (Selikowitz, 1998; Beaton, 2004). Kussmaul described this problem as *reading blindness*. On November 7, 1896, the British Medical Journal highlighted the case of a 14-year-old intelligent boy who was unable to read, despite having undergone significant learning interventions. They described his condition as *congenital word-blindness* (Beaton, 2004) and this particular case represented the formal record of what today is widely regarded as developmental dyslexia or Specific Learning Difficulty (SpLD) (Morgan, 1896). The term *dyslexia* is formally accredited to a German ophthalmologist named Professor Rudolf Berlin (Aaron et al., 2008).

Since these early research projects, a large number of definitions and perspectives of the phenomenon of dyslexia have emerged as a result of its diverse manifestations. Today, people with dyslexia and their families commonly employ the term dyslexia, while scientists and healthcare professionals typically prefer to describe it as SpLD (Riddick, 1996).

This chapter is organised as follows: Section (2.2) describes some of the various definitions of dyslexia that have emerged in existing theories and research, while Section (2.3) presents an overview of some of the ways in which researchers have attempted to classify dyslexia. To provide an overview of the difficulties that dyslexic learners typically encounter, Section (2.4) discusses some of the common theories of dyslexia that have been published in recent years. Section (2.5) summarises the characteristics that are commonly accepted as being representative of dyslexia. Finally, Section (2.7) examines how dyslexic learners can vary in terms of learning style and provides an overview of existing models that define the learning styles.

2.2. A Definition of Dyslexia

Dyslexia has been the subject of significant research, and various definitions of the condition have emerged over the years. However, despite the numerous studies that have examined dyslexia and dyslexic learners, researchers have yet to agree on a formal definition of dyslexia. Variations in the definitions that are attributed to the condition can be broadly traced back to distinctions in the academic backgrounds of the researchers involved. In particular, differences in scientific approach leading to variations in how dyslexia is conceptualised (Ott, 1997). Many definitions of dyslexia have been proposed since it was first formally acknowledged in the academic and medical world. Ott (1997) described how there have been more than 50 attempts to describe the phenomenon of dyslexia. In fact, The British Dyslexia Association alone has published over ten different definitions (2009). According to Elliott and Place (2012), the various manifestations and symptoms of dyslexia render it difficult to develop a simple means of identifying and assessing it. Some researchers, such as Malatesha and Dougan (1982), go as

far as to argue that dyslexia is technically a group of disorders as opposed to being one single syndrome. Theorists who adopt such a stance claim that this is the reason why it is difficult to reach consensus on a distinct definition of dyslexia.

In 1968, the World Federation of Neurology published one of the first formally recognised definitions of dyslexia. This was as follows:

a disorder in children who, despite conventional classroom experience, fail to attain the language skills of reading, writing and spelling commensurate with their intellectual abilities. (Riddick, 1996)

The definition forwarded by the International Dyslexia Association (IDA) (2002) is more specific:

Dyslexia is a specific learning disability that is neurological in origin. It is characterised by difficulties with accurate and/or fluent word recognition and by poor spelling and decoding abilities. These difficulties typically result from a deficit in the phonological component of language that is often unexpected in relation to other cognitive abilities and the provision of effective classroom instruction. Secondary consequences may include problems in reading comprehension and reduced reading experience that can impede the growth of vocabulary and background knowledge.

However, in 2007, the management board of the British Dyslexia Association developed the following definition of dyslexia:

Dyslexia is a specific learning difficulty that mainly affects the development of literacy and language related skills.

It is likely to be present at birth and to be life-long in its effects. It is characterised by difficulties with phonological processing, rapid naming, working memory, processing speed, and the automatic development of skills that may not match up to an individual's other cognitive abilities.

It tends to be resistant to conventional teaching methods, but its effect can be mitigated by appropriately specific intervention, including the application of information technology and supportive counselling.

While variations in understanding of dyslexia are fully acknowledged, for the purpose of this thesis, an educational perspective of dyslexia will be applied. As such, the definition suggested by the British Dyslexia Association (BDA) will be considered in this research. It is anticipated that this definition represents a strong fit with the objectives of this research because it is not limited to children alone; rather, it has been specifically developed from an educational point of view and covers different types of dyslexia.

The variations in the definitions of dyslexia that have been developed over the years are representative of the fact that relevant authorities are unable to agree on the exact nature of dyslexia. This lack of agreement serves to support the view that dyslexia is complex, and that is interpreted in many different ways. Of the various definitions that have been published, it is the descriptive definitions that are of potentially more use to educators and parents because these offer a deeper understanding of what dyslexia is, as opposed to focusing on what it is not. Along these lines, this work will seek to provide insights into the most common classifications of dyslexia that have emerged and their associated symptoms and type models. Section (2.3) presents a broad overview of contemporary dyslexia classification approaches.

2.3. Dyslexia Classification

While comprehensive attempts have been made to present a system by which dyslexia can be classified, it is very difficult to categorise the condition because there are different types of dyslexia. However, these efforts are not in vain. Classifying dyslexia provides a means by which more detailed insights into dyslexia and the difficulties that people with dyslexia encounter can be developed with the intention of overcoming such difficulties.

Many theorists have developed dyslexia classification approaches that categorise dyslexia in accordance with the symptoms it presents. The classifications that have emerged often overlap, although some are mere representations of the author's own viewpoints.

- In light of the fact that all dyslexic students do not exhibit the same symptoms, Ingram (1964) presented a dyslexia classification system that relates to the symptoms dyslexics exhibit.
- In a bid to identify and distinguish between dyslexia subtypes, Johnson and Myklebust (1967) standardised reading tests and the tests used in reading diagnosis. Their research resulted in the development of two different subtypes of dyslexia that bore resemblance to those suggested by Ingram (1964).
- Boder (1973) also adopted a similar position to Ingram (1964) by categorising dyslexia in accordance with symptoms. She then created a diagnostic screening tool before developing a pattern called the Reading-Spelling Pattern Dysfunction (Boder 1973). Using the qualitative outputs of the application of her tool in combination with the pattern she had identified, she suggested three subtypes of dyslexia.
- Mattis, French and Rapin (1975) took a different approach and based their efforts to understand dyslexia types on the development of an understanding of the cause of dyslexia. Their research examined the intelligence quotient, vision, hearing and academic achievement of 113 different children. The study resulted in the identification of three subtypes of developmental dyslexia.
- Several other researchers have presented alternative classification models that are based on neuropsychological observations. Doehring and Hoshko (1977) identified three subtypes of developmental dyslexia through completing a factor analysis of oral, visual and auditory skills.
- Work by Denckla (1977) resulted in the identification of five subgroups of developmental dyslexia, each of which corresponded with a highlighted deficit.
- Later work by Smith (1982) attempted to identify a dyslexia classification by testing adults and children using the Weschler intelligence. In a similar fashion to Boder, Smith suggested three subtypes of dyslexia (Wiertelak, 2003).

The examination of existing literature on the categorisation of dyslexia highlights that there are broadly two types of dyslexia: developmental and acquired dyslexia. Acquired dyslexia is something that people develop as a result of sustaining neurological damage; for example, suffering a stroke or brain trauma. Acquired dyslexia can, therefore, affect any individual (Mattis, French & Rapin 1975), and certain injuries can result in people developing acquired dyslexia

and, therefore, losing their ability to read and write. According to Carlson (1998), on the other hand, developmental dyslexia is the result of a malfunction in 'normal' development.

As the discussion above outlines, theorists have suggested different dyslexia categorisation systems and methods of sorting dyslexia types according to these systems. However, despite the significant amount of papers that have been published, there is still a distinct lack of understanding of the condition. As such, developing an effective dyslexia categorisation system remains a significant challenge. The literature review reveals that the opinions of experts are solidly divided when it comes to the exact character of dyslexia. In light of the fact that the causes of dyslexia have yet to be understood, it is pertinent for research efforts to concentrate on condition symptom characteristics because consensus, to a certain degree, does exist between experts in this area. As such, this thesis is based on symptoms characteristics as opposed to theoretical definition or classification. To this end, the researcher adapts the approach suggested by Ingram (1964). Ingram identify three categories of dyslexia these are as follows:

(1) *Visuo-spatial difficulties*: people who suffer from this type of dyslexia experience problems distinguishing between letters, syllabus and phrase orders, and find it difficult to reproduce them. Such individuals typically attempt to identify a letter by guesswork as opposed to taking its context into consideration. As such, they experience difficulties identifying letters. People who have visuo-spatial issues may also read works back to front and mix up reversible letters such as "b" and "d", and "p" and "q".

(2) *Speech sound difficulties*: individuals who are diagnosed with this type of dyslexia find it difficult to form sentences and break words into syllables because they experience problems understanding oral language. Frith (1986) described this type of dyslexia as auditory dyslexia. People who experience speech sound difficulties cannot link the visual component of words with the corresponding sound.

(3) *Correlating difficulties*: this type of dyslexia manifests itself predominantly in writing difficulties. People who have correlating difficulties are unable to link an individual letter with the speech sound associated with it, and they experience problems with monosyllabic (single syllable) words in particular.

After establishing a solid understanding of the definition and classification of dyslexia, it is now important to consider existing dyslexia theories to better understand the problems that dyslexic learners encounter.

2.4. Dyslexia Theory

The word "dyslexia" is derived from the Greek words "dys" and "lexia". "Dys" means "difficult" or "abnormal", and "lexia" means "the words of a language" (Ott, 1997). As such, the term dyslexia literally translates to "a difficulty with words". This translation highlights the fact that symptoms of dyslexia are not confined to reading alone. On the contrary, they manifest themselves in a variety of elements of language processing, including concentration, memory, reading, spelling, and writing.

Dyslexia can have an impact on people in a variety of ways and two people who have dyslexia rarely exhibit the same symptoms. As such, the majority of dyslexic students have different needs and, therefore, require different learning experiences. This understanding is at the core of this research. In light of the fact that the needs and difficulties of students with dyslexia may vary from one learner to another, educators should not attempt to apply a one-size-fits-all approach to the design and implementation of learning material for dyslexic students. It is critical both that teachers and the people who develop learning tools for learners with disabilities deal with each student as an individual who has unique learning needs. Dyslexia theory provides comprehensive insights into some of the problems that dyslexic learners encounter, and examines the ways in which these may have an impact on teaching and learning experiences. The following subsection provides an overview of some of the prominent dyslexia theories that are of relevance to this research.

2.4.1 Phonological deficit theory

One of the most important dyslexia theories that have emerged in recent years is that of the phonological deficit theory. This theory states that the issues that people with dyslexia encounter are not related to IQ, but are the result of problems with phonological processing (Snowling, 2004; Shaywitz & Shaywitz, 2005). Researchers who apply the phonological deficit theory are predominantly interested in studying how “the brain codes or ‘represents’ the spoken attributes of the words” (Snowling, 2000).

Verbal language consists of a stream of spoken words that can be understood and committed to memory at a single-word level. However, to write effectively, we are required to master the ability to separate a given word into its constituent phonemes before converting these single units of speech sounds into their written counterparts. As such, learning to read involves mastering the skills needed to translate written forms into phonemes before then blending these to create words. Large amounts of research findings have supported the view that children who have poor phonological awareness will experience literacy problems, and that phonological problems persist into adulthood (Fawcett & Nicolson, 1995). As such, phonological deficit is of particular relevance to this thesis.

Phonological deficit can cause difficulties in verbal short memory, non-word repetition, phonological learning, and naming (Snowling, 2004). Research also suggests that people who have dyslexia exhibit short-term memory problems and that this results in them being unable to recall verbal items to the same extent as a non-dyslexic person of the same age (Snowling, 2004, 2000). This is because, in terms of speech code, verbal material is stored in an individual's short-term memory (Snowling, 2000). Research by Conrad (1964) revealed that people are more likely to make a mistake when letters sound similar to one another (e.g., c, e, g, p, t) than they are when they sound different (f, h, s, w, x) (Snowling, 2000; Miles & Miles, 1999). As such, theorists believe that dyslexia that manifests itself in a deficit in an individual's phonological coding will limit the number of verbal items that an individual can commit to memory.

The fact that dyslexic learners exhibit problems with their phonological representations and that this limits their reading abilities is widely accepted. As such, to help dyslexic students to develop

confidence and become more competent readers, teachers need to identify and employ methods of helping dyslexic students to improve their phonological skills. A number of research studies have been associated with the phonological deficit theory. These are outlined in Table 2.1.

Table 2.1 Experimental research that supports the phonological deficit theory

Author(s)/ Year of Research	Summary of Methodology and Findings
Baddeley, Thomson & Buchanan (1975) in (Miles & Miles, 1999)	• Dyslexic students were asked to recall lists of short, medium and long words as well as non-words. • The biggest issue dyslexic learners encountered was the repetition of non-words. • The researchers attributed the main finding to the fact that the repetition of non-words requires additional phonological processing.
Bradley & Bryant (1983)	• Preliterate six year olds were unable to identify the syllables and phonemes that form words, despite the fact they were able to demonstrate elementary reading and writing skills. • The researchers concluded that there is a causal connection between poor phonological awareness at an early age and impaired literacy later in life.
Paris & Oka (1986)	• This study concluded that students who experience problems reading tend to underestimate their true reading capabilities. They also exhibit lower self-perceptions of social-competence and need motivating by external parties.
Bruck (1992)	• The subjects of this research were older adult dyslexics and controls who were matched according to reading and chronological age. • The findings indicated that any deficit in phonological awareness that is observed in childhood will develop into adulthood, and cannot be alleviated through interventions that aim to improve reading ability. This supports the view that phonological awareness is a core deficit.

While existing studies pertaining to phonemic awareness theory are relatively extensive, they are only capable of explaining the symptoms of the phonological classification of dyslexia. Thus far, we have already established that alternative types of dyslexia exist. However, in order to develop a comprehensive understanding of the diverse symptoms that dyslexic's exhibit, it is important that the alternative theories are considered, be it in combination with the phonemic deficit theory or as stand-alone theories.

2.4.2 Magnocellular theory

People without any impairment do not follow text in a steady, unfaltering fashion. On the contrary, their eyes will flick back and forth across the text, giving them an idea of the written text that is ahead of them. Dyslexic learners tend to exhibit a reduced sensitivity to motion stimuli, and this indicates that the visual magnocellular system of such individuals may be damaged (Stein, 2001).

The visual magnocellular system is a critical element of the nervous system that allows a living organism to see by facilitating the process by which key signals are passed from the eye to the rest of the brain. In some research studies, dyslexics have described how words can sometimes appear to wobble as they are reading. According to Stein (2001), such visual symptoms result

from deficits in the visual magnocellular system. The role that cerebellar functions play in the magnocellular hypothesis is related to the fact that many dyslexics experience problems keeping good time and are often late or forget appointments altogether (Scott, 2004) and that the cerebellum itself contains magnocells (Reid & Fawcett, 2004). Despite having many supporters, it should be noted that the Magnocellular theory had recently received much criticism from many experts (Johannes et al., 1996; Skottun, 2000).

2.4.3 Cerebellar deficit theory

In more recent decades, alongside phonological and magnocellular theories, cerebellar deficit theory has emerged as a popular means by which scientists attempt to explain the causal effects of dyslexia (Nicolson & Fawcett, 1999; 2001). Traditionally, the cerebellum has been associated with motor skills and coordination. However, research by Leiner, Leiner and Dow (1989, 1993) concluded that it also plays a crucial role in the development of “language dexterity” (cited in Nicolson & Fawcett, 1999). Nicolson and Fawcett (1999; 2001) postulated that dyslexia is the result of abnormal cerebellar function, and specified that problems with writing, spelling and reading can be caused by direct and indirect cerebellar causation. Table 2.2 provides a summary of existing research studies that support the notion that cerebellar deficit theory plays a role in the development of dyslexia symptoms.

Table 2.2 Experimental research that supports the phonological deficit theory

Author(s)/ Year of Research	Summary of Methodology and Findings
Rae et al. (1998)	• Anti-motion-sickness medications improve reading performance as these drugs act as “cerebellar-vestibular stabilisers”.
Finch, Nicolson & Fawcett (2002)	• They examined the brains of four dyslexic adults. • The findings revealed that the brains of dyslexics exhibited significant differences in the posterior cerebellar cortex. Both the posterior and anterior lobe of the dyslexic brains was larger and contained fewer Purkinje cells. • The researchers concluded that this research produced direct neuroanatomical evidence of the link between cerebellar abnormalities and dyslexia.
Brookes & Stirling (2005)	• The findings of this study supported the earlier work by Nicolson & Fawcett (2002), and the researchers reached similar conclusions that there is a link between reading ability and extent of cerebellar normality.

2.4.4 Summary of dyslexia theory

A significant amount of the research into dyslexia described above studied children and a large number of theorists have applied a broad assumption that core deficits will persist from childhood into adulthood. There is, indeed, evidence to support claims that issues with phonological awareness (see Section 2.1), and working memory for phonological items (see Section 2.1), can continue through to adulthood. As such, dyslexic adults may have an impaired ability to master key skills, including timekeeping and organisational skills, may experience issues with the transient visual system, and may exhibit problems mastering intricate skills as a result of inefficient automatisisation (see Section 2.4.3). In many regards, adults are at an advantage to children because they have had an opportunity to develop compensation

strategies as they age. These strategies will vary from person to person in accordance with the person's strengths, weaknesses and experience. As a result of this, dyslexic adults often exhibit a balance of skills that differs from one another and to those of non-dyslexic adults (McLoughlin et al., 1994; Gilroy & Miles, 1995). Such differences in coping mechanisms may result in adult dyslexics adopting more unconventional ways of executing tasks and, as such, the learning approaches they employ will vary more significantly.

While the above examination of the most prominent theories of dyslexia is useful, these theories only go as far as to explain the symptoms that patients who are suffering from the phonological, cerebellar and magnocellular classifications of dyslexia. To enhance the value and applicability of these theories, there is a requirement to consider them in combination with one another with the intention of developing a broader view of the diverse symptoms that dyslexic learners may exhibit. It is anticipated that such a review will provide valuable insights that are of use when developing the dyslexia symptoms and signs model that is proposed as part of this research (Section 5.2.1). The next section provides a broad overview of the dyslexia signs and symptoms that have been described in existing dyslexia theory.

2.5. Signs and Symptoms of Dyslexia

Dyslexia can affect people in multiple ways. It is very rare for two people who have dyslexia to exhibit the same symptoms. This, coupled with the fact that dyslexic students typically encounter different learning experiences throughout the course of their lives, entails that dyslexic students have different needs. This basic understanding forms the basis of this study. In light of the fact that the needs and difficulties of students with dyslexia may vary from one learner to another, educators should not attempt to apply a one-size-fits-all approach to the design and implementation of learning material for dyslexic students. It is critical that teachers and the people who develop learning tools for learners with disabilities, deal with each student as an individual who has unique learning needs. However, in order to achieve this, it is important to consider existing theories that identify and describe the potential problems that characterise dyslexic people.

Dyscalculia is usually perceived of as a specific learning difficulty for mathematics. Developmental Dyscalculia has strong association with other developmental disorders such as dyslexia (BDA, 2009). Therefore, in this research we include difficulty for mathematics as one of dyslexia symptoms. Publications by the British Dyslexia Association, 2009; Homsby, 1996; and Thomson and Watkins 1998 provide a comprehensive overview of the key characteristics that are readily accepted as being the standard problems that dyslexic subjects exhibit. The characteristics that are deemed to be typical of dyslexic students can be categorised according to five groups. Each of these and their corresponding manifestations is outlined below.

1) Problems with Reading:

- Hesitate while reading.
- Experience anxiety at the prospect of reading aloud without an opportunity to prepare.
- Demonstrate a need to reread a given text many times in order to grasp and retain the meaning.

- Can typically identify mistakes if text is read aloud, but cannot see them when they are visually pointed out.
- Find it difficult to duplicate work or to copy something that is displayed on the board.
- Exhibit Meares/Irlen syndrome when asked to read words such as dance, float, blue and swirl.
- Incorrectly read text and struggle to understand the meaning as a result.

2) Problems with Writing:

- Despite opportunities to practice writing skills, exhibit a problem structuring sentences, punctuating written text and organising written work.
- Use unexpected and unpredictable approaches to spelling words.
- Exhibit a perceptible difference between written and verbal skills.
- Experience difficulties translating ideas into written form.
- Have a tendency to make mistakes with the order of letters when spelling a word out.
- Produce dysphonetic spelling errors. ("Bump" as "bunt") and phonetic spelling errors ("Knock as "Nock").
- Commonly confuse letters that are symmetrically similar (e.g. "p" and "q", "b" and "d").
- Regularly confuse letters that are similar in shape (e.g. "m" and "n" and "ow" and "un").
- Frequently mistakenly reverse words (e.g. "saw" and "was").

3) Speaking:

- Exhibit a perceptible difference between written and verbal abilities.
- Regularly pronounce words incorrectly, even when very familiar with them.

4) Memory (Short-term memory deficit):

- Experience problems committing facts, new names and new terms to memory.
- Find it challenging to match names to objects and people.
- Often recall sequences incorrectly.
- Have difficulties recollecting sentence structure. For example, when asked to repeat a sentence word-for-word, dyslexics often miss words out completely or change their order. However, they will retain the meaning of the original sentence.

5) Mathematics

- Exhibit difficulties performing calculations that consist of multiple parts.
- Have problems recollecting mathematical facts.
- Tend to have a poor ability to differentiate between mathematical symbols such as + x.
- Often find it difficult to understand mathematical language such as ratios.
- Have poor understanding of mathematical theories such as negative numbers.

From henceforth, any reference to dyslexia type or dyslexia difficulties in this thesis relates to one or more of the five types of dyslexia symptoms described above and their accompanying manifestations. Section (2.6) will revisit the key theories discussed in this section and will examine the implications they have for the objectives of this thesis.

2.6. Key Findings of Dyslexia Research and Their Underlying Implications

The theories discussed in Section (2.4) provided a solid grounding in existing research and understanding of dyslexia and include a review of dyslexia classification and the associated key concepts and symptoms. This will form the basis of the discussion presented in this section. Before proceeding with this discussion, it is worth reviewing the key findings thus far and the implications that they have for this work:

- a) There is no formal consensus on the nature of dyslexia. As such, there is no single classification system or universally accepted theory of dyslexia.
- b) While classification and symptoms cannot be definitively determined at this stage, there is some consensus on condition symptom characteristics. As such, further research efforts should concentrate on identifying and understanding these characteristics (see Section 5.2.1)
- c) The models of dyslexia that emerge as a result of understanding condition symptom characteristics should be based on suitable symptom alleviation strategies that are independent of any theoretical models (see Section 5.2.2)

The following sections will define the concept of learning style and will identify the existing learning style models that have been examined in the literature. This review will help the researcher to develop a more solid understanding of the relationship between dyslexia and learning style.

2.7. Learning Styles

Learning is a fundamental element of people's everyday lives. Learning experiences can take the form of our interactions with others, the repetition of a task, a work-based task, through attending an educational establishment, etc. Not everyone learns in the same way, and even people who are considered to have a similar standard of abilities or proficiency will exhibit different learning styles. This does not necessarily mean that some students are better than others; it means that students are different from one another.

2.7.1 A definition of learning styles

According to Keefe (1979), learning styles can be defined as the "composite of characteristic cognitive, affective, and physiological factors that serve as relatively stable indicators of how a learner perceives, interacts with, and responds to the learning environment" (p.30). As such, the term learning style defines the preferred method by which an individual perceives, processes and responds to information within a given learning environment.

An alternative definition was proposed by Mortimore (2003) as follows: "Learning style is the type of strategy used when an individual's cognitive style is applied to a learning situation" (p. 7). Learning style is distinct from cognitive style. Cognitive style refers to the way in which individuals process information, while learning style describes the strategies that a student uses to decipher information and commit it to memory (Mortimore, 2003; Reid, 2005). Standardised

tests, interviews or observation methods can be employed to identify learning styles. Various research studies to date have resulted in the development of more than 100 different instruments that can be used to identify learning styles (Mortimore, 2003; Reid, 2005; Coffield et al., 2004). These consist of standardised tests, interviews and/or observations. Section (2.7.4) provides a comprehensive overview of the learning style models that are more commonly employed for the purposes of developing adaptive e-learning systems.

2.7.2 Research on learning styles

Web-based educational systems can represent very effective methods of delivering learning experiences to students because they can be widely distributed and can be readily accessed, regardless of location or time. However, the current offerings are usually relatively standard without any differentiation; as such, they are not necessarily pedagogically beneficial if each individual student's level of knowledge and preferred learning style is unknown. Existing research into learning styles indicates that incorporating an understanding of a student's learning style in the instruction provided enhances the success of learning experiences (Dwyer, 1998). As such, creating learning materials that can be adapted to a student's preferred learning style represents a powerful means of personalising education that delivers optimal results. Such a personalisation has the potential to help students to develop a more comprehensive understanding of the topics under consideration and to reduce the time it takes to teach them new concepts and skills. If teaching methods take into consideration the fact that every learner has distinct learning preferences or a set learning style (Coffield et al., 2004), an enhanced set of resources can be developed that appeals to that learning style. This resources can, therefore, help the learner to develop a more readily develop a comprehensive understanding of a subject. Multiple studies have demonstrated that a learner's performance improves when teaching experiences are explicitly aligned with his or her learning style (Doyle, 2002; Mortimore, 2003; Reid, 2005). For example, in one study, Brooks and Weeks (cited in Mortimore, 2003) compared different approaches to teaching spelling. Their research concluded that learning experiences that were aligned with a student's cognitive style more effectively enhanced his or her spelling skills.

2.7.3 Existing understanding of learning styles and dyslexia

Research reveals that the learning styles of dyslexic students are different to those of non-dyslexics (Mortimore, 2003). Furthermore, learning experiences that are aligned with a student's preferred learning style are more likely to be effective and will increase the self-esteem of dyslexic students.

Exley (2003) supported the position outlined in Section (2.7.2). She found that when lessons were aligned with students' preferred learning styles, the students' level of performance and attainment increased. Morgan and Klein (2002) outlined how dyslexic learners exhibit very different learning approaches to non-dyslexics and, therefore, require different learning experiences that focus on more practical and relevant skills. All adults need to have the ability to complete the administrative tasks that are associated with everyday life, such as completing application forms. However, each learner has distinct needs that are dictated by their strengths

and weaknesses. Teachers need to develop methods by which learners can identify and understand their learning style and, subsequently, adapt it to their needs. This understanding will allow learners to improve the effectiveness of their learning and identify suitable methods of achieving their objectives.

Dyslexic adults often encounter feelings of frustration in the classroom setting because the lessons they are taught are not aligned with their preferred learning style. Although remedial help is sometimes available in the learning setting, this is not always effective because it is not explicitly adjusted so that it aligns with the learning style of the individual student. In one study, Morgan and Klein (2002) described a case involving a learner named Michael. While Michael did receive assistance at school to help him to advance his skills, this assistance took the form of conventional teaching methods and was, therefore, unsuccessful. Research by Scott (2004), proved that multisensory teaching is beneficial for dyslexic students (Scott, 2004). Furthermore, learning interventions that concentrate on addressing students' weaknesses are not as effective as those that focus on their strengths.

In light of the above, what constitutes an effective learning intervention in terms of content and mode of delivery differs from dyslexic and non-dyslexic and from dyslexic to dyslexic. It is, therefore, crucial that differences in learning style are taken into consideration in adaptive educational programmes, and that the learner has an opportunity to influence how such a programme is delivered. Allowing students some degree of control over the style of learning and the material presented enhances the likelihood that the information presented will be relevant to them and is in a form that they can understand. In addition to facilitating and enhancing the learning process, this will also increase dyslexic students' motivation to learn, something that is often lacking in members of this student population.

2.7.4 Learning styles Models

Learning style models can be employed to help students to identify their preferred learning styles. The majority of models typically involve a questionnaire that prompts students to provide key information that can be used to identify how they prefer to learn by selecting responses that are more closely aligned with their preferences.

As stated in Section (2.7.1), existing literature has described over 100 different learning style models. Furthermore, there is a lack of agreement as to the extent to which the uses of learning style models are beneficial to students (Coffield et al., 2004). The controversial nature of learning style models can be attributed to the fact that a large number of instruments are available. There is also a lack of agreement on the validity and reliability of the instruments used, and even lack of consensus on the extent to which aligning teaching interventions with a learning style is effective (Mortimore, 2005). According to Coffield et al. (2004), although it is very common for teachers to employ questionnaires to identify students' learning styles, the outputs of these assessment exercises are very frequently forgotten about afterwards and, as such, their benefits are questionable. Coffield believes that it is more effective for teachers to develop a flexible inventory of teaching approaches that they can then apply and adjust according to the situation that arises. They also believe that the development of a reliable and valid approach that accurately measures learning styles and approaches to learning could

represent a tool that encourages self-development, not only by providing detailed insights into how individuals learn, but also by helping them to enrich their learning.

2.7.4.1 Kolb's learning style model

The Learning Style Inventory (LSI) is one of the most renowned and widely employed learning style models. It is based on Kolb's learning styles, which, in turn, was developed according to experiential learning theory, as explained in the book *Experiential Learning* (Kolb, 1984). Kolb describes how the LSI incorporates two main dimensions: abstract/concrete and active/reflective. In addition to the LSI, Kolb's experiential theory (Kolb, 1984) describes how learning is a chronological progression of four stages. These are outlined in Table 2.3.

Table 2.3 The four stages of Kolb's experiential learning cycle

Stages	Description	Examples of Activities
Concrete experience	Learners require practical, concrete experiences to learn something. Simply watching a phenomenon or reading about it does not facilitate effective learning. To enhance learning, students need to actually engage in the activity.	Problem solving, discussion or team games
Reflective observation	Having experienced something, the learner reflects on what he or she learned during the first stage of the learning process and constructs his or her own theory as to what this information may mean. This stage involves asking questions and communicating with others.	Ask for observation or give feedback to other participants
Abstract conceptualisation	Abstract conceptualisation is the process by which a learner makes sense of what he or she has learned so far and attempts to identify and understand the relationships between key facts. At this stage, the learner draws comparisons between what they have learned and their previous understanding. They may also consult theory and read textbooks to frame and explain events.	Present models, give theories or give facts.
Active experimentation	During the final stage of the learning cycle, the learner puts what he or she has learned into practice. Through planning, the learner applies the newly acquired understanding to predict what will happen next or what modifications need to be made to refine or revise the way a task is completed.	Case studies. Role play.

According to Kolb's model, the ideal learning experience effectively employs all four of these modes in response to situational demands. He also argued that individuals who employ the four approaches tend to develop strengths in one experience-grasping approach and one experience-transforming approach. Kolb identified learning styles that each places the learner on a line between concrete experience and abstract conceptualisation, and active experimentation and reflective observation. These learning styles are as follows:

1. Accommodators: Concrete Experience + Active Experiment.
2. Converger: Abstract Conceptualisation + Active Experiment.
3. Diverger: Concrete Experience + Reflective Observation.
4. Assimilator: Abstract Conceptualisation + Reflective Observation.

The LSI emerged as an output of Kolb's experiential learning model and is now commonly utilised to determine an individual's learning style. Through applying the LSI, educators can identify whether a student has a preference for one of the four learning styles: Accommodating,

Converging, Diverging and Assimilating, and can then adjust learning experiences according to the Experiential Learning Theory model.

2.7.4.2 Peter Honey and Alan Mumford's model

Honey and Mumford (1982) developed their own learning style model which called the Learning Style Questionnaire (LSQ), which is directly derived from Kolb's (1984) theory. After employing Kolb's LSI instrument (described in Section 2.7.4.1) to study managerial learning, Honey and Mumford found that Kolb's LSI had low face validity with the management population. To overcome this, they studied existing methods by which differences in learning preferences were identified (Coffield et al., 2004) and subsequently developed the LSQ. The main difference between the LSQ and the LSI was that the LSQ indirectly, as opposed to directly, assessed people's learning preferences. Specifically, Honey and Mumford developed a questionnaire that examined general behavioural tendencies and they based this approach on the reasoning that the majority of people do not consciously reflect how they really learn. Honey and Mumford divided their model into four types of learning style preferences: activists, reflectors, theorists and pragmatists. Table 2.4 summarises these four learning styles.

Table 2.4 An overview of Honey and Mumford's learning styles model

Styles	Description	Examples of Activities
Activists	Can immediately do something when exposed to new experiences and the opportunity to work with others on team-based tasks. Are ready and willing to act and prefer to be actively involved in a task.	Problem solving, group discussions, role plays.
Reflectors	Can observe, review and think about what is happening. Have strong data analysis skills and prefer to study data.	Observing activities, paired discussions, questionnaires.
Theorists	Can study theories, models, concepts, stories, etc. Frequently ask questions and engage in analysis and synthesis. Have strong ability to draw conclusions.	Models, statistics, stories.
Pragmatists	Can apply new information to a real-world problem. Prefer practical things and are strong planners.	Case studies, discussion, problem solving.

2.7.4.3 Felder-Silverman learning style model

The Felder-Silverman learning style dimensions are neither original nor comprehensive. For example, the first dimension sensing/intuition is one of four dimensions of a well-known model based on Jung's theory of psychological types (Lawrence, 1993). The fourth dimension active/reflective processing is a component of a learning style model developed by Kolb (1984) (Section 2.7.4.1). The other dimensions of these two models and dimensions of other models (Dunn et al. 1981) also play important roles in determining how a student receives and processes information.

Felder and Silverman (Felder & Silverman, 1988) described how learners utilise different mechanisms to send, receive and process information; as such, they have different learning approaches. They developed the Felder-Silverman learning style model (Felder & Silverman, 1988), which rates students' learning styles according to a scale that consists of four dimensions see (Appendix A). They determined a learner's learning style through the use of a questionnaire that was developed in 1991 by Richard Felder and Barbara Soloman (Felder &

Soloman, 1991). This questionnaire is made up of 44 questions that are designed to categorise a learning style across four dimensions. Of the various learning models that are available, the Felder-Silverman Model is the only model that references the sensing/intuitive dimensions of learning. Table 2.5 summarises the dimensions of learning that are present in the Felder-Silverman model.

Table 2.5 Felder-Silverman learning styles dimensions

Styles	Description	Examples of Activities
Active/Reflective	Active learners learn by completing practical tasks in the external world with information, while reflective learners tend to carefully contemplate information before acting. Reflective learners are typically more interested in accessing the opinions of other learners and professionals than they are of engaging in the activities.	Active: group discussion. Reflective: Observing activities.
Sensing/Intuitive	Sensing and intuition represent the two main means by which people perceive the world. Sensing learners prefer to observing and gather data by using the senses, while intuitive learners tend to perceive data indirectly by way of the unconscious and imagination.	Sensor: Facts, Laboratory work. Intuitive: Abstract, mathematical formulations.
Visual/Verbal	Visual learners prefer to learn through visual representations such as images, demonstrations, films, time lines, flow charts and diagrams. On the contrary, verbal learners tend to prefer to be verbally taught through spoken explanations.	Visual: Diagram, picture, flowcharts. Verbal: Verbal explanation, verbal demonstration.
Sequential/Global	Sequential learners tend to prefer learning experiences that are implemented via linear steps, and they typically solve problems by following linear reasoning patterns. These types of learners have the ability to use materials providing they have a partial or superficial understanding of them. Global learners, on the other hand, tend to feel out-of-step and develop an understanding of materials in an arbitrary fashion. They often make intuitive jumps when solving problems and subsequently find it difficult to explain how they arrived at the solutions.	Sequential: flowchart, linear steps Global: divergent thinking, synthesis.

2.7.5 Learning styles recommendations

A student's learning style is reflective of his or her strengths and preferences. A large number of studies have highlighted the importance of identifying students' learning styles in order to identify the most appropriate learning strategies (Mortimore, 2005; Reid 2005). Research has also demonstrated that many students with dyslexia believe that explicitly understanding their learning styles has helped them to better understand the ways in which they learn and to develop strategies that make the most of their strengths while effectively overcoming their weaknesses (Cooper, 2006). The models described above have been applied and tested within a number of different e-learning systems. They have also been employed to detect, store and classify the student according to their learning styles, and provide them with adapted educational materials that are specifically adjusted to their individual learning preferences. Table 2.6 provides an overview of the key learning styles models and the e-learning systems in which they have been applied.

Table 2.6: Learning style model employed in e-learning systems

Learning Styles Model	E-Learning Systems
Kolb (1984)	MOT (Stash, Cristea & De Bra, 2004)
Honey & Mumford (1982)	AHA! (De Bra & Stash, 2002)
	INSPIRE (Papanikolaou, Grigoriadou, & Kornilaki, 2003)
Felder & Silverman (1988)	CS-383 (Carver, Howard, & Lane, 1999)
	ABITS (Capuano, Marsella, & Salerno, 2000)
	LSAS (Bajraktarevic, Hall, & Fullick, 2003)
	TANGOW (Paredes & Rodriguez, 2004)
	WHURLE-HM (Brown, Stewart, & Brailsford 2006)
	MOODLE (Graf, Lin, & Kinshuk, 2005)

Section (2.7.4) provided an overview of the prominent learning style models that have been developed and employed to identify students' learning styles. Having reviewed the multiple models that have been used to identify students' learning styles, in both electronic and paper form, a model was selected for further exploration in this thesis. Significant effort was invested as well in ensuring that the dyslexic participants did not experience any of the difficulties reported by Disability Right Advocate (DRA) when completing assessments that involved multiple-choice exercises (DRA, 2001). Therefore, the model selected for use in this research needed to meet the following inclusion criteria (Mortimore, 2005; Reid 2005; DRA, 2001; Beacham & Alty, 2006; Özyurt & Özyurt, 2015):

- (a) Assessments are relatively quick and straightforward to complete and would not induce fatigue;
- (b) were aimed at adults;
- (c) there was no risk that the assessments could be skewed by erroneous answers from inappropriate questions;
- (d) could account for an appropriate number of learner types;
- (e) are free and available online; and
- (f) employ a web-based model that allows students to complete the assessment at a time and place to suit them.

The Felder-Silverman Learning Model was selected for application in this research for a number of reasons. It met all of the inclusion criteria outlined above, it has been successfully used to test dyslexic students (Beacham & Alty, 2003), and it has been employed in a digital context and validated with adult university students. Zywno (2003) published a study that examined the validity and reliability of the Felder-Silverman Learning Model and assessed how students interacted and used the model. Moreover, Graf, Lin and Kinshuk (2005) investigated how different learning styles interact with one another, in particular the Felder-Silverman learning style model, and how they influenced one of the dyslexia deficits: working memory capacity.

2.8. Chapter Two Summary

It was over a 100 years ago that Dr Kussmaul first recorded the phenomenon of dyslexia and some of the symptoms associated with it. Since this condition first started to be formally recognised, a number of different terms have evolved to describe it. Despite the numerous

research studies that have been conducted, there remains no internationally recognised definition of dyslexia. However, at present, the definitions forwarded by the BDA and the IDA remain those that are most commonly used to assist specialists and educators to diagnose dyslexia. This chapter presented some of the various definitions of dyslexia that have emerged. Furthermore, it comprehensively reviewed existing theories of dyslexia and the methods that are commonly employed to classify it.

This chapter presented a comparative analysis of some of the most prominent learning style models that are available and assessed the extent to which these met the research objectives of this thesis. One model was subsequently selected, the Felder-Silverman learning style model (LSI), as the tool that will be incorporated into the Dyslexia Adaptive E-Learning System that is the subject of this thesis. The next chapter will describe the use of adaptive e-learning systems to provide different approaches to personalising learning experiences.

Chapter 3 Existing Literature on Adaptive Educational Systems

3.1. Introduction

Adaptive e-learning has the potential to enhance the effectiveness of e-learning systems by delivering information that is tailored to an individual's learning style, knowledge and needs through the use of a tailored linkage structure. Every learner has unique learning characteristics and requirements. As such, standard educational settings may not meet the needs of all learners and may put some people at a disadvantage. Adaptive e-Learning systems aim to address these challenges by assessing a learner's capability and preferred learning style, hence using this information to customise the learning path and learning experiences to that learner. This research is interested in the development of adaptive e-learning systems that can benefit dyslexic learners. As such, it examines how an adaptive system can use knowledge of a learner's dyslexia type to optimise learning outcomes.

Section (3.2) of this chapter presents an overview of learning management systems that are currently available, while Section (3.3) examines adaptive hypermedia, the different methods of adaptivity and how these can be employed within e-learning systems is presented in Section (3.3.2). Section (0) reviews some of the semantic modelling systems that use semantic web technologies, in particular ontology, to deliver personalised e-learning systems. It concludes by describing a number of surveys that have examined the effectiveness of the personalised e-learning systems that are currently on offer for students in general (Section 3.6) and students with dyslexia specifically (Section 3.6.2).

3.2. Learning Management System (LMS)

LMS are hypermedia systems that automate the fundamental organisation of teaching and learning experiences. Also known as virtual learning environments, online learning environments, course management systems or e-learning platforms, LMS can be used for a variety of purposes. For example, they can be employed to generate structured lessons, tests and/or surveys, and to distribute educational multimedia resources and documents, among other things. They can also support the teaching/instruction process through enhancing the educational resources, tools and services that teachers use to facilitate student's learning. Moreover, some LMS may include competencies management, planning sessions, certification controls, accessibility characteristics, e-learning standards, metadata description, etc. There are many commercial LMS in use in the educational setting. These include commercial software such Blackboard,² WBTmanager,³ Intralearn,⁴ Fronter,⁵ and Desire2Learn.⁶ However, in recent

² <http://www.blackboard.com/>

³ <http://www.wbtmanager.com/>

⁴ <http://www.intralearn.com/>

⁵ <https://eng.fronter.com/>

⁶ <http://www.desire2learn.com>

years, more and more LMS have started to become available under the open source philosophy. Such LMS offerings include dotLRN,⁷ ATutor,⁸ Moodle,⁹ Claroline,¹⁰ and OLAT.¹¹ It has become extremely common for teachers to deploy LMS within e-learning experiences and such systems are being increasingly used to improve and supplement traditional face-to-face learning and distance learning processes. A number of factors have contributed to the rising popularity of LMS and to answer why LMS are being increasingly used (Zenha-Reia & Carvalho, 2006; Yildirim et al., 2004; Cigdem & Topcu, 2015):

- They provide valuable resources that increase the level of interaction between students and teachers and enhance student participation in learning.
- They help teachers and administrators to create, administer, and manage online courses.
- They encourage and support students to achieve learning objectives through a range of different shared resources and activities.
- They combine key learning materials with a diverse range of educational resources including games and quizzes, real-time chats, participation in forums, assignments, wikis, etc.
- They make use of a wide variety of multimedia learning resources including text, photographs images, video clips, audio clips, links to online content, slides, music, etc.
- Users can interact with them both individually and collaboratively through a wide range of Internet and online user interfaces.
- In addition to being employed in the classroom setting, they are also commonly used by educational institutions and Technology-enhanced Learning (TeL) communities for research purposes.

One specific feature of LMS that has captured the attention of TeL researchers is the fact that these systems incorporate the ability to deliver flexible learning environments for learners, be it individuals or groups, by extending the time and place coordinates.

While LMS systems clearly hold a lot of value, from a pedagogical perspective, theorists have raised many questions about adapting and personalising learning environments. For example, Santally and Senteni (2005) challenged the commonly accepted notion that employing online resources as a type of distributed medium for learning materials adds meaningful value to a student's learning process. Arguments such as this introduced the need for adaptive hypermedia systems (AHS) that are more directly tailored to each individual user's learning style, interests, needs, and level of knowledge. Unlike more standard "one-size-fits-all" approaches to teaching and learning, AHS enriches learning experiences by tailoring them to an individual's needs.

A large number of LMS are available and they offer comparable features and functionality. However, there are some differences between them in terms of their flexibility and ability to

⁷ [http:// www.dotlrn.org/index.html](http://www.dotlrn.org/index.html)

⁸ <http://atutor.ca/>

⁹ <https://moodle.org/>

¹⁰ <http://www.claroline.net>

¹¹ <http://www.OLAT.com/>

integrate new features that enhance their ability to adapt to the individual learning needs of the students who use them (Graf, Lin & Kinshuk, 2005). Al-Ajlan and Zedan (2008) examined and compared a number of LMS with the intention of determining which of them offered a suitable level of adaptivity and personalisation. Their research concluded that, to be effective as a personalised learning tool, LMS must meet a distinct set of criteria. These are outlined below (Al-Ajlan & Zedan 2008):

- 1) Available in multiple languages,
- 2) can operate on various operating systems,
- 3) can be applied to a range of educational contexts,
- 4) can be modified, updated, and supported by developers,
- 5) can be maintained by an active community of people,
- 6) incorporates and presents basic learning tools,
- 7) is accompanied by clear and understandable documentation.

In their research (Al-Ajlan & Zedan 2008) established that, of the offerings that are currently available, Moodle was the highest rated LMS in terms of adaptation. However, all the systems assessed provided some degree of the required functionality including basic learning functionality; communicative, practical, participative learning tools; and appropriate support and management mechanisms, including administrative functionality, content development tools and course delivery applications. In light of the fact that traditional e-learning systems do not have sufficient functionality to deliver adaptable and personalised learning experiences, there is a need for the development of adaptive hypermedia systems. These will be discussed in Section (3.3).

3.3. Adaptive Hypermedia System (AHS)

A hypermedia system is a multimedia system that extends hypertext by incorporating graphics, images, video, audio and hyperlinks, all of which enhance user interaction. Brusilovsky (1996) defined adaptive hypermedia systems as software applications that develop a user model that incorporates some of the user's key features and subsequently uses this model to modify various elements of the system to align with this user model. To be considered an AHS, a system must fulfil three criteria: it should be a hypermedia system; it should operate through the use of a user model; and it should be capable of adapting the hypermedia to the user model. Essentially, an AHS will look different to different users.

When applied within the educational setting, the aim of AHS is to present learning systems that effectively overcome some of the limitations that are associated with more traditional e-learning systems. As such, AHS are capable of achieving learning objectives that would otherwise be impossible through the use of a standard e-learning approach. One of the major reasons for this is that e-learning systems present standardised learning content that treats all users as the same, regardless of their existing knowledge, capabilities or learning style. The flexible nature of AHS means that they represent a viable alternative to the classic "one-size-fits-all" approach to technology interventions by presenting learning experiences that are aligned with the user's interests, learning goals, learning needs and existing knowledge (Chen & Magoulas, 2005).

Learners can acquire and construct knowledge in a variety of ways (Brusilovsky, 1996). What is simple for one learner may represent a significant challenge for another. For example, one given task may seem extremely unclear to a dyslexic student while being easy for a non-dyslexic learner. According to Heift and Nicholson (2001), adaptive systems have been specifically designed to meet the diverse requirements of students with varied learning needs, knowledge and learning styles by employing user-adaptive systems to respond to user performance and the choices a user makes while interacting with the system.

One of the problems with AHS that is commonly cited is that users may become disorientated when interacting with them. During the process of seeking relevant information, they can often experience cognitive overload and lose their sense of location. One of the ways in which the more effective AHS attempt to prevent such disorientation is through the application of simple navigation structures combined with personalised presentation. This is made possible through the construction of a comprehensive model that incorporates the user's needs, personal preferences and existing knowledge and skills. Through this model, the system adapts the hypermedia pages that are presented so that they complement the needs and learning abilities of the user (Brusilovsky, 1996).

The level of adaptation that is integrated into AHS systems covers a spectrum of adaptation that ranges from adaptive to adaptable (Oppermann & Rasher, 1997). In the case of adaptable systems, users have the ability to modify key parameters for themselves and the system then adapts how it behaves accordingly. This takes into consideration the fact that an adaptive system may misinterpret a user's needs or preferences; as such, it provides the learner with some degree of control over the level of adaptivity. In contrast, the user has much less input into adaptive systems and these systems automatically adjust in accordance with the assumptions about the user's needs that the system has formed (Fink et al., 1996). Some researchers believe that the ideal system will balance both adaptive and adaptable functionality to deliver the benefits of each and, therefore, achieve an optimal approach to delivering personalised learning experiences.

3.3.1 Adaptive educational hypermedia systems (AEHS)

Adaptive Educational Hypermedia Systems (AEHS) incorporate all the main features of AHS while also offering a distinct educational aspect. In terms of the criteria set out by Brusilovsky (1996), AEHS rely on adaptation process that consists of three aspects: a hypermedia system, a learner model (i.e., a user model) and an adaptive factor. Figure 3.1 illustrates these three components.

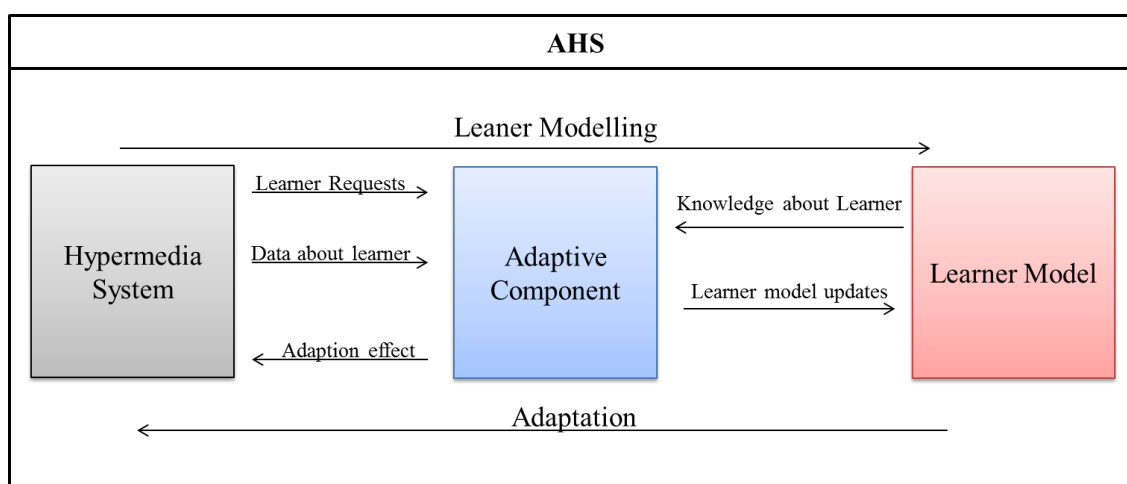


Figure 3.1 Simple scheme of an Adaptive Hypermedia System (AHS), (Brusilovsky 1996)

- The hypermedia system: This collates information and data about the learner that is supplied to the system (as is the case with an adaptable system) or system inferred as a result of the interaction with the learner (as is the case with the adaptive system). It also incorporates functionality and other visible elements that can be adapted.
- The learner model, which is generated through the system-acquired data or the information the user provides to the hypermedia system, assesses a learner's current status against a set of pre-defined learner characteristics.
- The adaptive component. This aspect of the system uses the learner model that has been generated to modify the functionalities or visible aspects of the hypermedia system. An adaptive component in the form of an adaption/decision engine is used to carry out this aspect of the process as follows: 1) information about the learner is received (i.e., learner requests, data about learner, and knowledge about learner), 2) the information about the learner is automatically processed, and 3) an adaption result/decision (i.e., adaption effect) is generated and this is subsequently used to generate the learner model updates.

Brusilovsky (1996) specifies that the most important feature of an AEHS is the functionality to perform hypermedia adaptation that utilises learner modelling. In order to achieve this and offer a learner who interactions with the system what he or she needs (for example, support, prompts, differentiated activities and materials, etc.) in accordance with his or her characteristics in a specific area, it is fundamental that the system generates data relating to the user's needs. The AEHS (Brusilovsky, 2001) offerings that have emerged can be considered to be superior to standard LMS because they specifically incorporate functionality that allows the personalisation of the educational experience. Regular LMS, such as the very popular Moodle and Blackboard, deliver exactly the same learning experience to every student that interacts with them and, as such, they are not adaptive. Pedagogical research has demonstrated that different students have different learning approaches (Coffield et al., 2004). This is something that the majority of modern-day teachers are aware of and differentiation features strongly in many of the lesson plans that are used in contemporary classrooms: if teachers observe that a learner is struggling with a subject, they will modify the way the material is communicated in an effort to use an approach that the learner can understand. Educational systems, be they in the physical or

virtual setting, that successfully adapt a presentation to an individual in accordance with the needs of every learner aim to enhance the efficiency and effectiveness of the learning process. The basic premise is that if every learner has a unique learning preference or learning style (Coffield et al., 2004) and the resources that are utilised to teach that learner are subsequently adapted in line with that particular style, not only will the student's learning be improved, he or she will develop a more comprehensive and solid understanding and knowledge of the given material. The main purpose of AEHS is to overcome some of the inflexibility associated with LMS methods. Examples of systems that have successfully achieved this are My Online Teacher (MOT) (Foss & Cristea, 2010), AHA! (De Bra & Stash, 2002), and WHURLE (Moore et al., 2001).

3.3.2 Adaptation process in adaptive educational hypermedia system

Three key mechanisms of adaptation can be employed within an AHS: rules, algorithmic methods, and hybrid rule-based/algorithmic methods for adaptation (Stefani et al., 2006). Rule-based AHS typically employ hard-coded rules to adapt the material that is presented to the user. The set nature of these rules is widely regarded as a major drawback of the rule-based approach; as such, this has been superseded by algorithmic methods, or at least combined with algorithmic methods to form hybrid rule-based/algorithmic methods. Algorithmic methods employ machine-learning techniques, such as data mining, to develop useful information about the user's behaviour (Stefani et al., 2006).

The next subsections describe the two key steps that are involved in the adaptation process that AEHS employ, and provide an overview of the process by which critical data about learners can be gathered and utilised to develop adaptive learning experiences. The discussion is focussed on the development of a classification of approaches that can be employed by AHES for the purpose of achieving effective student modelling and accurate adaptivity.

3.3.2.1 Student modelling

The student model is at the heart of the AEHS and is based on all the relevant data about the user that the system has gathered. This model then forms the basis of the adaptivity process. The process by which the student model is constructed, maintained and updated is referred to as student modelling. Self (1994) provided a detailed overview of the formal techniques that are involved in student modelling, while Brusilovsky (1994, 1996) categorised student models and techniques for student modelling according to the processes employed by existing systems. Brusilovsky (1996) differentiated between two different student modelling approaches: collaborative and automatic. In the case of collaborative student modelling approaches, the student model is constructed or updated in response to the explicit feedback that is provided by the learner. For example, learners may provide feedback on whether the information presented was relevant to their learning goals. This information is subsequently translated to data that influences the student modelling mechanism. Alternatively, students may be asked to directly perform the adaptation by explicitly telling the system what they want. For example, they may be provided with the option to reorder the hyperlinks that appear at the top of a resource so that the presentation is better aligned with their preferences. An alternative option is that the users

themselves can directly modify the information contained within the student model. One approach that is commonly employed to establish the learning styles of dyslexic students is to provide students with an opportunity to complete a questionnaire about their learning preferences. In the case of the automatic student modelling approach, the student model is automatically updated in accordance to the behaviours the students exhibit as they are interacting with the system and the actions they follow. When this approach is employed, students are firmly focused on their learning as opposed to being prompted to provide the system with feedback or information about their learning preferences. However, one of the drawbacks of the automatic student modelling approach is that it can be challenging for the system to generate sufficient and reliable information about the user to construct a valid and robust student model (Brusilovsky 1996).

In light of the issues with the automatic student modelling approach described above, Brusilovsky (1996) proposed that the system makes use of supplementary and more reliable sources of information about the learner in the student modelling process; for example, the results of tests. In addition, student modelling can be performed statically or dynamically. When a static student modelling approach is employed, the student model is initialised only once (usually at the point of registration for the course). On the other hand, when a dynamic student modelling approach is employed, the information that is used to generate the student model is frequently updated.

The student model can incorporate a variety of data and information about the user. Brusilovsky (1994) differentiated between two major types of information: models of course knowledge and models of individual subject-independent characteristics. Each of these has very different implications in terms of the form of representation of the model and the methods by which it is constructed and applied. In the early days of these technologies, research studies that focussed on student modelling were primarily concentrated on models about the course knowledge; however, in recent times, more attention has been invested in understanding and modelling learner's individual characteristics such as their learning styles or special needs.

3.3.2.2 Providing adaptivity

Once the data about the learner has been acquired and a student model has been produced, the adaptivity can be generated. A number of different elements have to be taken into consideration when developing adapted courses that are aligned with a student model. Of these, the question of what material can be adapted in a system is of significance. A number of different approaches can be used to develop adapted courses for students. The method that is employed will directly determine which features of the system are adjusted for which students according to which student needs. Brusilovsky (2001) categorised adaptation features into two groups in accordance with their aim: adaptive presentation and adaptive navigation support (Brusilovsky, 2001).

– Adaptive Presentation

Adaptive presentation involves presenting the content in an adaptive manner to ensure that suitable learning experiences and materials are presented to the learner at an appropriate time and in the most fitting fashion. An example of adaptive presentation can be observed in the

case of dynamic web content, which modifies the content of a website according to the device upon which it is viewed (device adaptation). The presentation adaptation layer of the system will deliver much smaller units of information to a mobile phone than it would to a desktop computer. Another example could be that of an online resource that contained information that spanned from beginner through to expert learners. Depending on the user's existing level of knowledge, the appearance of the page and the information presented on it would change. Brusilovsky's taxonomy describes several types of adaptive presentation. Of these, the one that is most commonly implemented is the "canned text adaptation", which is a subset of the "adaptive text presentation". Canned text adaptation can be in various forms; these are as follows:

- Adaptive insertion and removal. Information is added or removed to modify the overall content of the learning experience to suit the learner's existing knowledge and/or learning style.
- Adaptive sorting. The text of a lesson is reordered in a manner that is designed to match the needs of each specific user.
- Adaptive altering. The text within each unit of information is altered to match the needs of each specific user.
- Stretchtext. A keyword or phrase is "stretched" to deliver more advanced and comprehensive information to advanced students.
- Dimming fragments. Fragments of the text that are deemed to be inappropriate to a learner are displayed on the screen but are dimmed as opposed to being removed.
- Adaptive Navigation Support

Adaptive navigation support modifies the "structure" of a lesson as opposed to the contents. This often involves modifying the navigational structure so that only links to content that is appropriate to the user are displayed and accessible. As per the example outlined above, if a learner was identified as being an expert in a given subject, he or she would be presented with more links to more advanced content. However, these links would not be displayed in the navigational options that are displayed to the beginner learner. Adaptive navigation support comes in a number of forms:

- Adaptive link annotation
- Adaptive link hiding
- Adaptive link generation
- Map adaptation
- Adaptive link sorting
- Direct guidance

A further dimension of the system involves considering the type of information about the learner that is employed as a source for the adaptation. Adaptivity can be performed in accordance with the various characteristics and needs of the learners involved. For instance, adaptivity can be enacted in relation to the learner's existing knowledge, learning objectives and goals, cognitive abilities, and individual learning styles.

An additional dimension exists for the purpose of adapting learning experiences to the user's preferences and skills, especially in the context of learning styles. The purpose of this

dimension is to achieve the goal of providing adaptivity (Jonassen & Grabowski, 1993). The most common approach is to align the instructions that are provided to the learner with their preferences or needs, and to teach in accordance with their strengths.

To overcome the limitations of existing adaptive e-learning systems, this research focused on the application of Semantic Web technologies as a means of representing knowledge, modelling the required components of personalisation, and reasoning about conceptual knowledge (Dolog & Nejdl, 2007; Henze et al., 2004; Gasevic et al., 2006). As such, the next section presents an overview of Semantic Web technologies and how they can be employed to model the components of personalisation.

3.4. The Use of Semantic Web Technologies in Semantic Modelling

One of the issues associated with the web in its current form is that it cannot be read by machines in the same way it can by humans. For example, an individual who searches the Internet for information about the blackberry fruit will be presented with results that do not have a semantic relationship with the user's search term. The search engine will likely return a set of results that include the BlackBerry mobile device, the blackberry fruit, and even an online shop named Blackberry. To resolve this ambiguity in the results, there is a need to semantically annotate web resources so that more intelligent results can be presented to the user.

The semantic web represents the next-generation web through which information resources are provided with "a well-defined meaning," that allows technical resources and people to cooperate more closely (Berners-Lee et al., 2001). Semantics can help computers to more effectively process, interpret and combine information so that the needs of users are better served through more intelligent semantic decisions. Several different technologies have emerged to facilitate the Semantic Web, and these operate by applying fine-grained semantic structures to the information stored on the Internet (Dolog & Nejdl, 2007). Specifically in the field of personalised e-learning, ontologies are used to semantically model key information about the content of the learning intervention, the learner's profile and the pedagogical strategies.

The Semantic Web has been designed to improve the effectiveness and relevance of research results through providing an additional layer of information that machines can interpret. This information is referred to as metadata. Created by Tim Berners-Lee, the Semantic Web acts as "... an extension of the current web in which information is given a well-defined meaning, better enabling computers and people to work in cooperation" (Berners-Lee et al., 2001, p.37). According to Antoniou and Harmelen (2004), there are three main steps involved in developing metadata that can deliver the objectives of the semantic web: creating a syntax by which the metadata can be represented, developing vocabularies for expressing the metadata, and producing metadata for a large volume of web-based resources.

The Semantic Web is based on a number of technologies (Antoniou & Harmelen, 2004), as follows:

- **Explicit Metadata:** As opposed to being reliant on text-based manipulation, the Semantic Web employs metadata that a machine can process.

- **Ontologies:** The ontologies involved in the Semantic Web can be viewed as a method by which concepts can be explicitly and formally defined (this topic is discussed in depth in the next Section 3.5).
- **Logic and Inference:** Logic and inference technologies allow automated reasoners to infer a set of solid conclusions from the knowledge provided.
- **Agents:** Agents are computer-based applications that work independently on behalf of the user. They process tasks, make autonomous decisions and provide answers.

As explained above, one of the most important elements of the Semantic Web is ontology because this provides a mechanism by which domain knowledge can be modelled. Existing research studies have found that Semantic Web technologies can also address the challenges associated with personalisation decisions in e-learning systems by formalising domain ontologies and the metadata that is created from them (Dolog & Nejdl, 2007; Jovanovic et al., 2009; Henze et al., 2004; Vesin et al., 2012).

For personalised e-learning systems to be effective, they must incorporate knowledge about three elements: the learner, the content, and the adaptation strategy, and must develop an optimal method of representing this knowledge so that the learning path is aligned with the required outcomes. Ontology-based semantic models employ high-level modelling capabilities to characterise major components of personalisation in e-learning systems. In addition, they also offer reasoning mechanisms that achieve supplementary semantic enrichment stages that execute the adaptation. As such, the three main components of personalised e-learning systems are the domain, the learner and the adaptation. The domain models describe both the semantics and structure of the learning material, the learner model retains the learner's characteristics to enable the personalisation, and the adaptation strategies represent the details of the educational process; e.g., suggest a document that can facilitate learning or generate optimised learning paths, etc. The next section presents a detailed overview of ontology and its associated languages as a background to explain how ontologies can be employed in personalised e-learning applications.

3.5. Ontology

This research focuses on the use of semantic web technologies, specifically ontologies, to represent knowledge, formally model the key components of personalisation, and reason about conceptual knowledge (Dolog & Nejdl, 2007). As such, the proceeding section presents a review of the semantic web technologies that are available, in particular ontology, and how these can be employed to model the key components of personalisation. Moreover, this section also presents a comprehensive review of the most prominent ontology languages for representing knowledge such as the Resource Description Framework (RDF) and Ontology Web Language (OWL).

3.5.1 Ontologies: definition and design principles

The existing literature that describes ontological engineering utilises a variety of definitions to explain what ontology actually is. One of the most common definitions of ontology that features

in existing studies is that forwarded by Gruber (Gruber, 1993), which specifies that ontology is a formal, explicit specification of a conceptualisation. The term *conceptualisation* emphasises how ontology represents an abstract model of a phenomenon in the world that helps to recognise appropriate domain concepts and the semantic relationships between them with formal definitions in terms of axioms (Chi, 2009). Such axioms are declarative and, as such, ontology can be employed to declaratively represent the conceptualisation. *Explicitness* in the ontology definition specifies that the kind of concepts and the constraints on their use are explicitly defined. *Formality* means that the ontology prevents unexpected interpretation of the concept, relations and constraints and, therefore, allows an ontology to be machine readable. Studer (Studer et al., 1998) defined ontology as a formal, explicit specification of a shared conceptualisation. According to this definition, *Shared* means that an ontology captures agreed knowledge; it is not specific to an individual but is accepted by a group (Studer et al., 1998). Kalfoglou (2001) described the criteria for the proposed principles in designing ontologies using the terms clarity, coherence, extendibility, minimal encoding bias, and minimal ontological commitment. In this context, these can be interpreted as follows:

- *Clarity*: the meaning of the ontology can be readily captured by minimising ambiguity and presenting examples that help the reader/user to understand the ontology.
- *Coherence*: the ontology should be internally and logically consistent.
- *Extendibility*: the ontology terms can be extended without the need to revise existing definitions.
- *Encoding bias*: representation is developed solely for the convenience of notation or implementation. It should be minimised to enhance knowledge sharing between agents.
- *Minimal ontological commitment*: ontology should model the domain with fewer claims.

It is important to note that ontology designers do not necessarily accept the criteria and definitions outlined above. As such, according to Kalfoglou (2001), the main notion that needs to be tackled is the criteria of ontological commitment due to the important role that this plays in software systems. This thesis adheres to the criteria proposed by Kalfoglou as much as possible, to ensure that the ontologies that are developed can be replicated for use with a wider audience.

3.5.2 Types of ontologies

According to Van Heijst et al. (1997), there are four different types of ontologies: 1) *application ontologies*, 2) *domain ontologies*, 3) *generic ontologies* and 4) *representation ontologies*. Application ontologies contain the knowledge required to model a given application. Domain ontologies express concepts that are specific to a particular domain. Generic ontologies define concepts that are generic and can, therefore, be applied to a variety of disciplines. Finally, representation ontologies provide a representational framework that is based on a neutral view of the world.

Bruijn and Fensel (2005) presented an alternative classification of ontologies that is based on their generality (i.e., scope) and expressiveness (i.e., level of details). The level of generality can be further divided into three different types of ontologies as follows:

- Top-level ontologies that are shared by many people in different domains, such as Cyc¹², WordNet¹³;
- domain ontologies that are shared between stakeholders in a particular domain, such as UNSPSC¹⁴, The United Nations Standard Products and Services Code for classifying products and services; and,
- application ontologies that are used for a specific application, such as an ontology for a course.

Alternative orthogonal classifications of ontologies are based on the different levels of expressiveness they incorporate; for example, thesaurus (e.g. WordNet), controlled vocabulary (e.g. Dublin Core¹⁵), informal/formal taxonomy (e.g. Yahoo directory¹⁶/UNSPSC), frames (e.g. RDFS), value restrictions (e.g. OWL datatype), limited logic constraints (e.g. OWL DL¹⁷) and general logic constraints (e.g. OWL DL). Finally, Bruijn and Fensel (2005) also described how the level of expressiveness can be perceived as two discrete categories: light-weight ontologies, which include the concepts and the relationships between them, and heavy-weight ontologies, which include axioms and constraints. This research is going to focus on the use of domain ontologies that offer a lightweight level of expressiveness.

3.5.3 Ontology language

An ontology language is the formal language that is employed to encode the ontology. It forms the basic foundation of ontological systems and, therefore, allows the construction of knowledge about specific domains. It also often includes reasoning rules that are employed to support the process by which knowledge is processed. Over the course of the last few years, several ontology languages have emerged. These include Knowledge Interchange Format (KIF),¹⁸ Cycl, FLogic (Kifer et al., 1995) and LOOM¹⁹ (based on description logic). There are also a number of additional languages that are based on XML syntax. These include the Ontology Exchange Language (XOL) (Karp et al., 1999), SHOE,²⁰ the Resource Description Framework (RDF)²¹ and the RDF Schema.²² In addition, three further languages have been developed to improve the features of RDFs: the Ontology Inference Layer (OIL) (Fensel et al., 2000), the DAML+OIL (Horrocks, 2002) and the OWL (Patel-Schneider et al., 2004).

In recent years, ontology developers have relied on graphical ontology editors to create or modify ontologies for a given purpose. Such editors allow developers to generate ontologies without having to manipulate ontology language codes. The output of these editors is in the form of one of the web ontology languages that the ontology editors support. The more

¹² <http://www.opencyc.org/>

¹³ <http://wordnet.princeton.edu/>

¹⁴ <http://www.unspsc.org>

¹⁵ <http://dublincore.org/>

¹⁶ <http://dir.yahoo.com/>

¹⁷ <http://www.w3.org/TR/owl-guide/>

¹⁸ <http://suo.ieee.org/SUO/KIF/suo-kif.html>

¹⁹ <http://www.isi.edu/isd/LOOM/>

²⁰ <http://www.cs.umd.edu/projects/plus/SHOE/spec.html>

²¹ <http://www.w3.org/TR/PR-rdf-syntax/>

²² <http://www.w3.org/TR/rdf-schema/>

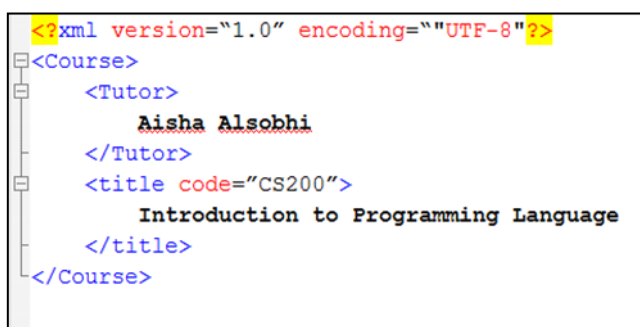
commonly employed ontology editors are Protégé (Noy & Musen, 2000) (see Section 3.5.3.4), OWL-P (Desai et al., 2005) and OilEd (Bechhofer et al., 2001).

The following section describes some of the web languages that are most commonly employed to represent ontologies. Within this section, XML and XML Schema, which form the syntactical basis of the semantic web language, will be discussed in depth. As too will web languages that are based on XML syntax (Antoniou & Harmelen, 2008) but that employ different terminologies and expressions such as the Resource Description Framework (RDF), the RDF Schema (RDFS) (Antoniou & Harmelen, 2008) and the Ontology Web Language (OWL).

3.5.3.1 XML/DTD/XML schema

While XML is not an ontology language, it is a core technology in the semantic web. eXtensible Markup Language (XML) is an application of SGML (ISO 8879) and it is a structured language that was specifically developed to overcome the known limitations of HTML. XML facilitates the exchange of data between web applications through the use of a common vocabulary. Examples of such vocabularies are MathML²³ (for mathematics) and NewsML²⁴ (for news).

Logically, an XML document consists of Prolog, elements and attributes (Figure 3.2), each of which is declared by explicit markup. The XML markup encodes the storage layout and logical structure of the document.



```
<?xml version="1.0" encoding="UTF-8"?>
<Course>
  <Tutor>
    Aisha Alsobhi
  </Tutor>
  <title code="CS200">
    Introduction to Programming Language
  </title>
</Course>
```

Figure 3.2 A snippet of XML code

The prolog, which provides important information about the document, contains an XML declaration and reference to other documents (e.g. `<?XML version="1.0"?>`). Elements are the basic building blocks of XML files and represent the ‘things’ that the XML document talks about (e.g. Tutor). Finally, the value of the attribute is denoted in the opening tag of an element and is a characteristic of elements (e.g. code).

An XML document is a well-formed document, which means it is restricted to a strict set of syntactic rules. Two different methods can be employed to define the XML structure:

- **Document Type Definition (DTD):** the document can be within the XML file (internal) or on a separate file (external).
- **XML Schema:** the syntax of the XML is based on XML documents. This provides a richer language to define the structure of an XML. The XML schema is beneficial because it can be reused and refined.

²³ <http://www.w3.org/XML/>

²⁴ <https://iptc.org/standards/newsml-g2/>

3.5.3.2 Resource Description Framework (RDF)

The Resource Description Framework (RDF) was developed by the World Wide Web Consortium (W3C, 2015), and it is a set of specifications that allows structured metadata to be encoded, exchanged, and recycled. Through providing a framework of common conventions for the semantics, syntax and structure, the RDF facilitates metadata interoperability. As opposed to specifying semantics for every resource description community, the RDF acts as a mechanism by which these communities can define metadata elements as required. RDF uses XML²⁵ as the common syntax by which metadata is exchanged and processed. The RDF is a relatively basic language. It operates on the basis that statements about resources can be conveyed in the form of subject-predicate-object expressions that are referred to as triples. XML syntax can be employed to express RDF triples in various ways. An example of RDF using XML syntax is presented in Figure 3.3, an example of RDF using N3/Notation3 is presented in Figure 3.4, an example of RDF using binary predicate form, e.g. Property (object,value) is presented in Figure 3.5, and an example of RDF as a directed labelled graph is presented in Figure 3.6.

```
<rdf:Description rdf:ID="http://www.example.com/Aisha">
<Name>Aisha</Name>
</rdf:Description>
```

Figure 3.3 RDF using XML

```
<http://www.example.com/Aisha> <Name> "Aisha"
```

Figure 3.4 RDF in N3.

```
Name("http://www.example.com/Aisha", "Aisha").
```

Figure 3.5 RDF as a binary predicate.

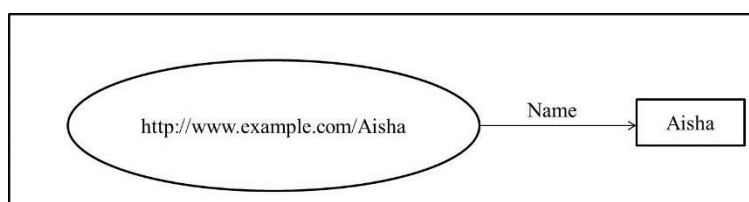


Figure 3.6 RDF as a graph.

RDF is a domain-independent language. This essentially means that it does not act as an extension to any particular host language and no claim about a specific domain is made. As such, there is an underlying implication that, when RDF is employed, there is a need to define the appropriate terminology using RDF Schema (RDFS). Also, RDF does not contain vocabulary to author metadata; as such, the accompanying RDF Schema needs to present a

²⁵ <http://www.w3schools.com/xml/>

list or set of predefined vocabulary that will be employed in combination with the metadata generation.

RDFS is intended to model a domain in a hierarchical fashion; as such, it is limited in terms of its ability to represent ontological knowledge. For example, we may wish to specify that two classes are disjoint; however, RDFS does not have the ability to represent a “disjointness of classes”, it only has the capability to show the subclass relationship. As such, a more expressive language, such as OWL, is required.

3.5.3.3 Ontology Web Language (OWL)

The expressivity of both RDF and RDFS is purposely very limited. While RDF is (generally) limited to binary ground predicates, RDFS is limited to a subclass hierarchy and a property hierarchy, with domain and range definitions of these properties. The Web Ontology Language OWL²⁶ represents a language that was specifically designed for applications that need to process the content of information as opposed to merely presenting it to humans. Along with the formal semantics, OWL also provides additional vocabulary and this allows it to facilitate greater machine interpretability of web content than XML, RDF, and RDFS. OWL employs three increasingly expressive sublanguages: OWL Lite, OWL DL, and OWL Full.

- **OWL Lite** is a relatively limited version of OWL that provides a classification hierarchy together with simple constraints. Examples of OWL Lite include thesauri and taxonomies.
- **OWL Description Logic (DL)** includes all the OWL language constructs and provides the maximum expressiveness while maintaining a finite computation time.
- **OWL Full**: includes all OWL language constructs and provides the maximum expressiveness with no computational guarantees.

In light of OWL's power of expressivity and the fact that it offers a much stronger development potential for the future, OWL was chosen as the language of choice to represent the dyslexia adaptive e-learning system that is the subject of this research. While ontologies in OWL can be developed using any text editor, there are a number of dedicated tools available that make the process much more straightforward. The most well-known of these is Protégé.²⁷

3.5.3.4 Protégé and OWL

Protégé is a free, open-source platform that encompasses a suite of tools that can be employed to construct domain models and knowledge-based applications with ontologies. It operates on a rich set of knowledge-modelling structures and actions that facilitate the creation, visualisation and manipulation of ontologies in a variety of representation formats. Protégé can also be customised and, as such, it represents a domain-friendly support platform that can be employed to create knowledge models and input data. The enhanced functionality of Protégé entails that it was selected as the development tool that was used to generate the OWL ontologies used within this research. The next section describes the methodologies for ontology engineering.

²⁶ <http://www.w3.org/2001/sw/wiki/OWL>

²⁷ <http://protege.stanford.edu/>

3.5.4 Ontology engineering methodologies

In light of the fact that ontology forms the main pillar of the semantic web, which is a conscious version of the WWW, methodologies are critical to the process by which ontologies are created. Methodologies provide guidelines that direct the development of ontologies through encouraging the selection of appropriate techniques for every activity involved in the construction process. A large number of different methodologies have emerged since the 1990s for the purpose of building ontologies. These typically employ different methods. Some have been specifically created to facilitate the development of ontologies from scratch, while others reprocess existing ontologies.

Those involved in the ontological engineering community widely agree that the construction of ontologies is more of an art than it is an engineering activity. Every approach through which an ontology is built follows a distinct activity and design, even if the developer has no knowledge as to whether the approach will be successful or not. This absence of uniform guidelines and methodologies is generally accepted as being one of the disadvantages of ontology development (Gasevic et al., 2006). The methodologies that are employed to develop ontology can be broadly classified as one of three categories:

- Building ontology from scratch. Notable examples of this methodological approach are the Cyc methods that were employed in the 1990s by Lenat and Guha (1990), the ontology enterprise modelling (TOVE) that was proposed in 1995 by Uschold, and King and Grüninger and Fox's 1995 methods in the same field of ontology enterprise.
- METHONTOLOGY. In 1996, Uschold and Grüninger proposed a set of outlines of developing ontology at the knowledge level. This evolved into METHONTOLOGY and these outlines have been employed to construct ontology using tools such as OntoEdit and Protégé. METHONTOLOGY provides a general framework that defines the criteria that should be employed to construct the ontology criteria (Noy & Musen, 2000).
- A year later, in 1997, METHONTOLOGY methodology was extended, which proposed the development of SENSUS, a vast ontology. Nevertheless, it still represents methodology for constructing ontologies from scratch (Fernandez-Lopez & Gomez-Perez, 2002).

The next section provides a compression of these methodologies.

3.5.4.1 Comparison of methodology

In general, the majority of existing methodologies are based on the experiences that have been gained while developing enterprise ontologies. They employ common development stages that guide ontology engineers. The main phases of development consist of identifying the objective of the ontology in terms of purpose and need, acquiring relevant knowledge, and codifying the concepts and their relations. No consensus has been reached as to one methodology that is the most effective for designing and constructing ontologies because the decisions that are made during the process of development will depend on the application and its purpose (Noy & McGuinness, 2001). However, it is critical that purpose and need form the foundation upon which a new ontology is constructed or an existing ontology is reused (Pinto & Martins, 2001).

This research compared existing methodologies according to ontology dependency level with respect to its application. As such, methodologies can be categorised as follows:

- Application independent: the ontology process operates independently from users. This was the case with METHONTOLOGY, Cyc and the methodologies developed by Uschold and King (1995).
- Application dependent: A specification process is followed to identify and develop scenarios of ontologies.
- Application semi-dependent: the ontology is specifically developed in accordance with the application that will use it; for example, SENSUS methodology (Fernandez-Lopez & Gomez-Perez, 2002) and the methodology employed by Gruninger and Fox (1995).

In the discussion above, the various methods that have been employed within different ontology projects have been described as a way of validating the use of METHONTOLOGY, which represents a mature methodology (Fernandez-Lopez & Gomez-Perez, 2002). METHONTOLOGY is a framework that enables the construction of ontologies at the knowledge level. METHONTOLOGY offers a methodology that can be applied to either construct ontologies from scratch or to reuse an existing methodology. It involves six stages: conceptualisation, requirements analysis, formalisation, implementation, maintenance and evaluation. METHONTOLOGY is often employed in re-engineering approaches for the purpose of generating a conceptual model. While, re-engineering methods can be viewed as an extension of the METHONTOLOGY framework, METHONTOLOGY incorporates an option to return to a previous activity if limitations are identified later in the process. SENSUS methodology does not involve a life-cycle model. There is a similarity between constructing ontologies. In the Uscholdard method proposed by Gómez-Pérez (1996), the first phase involved in constructing a chemical ontology is knowledge acquisition, while the second phase involves developing a solid requirements specification. The Cyc method was first introduced in the 1980s. This approach does not involve the codification of the information contained in books and published papers, rather it looks at the knowledge that is available to readers, and subsequently identifies methods of representing this knowledge. Languages such as ODE and WebODE both support METHONTOLOGY. METHONTOLOGY was selected as the ontology development methodology of choice for the research work outlined in this thesis for the reasons outlined above. The next sections highlight the importance of ontologies in different educational context.

3.6. Ontologies in Education

Education ontology emerged as a result of the introduction of semantic web technologies into the educational setting. An educational ontology is an ontology that captures the knowledge of an education system and the related pedagogical information. According to Stojanovic et al. (2001), there are three categories of ontologies in education: content (domain) ontologies, context ontologies and structure ontologies.

Content (domain) ontologies outline the content of a learning document in the process of searching for the learning material as well as in the process of supplying the learning material.

Context ontologies outline the location where the learning material will be presented. Structure ontologies characterise learning materials as a series of small units and join these small units together to construct a complete course. In this thesis, the researcher adopted an approach that was based on content domain ontologies.

Examples of more recent education ontologies are:

- EduOnto – An Ontology for Educational Resources (Qin & Hernandez, 2004);
- OntoEdu – An Ontology-based Education Grid System for e-Learning (Guangzuo et al., 2004);
- OntoWeb²⁸ – is an ontology-based portal that serves the academic and industrial communities through the development of ontology-based information sources that can be employed for the purposes of knowledge management and electronic commerce.

The important role that adaptation support can play in enhancing online educational systems has become increasingly recognised in educational technology development; however, the development of effective systems remains challenging. Education ontologies represent a promising means of overcoming these challenges. Educational ontologies arrange educational resources in a “conceptual domain presentation” fashion. Concept-based course sequencing has been developed to allow adaptive courseware authoring, concept-based navigation, and searching for courseware and Topic Maps (Widhalm & Mueck, 2003), which organise Learning Objects (LOs) according to topic.

3.6.1 Ontology application in education

Ontologies have been utilised to great success in many educational systems and applications and it is, therefore, not possible to produce a comprehensive list of all educational applications that employ ontologies. However, this section will describe some of the applications that are available in the learning technologies discipline in order to emphasise the areas in which the current research breaks new ground. The most notable educational applications that employ ontologies are listed below:

- 1) TANGRAM (Jovanovic et al., 2009) is a web-based intelligent learning environment for the domain of intelligent information system (IIS). TANGRAM tailors the content of a learning exercise to the user’s current level of knowledge, learning style and other personal preferences. It also expedites access to key educational context, such as examples and definitions, that are of relevance to the topic being explored (e.g., RDF documents or semantic web, which belong to the IIS domain). TANGRAM utilises ontologies for the purpose of automatically decomposing LOs into reusable smaller units before dynamically reassembling these units into personalised learning objects that are aligned with the student’s domain knowledge, preferences and learning styles in accordance with the Felder and Silverman learning styles (Felder & Silverman, 1988).
- 2) DIOGENE (Sangineto, 2008) is a Learning Management System (LMS) that operates on an adaptive e-learning platform that uses both statistical and static knowledge to produce

²⁸ <http://ontoweb-lt.dfki.de/>

personalised courses. Statistical knowledge is the information about the learner that the system acquires as he or she interacts with the activities executed during the learning session, and it is collated at the end of each session. The student's knowledge and preferred learning modalities are continually updated in response to the online feedback that the student provides. Static knowledge includes information concerning available learning objects in a specific domain (e.g., "Euclidean Geometry," "Object Oriented Programming Languages," etc.). This is presented in a form that the machine can interpret as well as in an ontological description about the didactic relations (i.e., prerequisite, ordering and hierarchical relations) between the concepts associated with that specific domain.

- 3) A semantic network presents ontologies that consist of nodes that represent concept domain. Orientated edges are used to link different nodes and, thus, denote the relationships between ontologies. The Diogene's student model consists of two modules: the cognitive state and the learning preferences. The cognitive state module describes the student's degree of knowledge about each domain concept that is present in the ontology. The learning preferences module represents the student's learning styles and other key characteristics about the user that are employed during the LO selection process. The learning content is adapted to a student in accordance with the Felder and Silverman learning styles (Felder & Silverman, 1988).
- 4) Protus: PRogramming TUtoring System (Vesin et al., 2012) is a tutoring system that was specifically designed to teach students the Java programming language. The system presents personalised learning content that is aligned with a student's learning style (Vesin et al., 2011). The original system was enhanced and released as Protus 2.0. This new version employs semantic web standards and technologies to achieve effective personalisation. In particular, the system relies on ontology and adaptation rules for knowledge representation and inference engines for reasoning.

The systems listed above offer personalised learning experiences and materials that incorporate consideration of the user's learning style and level of knowledge. None of the three systems described above accommodate peer recommendation or groups based on students' knowledge level. To be truly effective, a system needs to take more factors other than learning style and knowledge level into consideration to generate a satisfactory and pedagogically suitable learning path. The system that is proposed in this research includes a third student characteristic, dyslexia type, to recommend assistive technologies, guidance and learning materials that are aligned with the student's dyslexia type. This feature is available to all students, dyslexics and non-dyslexics alike. It also offers social annotations: where multiple users (authors and/or students) can discuss the content of the materials and share their feedback with each other. Ahn et al. (2006) employed social annotation to enrich information visualisation by delineating visual pointers that provide information about a users' (and a groups') annotations of web resources.

3.6.2 Ontology applications for students with dyslexia

The application of explicitly expressed ontologies is by no means a novel idea in the e-learning domain. A number of applications are available that offer personalised learning experiences through the use of ontology representation that can meet the specific needs of a user. Over the last few years, various software systems have been introduced that automatically adapt content to the needs of dyslexic learners. It is worth examining a number of these applications in order to identify and understand some of the main problems associated with the existing approaches.

- 1) AGENT-DYSL Tzouveli et al. (2008) aimed to develop an ontology-based software that could support children with dyslexia to overcome their reading difficulties by manipulating the learning process. The software, which was named AGENT-DYSL, incorporates a reading system for dyslexic children that customise the presentation of reading materials to meet the personal needs of the user. To enhance the effectiveness of these learning experiences, the system employs age-appropriate and dyslexia-sensitive user interfaces. Furthermore, it can be integrated with the school environment and takes learning context into consideration. The main difference between AGENT-DYSL and alternative software programs that are aimed at users with dyslexia is the personalised assistance. Such assistance has been proven to be of significant help to children with dyslexia because it provides a combination of speech recognition, state recognition via image, and error type profiling via adaptive and personalised support. However, the system is not without its limitations. It was developed for children and, therefore, is not suitable for use with adults with dyslexia. In addition, it is limited to just one of the dyslexia difficulties: reading. Finally, the extent of the personalisation is limited to reading materials and does not take into consideration the learners' characteristics.
- 2) Ivanova et al. (2010) developed a framework for an adaptable e-learning environment that was specifically aimed at presenting personalised e-learning experiences to students with dyslexia. They developed an open agent-based framework that supports the production, consumption and use of automated ontology-based learning facilities. It also supports the management, reuse and retrieval of external resources. The software includes a knowledge expert agent, teacher agent, dyslexic learner personal agent, collaboration agent, evaluator agent, ontology search agent, web search agent, mapping, annotation agent and external resource agent. This software holds great promise because it incorporates a reuse platform that promotes an effective and efficient e-learning environment through the use of the capabilities of semantic and agent-based technologies to achieve flexibility and semi-automation. However, as with the AGENT-DYSL, the model does not cover adults with dyslexia and does not support different dyslexia difficulties.
- 3) The ONTODAPS system (Nganji et al., 2012) is an ontology-driven disability-aware e-learning system that offers personalised learning resources and services to a range of students, both with and without disabilities. This system incorporates learner control by allowing the user some input in how the learning resources are personalised. The

learner is requested to provide the system with information about his or her disability type, learning goals and preferences. This data is then stored in the learner's profile and used to authenticate the user in later sessions and to personalise the learning experiences. This model covers many forms of learner disability, including dyslexia. When interacting with dyslexic students, the system presents the students with a range of options in terms of how the learning materials are presented and the user can select the format he or she prefers. To the best of the author's knowledge, this system does not support assistive technologies for students with dyslexia and does not consider students' learning styles.

The next section highlights the way in which technology can be employed to alleviate some of the problems that dyslexic learners typically encounter.

3.7. Providing Dyslexia Assistance Through Technology

Technological advancements, particularly in the field of computing, have been dramatic over the past three decades and a large number of researchers have specifically attempted to exploit technological capabilities to reduce some of the challenges that dyslexic students typically encounter (Van Aarle & Van Den Brecken, 1999; Dickinson et al., 2000). However, the majority of studies that have been conducted involved children with dyslexia (as opposed to adults). These systems were designed to assess the cognitive processes such learners use to determine specific deficits and to subsequently develop effective assistance programs that are capable of improving the efficiency with which dyslexic children can learn to read and write. However, existing research into learning disability (LD) has demonstrated that dyslexia problems can persist from childhood through to adulthood (Callens et al., 2012). An assessment of the existing knowledge and understanding in this domain reveals that there is significant potential for adaptive e-learning systems that are specifically designed for adult students with dyslexia.

The following sections will provide an overview of the most promising examples of technology that have been employed to support students who have dyslexia. The findings of the literature review have been separated into two main categories, support tools and support environments, as follows:

- Assistive technologies are technological applications that enhance an existing software application or environment that was not specifically designed for dyslexics.
- Support environments are independent software system solutions that have been specifically designed and developed for dyslexic subjects.

3.7.1 Assistive Technologies (ATs)

Assistive technologies (ATs) have been employed to enrich the learning experiences of members of the dyslexic population to good effect in a variety of tasks. Table 3.1 describes 17 existing applications that were not specifically designed but they facilitate dyslexic students in their educational process. In this table, the dyslexia symptom that each respective system aims to address has been matched with the appropriate group of assistive technologies.

Table 3.1 Existing assistive technologies that help students with dyslexia

Assistive Technologies for Dyslexic Students					
Reading					
Text Readers		Optical Character Recognition			Reading Pens
Writing					
Word processor	Word Prediction Software	Digital Recorders	Voice Recognition Software	Electronic Dictionaries	Spellcheckers
Memory					
Mind-mapping Programs		Personal Organisers			Map-reading software
Speaking					
Speech recognition programs			Voice Recording Programs		
Mathematics					
Calculators		Spreadsheets Programs		Speech recognition for Mathematics	

Some of the key technologies described in Table 3.1 are discussed in more depth below together with the main symptoms of dyslexia they have been found to alleviate.

1. Word processors:

Of the tools that are available for dyslexics, word processors are perhaps the most valued. They contain a series of functions that help dyslexic students to reduce the number of errors in the documents that they produce.

2. Spellcheckers:

Spellcheckers can be useful to support typically bad dyslexic spelling (Miles, 1993). Some of the more enhanced software offerings have the capability to identify patterns in user's spelling mistakes and to use these to develop appropriate feedback for the student. Spellcheckers are becoming increasingly sophisticated and many contemporary offerings can now identify phonetic spelling errors (Boder, 1973). Grammar checkers can effectively highlight other typical dyslexic errors including repeated words, commonly confused words, inappropriate use of punctuation and incorrect sentence syntax.

3. Word Prediction Software:

Word prediction software is often incorporated into applications that require some form of textual input. In these cases, the user may start to input the first letters of a word and the word prediction software will automatically generate a number of suggestions as to the word that the user may be spelling; for example, if a user enters "sp", the software will generate the suggestions of "spelling", "sport", "spine", "split", etc. Word prediction software can be of particular use to learners who exhibit such extreme patterns of spelling inaccuracies that spellchecking software is unable to identify the word and, therefore, suggest the appropriate spelling.

4. Speech recognition programs

Speech recognition programs are of particular use to dyslexic subjects who exhibit severely retarded reading and spelling performance (Miles, 1993). In these cases, the software is trained to recognise the voice patterns of the subject and will then translate his or her spoken words into text. These software applications combine speech recognition software with a speech

recognition word processor to provide a system by which the dyslexic subject can dictate the required text while the system renders it in an electronic format that is free of spelling and grammatical error. Many of these software offerings allow the subject to verify the content of the document using text-speaker software. This allows the user to sidestep standard spelling and reading prerequisites. Speech recognition software can be integrated with a variety of software applications and can be very effective as it substantially reduces the need for the dyslexic user to input any text.

5. Text-speaker or text-reader software

These types of software allow dyslexic subjects to listen to sections of text as opposed to being required to read them. Such an approach can significantly enhance a dyslexic user's level of comprehension of a given text while also reducing the effort required to read (Leong, 1992; Elkind et al., 1996). It is not uncommon for dyslexic subjects to process text very slowly. Text readers, therefore, are beneficial because they read the given text at a standard pace and, thereby, significantly reduce the time it takes the student to process it. Elkind et al. (1996) suggested that computer readers can be of particular benefit to adult remediation programs because the use of text-readers allows students to read more and, therefore, motivates them to engage in reading practice, which, in turn, allows them to progress more quickly. However, not all researchers are in agreement on the virtues of text readers. One criticism that is commonly leveraged at them is that the output generated by the text speakers is monotone, which makes it difficult for students to maintain concentration over prolonged periods of use (Lundberg, & Olofsson, 1993). However, contemporary versions of text reader software offer more natural speech-synthesis that more effectively holds readers' interests and, subsequently, improves their comprehension.

3.7.2 Support environments

Currently, some LMS have specific functionality that caters for students with dyslexia. Examples of these are as follows:

- Blackboard, ATutor, and LearnWise, which include accessibility policies and may provide accessibility recommendations to its users (Phipps et al., 2002);
- dotLRN²⁹, which prioritises assisting student with disabilities through the implementation of an accessibility mechanism;
- LearnWise, which includes an adaptive interface and text-to-speech applications (Phipps et al., 2002); and
- IntraLearn, which offers a series of specialised tools that have been specifically designed to support students who have specific types of difficulties.

In addition to these systems, a number of research projects have specifically proposed the development of new LMS or extension of existing systems to explicitly incorporate features and functionalities that can cater for dyslexic students. Some of these are as follows:

- EU4ALL (European Unified Approach for Accessible Lifelong Learning). This project was specifically aimed at university students and sought to promote accessible lifelong

²⁹ <http://dotlrn.org/product/accessibility/>

learning through a combination of three key strategies: employing technology to adapt to diversity, providing support services to students with disabilities, and providing accessibility mechanisms so that services can be provided to all. To achieve these strategies, the developers proposed the design and implementation of an open service architecture that was based on e-learning standards. This project was developed over dotLRN LMS (Douce et al., 2010).

- **DysLextest** (Development of the e-learning system for dyslexia rectification and automatic effectiveness assessment of its utilisation). This project aimed to help dyslexic children and adults, and their teachers. The fundamental goal of the project was to create a web portal that contained an LMS that allows dyslexic students to access exercises and tests that have been specifically designed and recommended by qualified professional therapists. The project also provides quality information for the instructor and learners (Indera, 2012).
- **TechDis** (online information repository). The aim of this project was to develop effective support strategies for users with dyslexia or other disabilities. TechDis was formed in 2002 and is funded by the Joint Information Systems Committee (JISC). TechDis provides institutions with online access to expert advice, guidance and support in the following areas: a) technology and disability; b) strategies by which they can accurately identify and support the users of dyslexic technology; c) the implications of accessibility and disability legislation on institutional technology practices (TechDis, 2002).
- **CMS** (computer-based academic assessment system). The aim of this project is to identify college-level students who have specific reading disabilities (dyslexia). The CMS assesses reading skills via a series of computer-presented reading tasks that measure reading speed and accuracy (Cisero et al., 1997).

3.7.3 Comparison of dyslexia support environment

Having explored the existing support environment that caters to the needs of students with dyslexia, it is now worthwhile examining a comparison between the dyslexia support environments that are available as a means of better understanding the full picture. At present, there are no standard frameworks by which existing technologies that offer dyslexia support can be compared. The criteria listed below have been specifically developed to enhance the learning experience of students with dyslexia. All aspects of these criteria can be met by providing **Resources** that have been explicitly designed to meet the needs of students with dyslexia or through the development of collaborative learning interventions that promote **Social interaction**. As such, for the purposes of this research, the offerings will be assessed against the following features (Luna, 2009; Vickerman & Blundell, 2010; Corredor & Gesa, 2012):

- **User roles**: The extent to which the model clearly supports different roles, such as teachers and learners, or different types of authors.
- **Standards**: The extent to which the model supports any accessibility standards.
- **Resources**: Whether the system offers digital educational resources that are specifically designed for students with dyslexia.

- **Assistive technologies (ATs):** Whether the system incorporates any type of assistive technologies.
- **Social interaction:** The extent to which the model supports the activities associated with social media use such as tagging, rating and providing feedback.
- **Dyslexia Types:** Whether the system supports different dyslexia problems or just reading alone.
- **Assessment:** The extent to which the system employs mechanisms by which the performance of students with dyslexia can be assessed.
- **System design:** Whether the system is designed for a course core curriculum with learning purposes (course target), or can be used in an LMS as a general tool to support or orient difficulties (general tool).

An extensive evaluation of the existing support environments that are available for students with dyslexia was performed against the features outlined above. Table 3.2 presents an overview of the findings of this critical review. A tick (✓) denotes that there was strong evidence to demonstrate that the system incorporated the feature; while a cross (×) denotes there was no evidence to suggest that the systems offered the required features. Finally, a question mark (?) denotes that insufficient information was available to determine whether or not the features were available in the system under assessment.

Table 3.2 Comparison of existing dyslexia support environments against key features

Systems	User role			Standards	Resources	ATs	Social Interaction	Dyslexia Type	Assessment	System Design	
	Student	Teacher	Other							Course target	General Tool
EU4ALL	✓			✓	✓	✓	×	×	×	✓	×
DysLextest	✓	✓		×	✓	×	×	?	×	×	✓
TechDis			✓	✓	×	✓	×	?	×	×	✓
CMS	✓	✓		×	×	?	×	×	✓	✓	×

As Table 3.2 indicates, none of the LMS systems assessed incorporate both assessment and specific learning resources to assist students with dyslexia. It is also worth noting that none of the systems offer guidance or personalisation that is aligned with students' dyslexia type or incorporate consideration of their preferred learning style. The thesis aims to develop an adaptive e-learning system that incorporates consideration of dyslexia classification, type, symptoms and learning styles.

3.8. Chapter Three Summary

This research aims to develop an adaptive e-learning system. This chapter described the methods of adaptivity that are currently in use in many software systems and assessed how they may be potentially incorporated in e-learning systems. In addition to considering some of the state-of-the-art, technologies that are available to assist students with dyslexia, this analysis also examined the potential benefits of these technologies. A number of interesting assistive LMS technologies and projects that were designed to meet the needs of students with dyslexia

were identified. Ontologies play a significant role in the semantic web discipline. This chapter described the importance of ontologies in different educational contexts. In addition, it provided a comprehensive overview of the definition, languages, and types of ontologies. This chapter reviewed, analysed and compared contemporary ontology-based adaptive e-learning systems. It also highlighted their respective strengths and weaknesses. The next chapter will outline the source of the fundamental dyslexia framework models and provide a justification for their construction.

Chapter 4 Research Methodology

4.1. Introduction

The previous chapters described the literature review and discussed the main issues and challenges that are relevant to this thesis. The objective of this thesis is to propose a novel approach by which adaptive personalised e-learning systems for dyslexic students can be developed. This novel approach will seek to enhance the flexibility, extensibility and reusability of existing e-learning systems while also ensuring that learners are provided with pedagogically effective learning experiences that meet their learning needs in a satisfactory manner. This chapter will describe the research process that will be employed to collect and analyse the information and data required to answer the research questions (Section 1.4.2). This chapter will commence by reviewing the purpose of the present study, and this discussion will underpin the research approach and methodology (Section 4.2). This is followed by a discussion of the research methodology. Specifically, the quantitative (Section 4.2.1) and qualitative (Section 4.2.2) methods employed to acquire data and information that can adequately answer the research questions will be presented together with a full justification as to why these approaches were deemed to represent the most suitable approaches for this research (Section 4.2.3). The chapter will then progress to describe popular research methods and will briefly discuss the most appropriate research technique to collect empirical data and reasons as to why these represent possible methods for this research study (Section 4.3). Finally, the chapter will present an overview of the challenges associated with the research topic (Section 4.4); the plan by which the research will be implemented, and the anticipated outcomes of the study (Section 4.5).

4.2. Methodology

While many research methodologies are available that had the potential to generate meaningful data and insights that would answer the research questions of the current study, it was important that an approach was selected that would be fully aligned with the objectives of the research. Bryman (2007) highlighted how researchers are free to utilise the methods that are most suitable to answer their research questions and, in order to establish these, they should ensure that the approach they employ is based on the research question as opposed to the paradigm. To ensure that an appropriate methodology was employed within the current study, the methodologies and approaches that have been employed in previous research studies in this domain were carefully examined.

Research in the field of information systems (IS) has previously adopted diverse research paradigms. Oates (2006) defined a research paradigm as “A set of shared assumptions or ways of thinking about some aspect of the world” (p. 282). There are two broad paradigms or underpinning schools of thought that are of relevance to research of this nature: the positivist school, which is generally adopted in the fields of natural and physical sciences, and the

constructivist or interpretivist school, which is generally used in research involving the social sciences and humanities (Kuhn, 1970). Each of these will be reviewed in more detail below.

The positivist school of thought is based on the notion that it is important to use quantitative methods when generating knowledge about phenomena because these are more likely to result in information that is measurable, tangible and objective (Holstein & Gubrium, 1998). In addition, Willig (2001) described how positivists believe that reality is objective in so much as relationships can be established between people's attitudes or beliefs and the world in which they exist. A positivist approach to research involves testing a hypothesis to generate knowledge via examining and assessing existing cause and effect relationships (Chen & Hirschheim, 2004).

On the other hand, the interpretive school of thought places more of an emphasis on the use of qualitative methods to generate knowledge. Interpretivists believe that value judgement and subjectivity play an important role in any research that involves studying human beings and behaviours. Orlikowski and Baroudi (1991) argued that the information that researchers gather and develop in relation to a given phenomenon is subjective and, as such, researchers who adopt an interpretivist paradigm develop theories that are based on the outcomes of research (Patton, 2002).

In light of the above discussion, it is apparent that different research methodologies can be adopted in any given study and that the approach that is selected should be determined in accordance with the type of information that the researcher would like to acquire about the phenomenon under consideration. Adding further to this discussion, Cohen and Maldonado (2007) highlighted how, when devising the research methodology for a given study, researchers should focus on the research questions that this methodology aims to answer as opposed to concentrating on the research paradigm. As such, the nature of the study underpins the criteria that should be taken into consideration when selecting an appropriate research paradigm. In light of all this, the researcher decided that the most appropriate research paradigm for this research was the positivist one.

Due to the nature of the current research, a mixed-method research approach was employed that consisted of a combination of qualitative and quantitative methods. Lee et al. (2003) suggested that qualitative methods should be combined with quantitative approaches in order to provide deeper insights into a given phenomenon. Midgley (2014) supported this view, arguing that qualitative methodologies can enhance the effectiveness of quantitative approaches by generating new insights. Before considering the methods employed in this research in more detail, it is first worthwhile describing both of the approaches that are commonly used in IS research. The next subsections will provide a broad overview of the quantitative and qualitative methodologies.

4.2.1 Quantitative methodology

In more traditional research practices, qualitative and quantitative research methods are treated as two very separate approaches and are seldom combined. However, in IS research, it is quite common for these two distinct methods to be used in combination to develop meaningful insights into data and facts that provide explanations about the events and phenomenon that

can be observed in the social world. The positive methodological approach involves examining relationships between variables in a measurable manner on the basis that correlations between variables can be examined through a process of precise statistical and systematic analysis that results in solid data that can either prove or disprove the relationship between phenomena (Kuhn, 1970). Positivists believe that theory is derived from amalgamated knowledge that is accrued from the facts and data resulting from an empirical study. Data gathered through such an approach can be used to either accept or reject a hypothesis (Smith, 1998).

Quantitative research approaches are focused on the relationships that can be observed between phenomena. This approach is based on the notion that logical and numerical insights are required to establish solid links between the given variables. When employing quantitative methods to study the phenomenon that arises in the social world, it is important to apply a set of standardised instruments that replicate those employed in natural sciences to develop insights into the different perspectives and experiences of the people involved. Common approaches that are used within quantitative research processes are surveys and experiments (Bryman, 2001; May, 2001). These instruments need to be standardised and repeated in such a manner that the different perspectives of the research participants can be assessed and compared across a limited number of programmed response categories.

One of the most significant advantages of quantitative methods when applied within the domain of IS research is that they provide a mechanism by which the reactions of a large number of people can be assessed within the realm of a distinct set of questions and, therefore, they allow research outcomes and statistics to be compared and aggregated. The second biggest advantage of quantitative approaches is that they typically generate more universally acceptable outcomes that are less subjective and open to interpretation than those generated by qualitative approaches (Smith, 1998).

However, quantitative research methods are not without their disadvantages. One of the biggest disadvantages of this research approach is that it operates on the assumption that natural science, and by extension the natural environment, is imported in studying the social world. Unlike the natural sciences, in which the research environment can be controlled (for instance, pressure, temperature, height, etc.), it is not possible to predetermine and control human behaviour. As such, a static principle that drives research in the natural world will not conform to reality in the social world. Furthermore, it is possible for a researcher to conduct research in a detached manner because of the human nature of the study. Finally, because they are numerically driven, findings that are based on quantitative analysis can lack meaningful insights and, as such, may not be sufficiently reflective of the true undercurrents of the phenomena (Bryman, 2001).

4.2.2 Qualitative methodology

The qualitative method uses ethnographic data to identify and generalise relationships between the phenomena that can be observed in the social world. As such, the development of knowledge using qualitative information can be considered to represent the interpretivist paradigm; that is, the view that the best method of understanding the relationship between two

variables is to monitor and evaluate human interaction and expression as opposed to producing abstract statistical analysis (Atkinson & Hamersley, 1998).

To effectively apply the qualitative method, the researcher needs to develop a creative and proactive relationship with the research participants. This will allow the researcher an opportunity to generate and document meaningful information related to the participants' ideas and perceptions. When implementing a qualitative research study, the researcher is typically interested in two forms of communication: verbal communication, through which the subjects vocally share their opinions, and non-verbal or action communication, through which the subjects communicate their thoughts and feelings through body actions, writing, interpersonal interaction, physical gestures, etc. Qualitative research involves studying these forms of communication and then analysing behaviour patterns (Atkinson & Hamersley, 1998). Numerous different study techniques can be used during qualitative research. Examples include literature reviews, which allow the research an opportunity to study existing knowledge and understanding in the area; case studies, through which the researcher can elicit socially constructive data; focus group discussions; and interviews, which can be structured, semi-structured or unstructured.

Qualitative research is strongly concerned with individual experience and, as such, involves studying the richness and significance of this in detail (Cooper, 2001). The fundamental aim of a researcher who is involved in qualitative research is to discover the world in accordance with the subject's experiences and understanding and, subsequently, to communicate phenomenon according to the respondent's view (Hammersley, 2004). Qualitative research methods generate significant information about a smaller number of people and situations than quantitative research. However, they offer a deeper understanding of the cases studied, albeit one that is more subject to generalisation. In fact, according to Oates (2006), over generalisation represents one of the most significant challenges associated with qualitative research.

The qualitative approach to research can be advantageous in a number of ways. First, it allows both the researcher and the subjects to productively engage in knowledge generation. This entails that the data generated is generally more transparent and open than that developed during quantitative research, which is more statistical in nature. Second, quantitative research offers more flexibility to take into consideration the dynamic nature of human beings as opposed to producing static generalities about social phenomena. Rather, it seeks to develop insights into the relationship between the study variables through examining and analysing the thoughts and actions of the study population.

The current study employed a combination of qualitative and quantitative research methods and the justification for this approach is described in the next section.

4.2.3 Methodological justification

The fundamental aim of this research was to develop an adaptive e-learning system that is pedagogically effective while also offering satisfactory learning experiences to students with dyslexia. To achieve this objective, it was important that an effective research methodology was developed and implemented that combined both qualitative and quantitative approaches. Many

researchers have pointed out that there is an increasing tendency for IS researchers to conduct studies that rely purely on quantitative analysis alone (Szajna & Scamell, 1993; Brown et al., 2003; Dabholkar & Bagozzi, 2002; Venkatesh & Davis, 2000; Midgley, 2014). As such, it was acknowledged at an early point that a mixed methods research approach would represent an appropriate methodology for this study. The rationale underpinning this decision was threefold. First, the quantitative approach has been extensively tested and has proven to result in testable findings. It was envisaged that such findings would help to ensure that the theory and the hypotheses could be examined. This is aligned with the deductive approach, which reflects the statements and processes of a quantitative approach. Second, it was envisaged that using a quantitative approach that was very similar to that employed in existing IS research would result in findings that could readily be compared and contrasted with those of previous studies and, therefore, the variables validated. Third, as described by Malhorta and Birks (2003), the mixed research approach provides researchers with an opportunity to measure both attitudes and behaviour, and this can enhance the reliability of the results. As such, the mixed-methods approach was chosen to help the researcher develop an appropriate research instrument that could facilitate the testing and validation of the research outcomes.

The use of either a quantitative or qualitative approach in isolation can limit the results by generating uni-linear results; i.e., outputs that are based on the outcome of a single research methodology. To prevent such 'uni-linear limitation', it was necessary to combine quantitative and qualitative research methodologies in a manner that supported and complemented one another. Bryman (2001) described such an approach as a dual-strategy method, whilst Miles and Huberman (1994) suggested that the combination of a variable-oriented and a case-oriented approach to data analysis could significantly enhance the outcomes. The use of a mixed-methods approach offered the current study two interrelated merits. First, it was envisaged that the findings of the combined approach would be more precise, significant and secure, since they emerged from an in-depth analysis that allowed key information to be compared and interactions and overlaps to be analysed. It was assumed that this would ultimately produce more holistic and reliable results. A further advantage of the mixed-method approach was that it allowed the researcher to gain more in-depth insights into the research problem and broke down the intricacies of the phenomena more effectively than one of the approaches in isolation would have been able to achieve (Cresswell, 2003).

The next section provides a detailed overview of the data collection method that was employed together with the reasons why this approach was determined to be the most appropriate.

4.3. Research Method and Instrument

To understand the proposed models, frameworks and system that underpinned the research methodology employed in this study, it is first worth broadly examining the research methods that were available. Bryman (2004) described a research method as a procedure that is employed to gather meaningful data about the subject under examination. Data can be collected using a variety of different methods including case studies, observation, experiments, surveys, ethnography and action research. Of these, the survey is one of the most widely

accepted methods of collecting data because it has been proven to effectively collect key information about people's attitudes, views, beliefs and other constructed aspects. According to Cresswell (2003), the main goal of a survey is to access the opinions of a large sample of a population that covers a broad area. The two methods that are commonly used within a survey-based research approach are questionnaires and semi-structured interviews (Bryman, 2004). However, Oates (2006) stressed that the data collated through surveys can also be supplemented with observations and documents. He argued that survey methods are typically related to positivist paradigms when they involve the generation of generalisations. For the purposes of this study, quantitative and qualitative data was collected using a survey, which consisted of a questionnaire. In addition, an experimental design was employed to assess the effectiveness of the proposed adaptive e-learning system (see Section 4.5.1).

4.3.1 Rational of using experiment

Experimentation is often referred to as 'research in the small' because it typically involves conducting experiments in artificial settings, such as in a lab or classroom, that are highly constrained due to several factors including space, time limits, the availability of subjects, etc. However, while they may be constrained, one of their basic advantages is that they can be carefully planned and controlled, and this allows the researcher to test a very specific hypothesis. There are two main risks associated with experiments: the lack of problem domain knowledge from experimental subjects and the fact that the experiment is usually conducted in isolation of the real problem environment. Both of these risks can have significant implications for the external variability of a study. However, they can be controlled to a certain degree by providing subjects with familiar tasks.

Experiments have proven to be very useful in many domains, especially those related to the study of human behaviour. They also offer a high degree of validity because the results and conclusions can be more readily generalised to the larger population (Kaplan & Duchon, 1988). Furthermore, many researchers favour experiments because they offer more in-depth insights and are typically more persuasive and interesting to a mainstream audience. It is for this reason that they have attracted such significant attention from policy makers, practitioners and the media.

4.3.2 Rational of using survey

There are many ways in which questionnaires are suitable for this kind of research. First, questionnaires offer a very useful method of generating a broad range of data about the primary characteristics that are under investigation (Williamson et al., 1982). In addition, they can be readily adapted to the wide variety of subjects and research problems (Williamson et al., 1982). A further advantage of questionnaires is that they represent cost-effective research approaches because they do not generate interviewer wages and travel costs and, if closed questions are used, do not incur significant data expenses (Wright, 2005).

Bailey (1978) presented a detailed overview of the comparative cost advantage of questionnaires over interview methodologies. He described how research costs are rising due to interview and labour cost increases. Questionnaires tend to be less time consuming than the

alternative methods that are available, and can usually be completed at the respondents' leisure. As such, they can be much more cost effective. In addition, in many cases, they allow the respondents to consult personal records and other sources, think about their answers or even conduct their own research before providing a final answer (Bailey, 1978). In many regards, questionnaires are considered to be more reliable than the alternative techniques that are available, such as case studies, because they allow a researcher to collect data from a large sample. Furthermore, this research approach is typically more suitable for research that involves assessing and collating information related to the subjects' beliefs, behaviour, perceptions, ideas and attitudes (Malhorta & Birks, 2003).

Due to the various benefits of questionnaires outlined above, the questionnaire was chosen as the research tool of choice for this study according to the following rationale: (1) It matches the selected research paradigm and is associated with the selected strategic approach. (2) It is suitable for collecting information related to attitudes, beliefs and behaviours, which was deemed to be required for this research. (3) This research involved the use of a learning styles (LSI) survey to measure the preferences of dyslexic users and the responses provided in a questionnaire are used to construct this LSI. (4) It was anticipated that this method would allow the collection of data related to all of the DAELMS adaption features and could be conducted with all participants.

The instrument design and the process of measuring the constructs will be presented in Chapter 7 and Chapter 11. The next sections provide an overview of how the research methods outlined above were applied within the current research.

4.4. Challenges of the Research Topic

The three fold aims outlined in Section (1.4.3), in combination, sought to develop a means by which an adaptive technology can be developed that is capable of providing a pedagogically robust learning experience that meets the needs of students who have dyslexia. Unlike previous studies in this domain, the research conducted as part of this thesis was not the work of independent external researchers. Rather, it closely involved participants who have dyslexia with the intention of developing detailed insights into the challenges they encounter when interacting with e-learning systems and their perceptions of the offerings that are currently available.

Research of this nature is complex and multifaceted and should commence with an in-depth analysis of existing understanding through a comprehensive literature review of existing studies. Specific attention was paid to existing research and theories pertaining to e-learning, the learning experiences provided to dyslexic students in higher education settings, and adaptive e-learning technologies.

The research was implemented in four main phases. These are outlined below:

- **Phase One:** This involved a comprehensive search for existing studies that related to the research objectives with the intention of developing a set of recommendations based on the outputs of these studies.

- **Phase Two:** To develop and test a framework that clearly delineates the key functionality that an e-learning system must offer in order to meet the needs of dyslexic learners. Such a framework should take into consideration the unique learning needs of students who have dyslexia in relation to the type of dyslexia they have. In addition to testing the framework to evaluate the extent to which students are open and susceptible to such an approach, the Technology Acceptance Model proposed by Davis (1989) was employed to assess user's perceptions of the relative importance of the identified usability dimensions. A purpose-driven survey was conducted with 149 participants, and a multi-validation approach was subsequently employed to corroborate the outputs (see Chapter 7).
- **Phase Three:** During the third phase of the research, a novel semantic method was developed that aimed to overcome the issues associated with the current e-learning technologies by offering an adaptive experience that was aligned with the needs of dyslexic learners (see Chapter 8). The system design incorporated an ontological architecture that was capable of generating flexible learning experiences that are aligned with user's needs. As opposed to relying on knowledge of a given domain or adaptation strategy, the engine employs ontologies to obtain the required information. The outputs of this stage of the research resulted in the development of a new e-learning application called the Dyslexia Adaptive E-Learning Management System (DAELMS) (see Chapter 9 and Chapter 10).
- 1. **Phase Four:** During the fourth phase of the research, two different versions of the same application were designed. The first of these was an adaptive system that could actively support the learner through a given learning experience. The second was a direct replica of the first system; however, it did not incorporate any adaptive features. Both systems were then tested, with the learners using the first system for one course and the second for another. Each test session consisted of a five-minute pre-test, followed by an exercise that provided the user with an opportunity to interact with the system for 30 minutes and finally a five-minute post-test. The pre- and post-tests were employed to identify how much knowledge the students had gained as a result of their e-learning experience. Once the experiment was complete, the students were asked to complete a survey in which they shared their feedback on the two systems and their perceptions of the technologies employed. The total sample size involved in the evaluation aspect of this study was 48 experimental participants. These consisted of 11 dyslexic subjects, 23 participants with symptoms of dyslexia (possible dyslexics) and 14 non-dyslexic participants. The system evaluations are discussed in detail in Chapter 11.

4.5. Plan and Anticipated Outcomes of the Research

The research design employed within this research was formulated in accordance with the research question and objectives, the type of investigations required to adequately answer the research question, the sample, and the data collection and analysis functionality available. It consisted of both qualitative and quantitative approaches. The research methodology was

based on the assumption that, if the system adapts itself according to the students with dyslexia learning style, it will enhance their learning experiences.

4.5.1 Methods of data collection

Studies of this nature typically involve qualitative or quantitative research methods or a combination of the two. Quantitative research is data-driven and uses numerical information to draw conclusions about a given phenomenon or outcome. Qualitative research involves collating observations and information that is not in a numerical form. This research employed a combination of quantitative and qualitative as discussed in Section (0) research in the following ways:

1. **A participant survey:** A questionnaire was distributed to the participants. This consisted of both multiple-choice and open-comment sections. The questionnaires elicited the participants' perceptions of the features that they would like to see in an e-learning application, and they were required to rank the options using a Likert-type scale (Likert, 1932) that ranged from most important to least important. The outputs of the ranking exercise were quantitative in nature. However, the open comments that the respondents provided were qualitative. Further information is provided in Chapter 7.
2. **Pre- and post-test learner scores:** The learner scores provided quantitative data that could be statistically analysed to develop solid numerical insights into the extent to which each of the two systems were effective in terms of facilitating dyslexic learner's educational progress. Further information is provided in Chapter 11.
3. **Outputs of the learners' satisfaction questionnaire:** The questionnaire that was distributed to the participants consisted of 24 questions together with an open field area in which they could add their own comments. The questions were designed to elicit the students' opinions about their experiences with the system and the responses were assessed using a Likert-type scale (Likert, 1932) that ranged from "strongly agree" to "strongly disagree." The data acquired from this questionnaire was quantitative because it included a scale from 1 to 5. The information provided in the open comments section was qualitative and could not be assessed in numerical form. Further information is provided in Chapter 11.
4. **Dyslexia and learning style:** The analysis that assessed the relationship between dyslexia and learning style was quantitative. Further information about how the research compared the learning style preference of students with dyslexia with the existing theories presented in the literature can be found in Chapter 11.

This section provided a broad overview of the methodology that was employed in this research. For more in-depth details of the research approach and the analysis involved, see Chapter 7 and Chapter 11.

4.6. Chapter Four Summary

The aim of this chapter was to provide a justification for the research methodology that was adopted for this research. The chapter started by presenting the purpose of this research, and this helped to create a clear idea of the objectives that underpinned the research methodology. The chapter then progressed to provide a brief overview of the main paradigms that are typically used in IS research, positivism and interpretivism, and presented a detailed discussion of the philosophical assumptions on which they are applied. Accordingly, an explanation of the two most popular research methodologies, quantitative and qualitative, was provided together with the advantages and disadvantages of each these. Consequently, a justification of the researcher's decision to adopt a positivist paradigm in combination with mixed-methods research involving both quantitative and qualitative approaches was presented.

In addition, the chapter identified the various research methods that were available to the researcher with a specific focus on those employed within IS research. Although case studies are the second most popular method in the domain of IS research, particularly in research that is concerned with the adoption of technology, this method is typically employed in research at an organisational level. Given that the objective of the current study was to examine the relevant phenomena at the level of the individual, survey questionnaire and experiments were selected. Furthermore, such tools are the most popular research method in IS research and, therefore, was deemed to be suitable for the current study.

Chapter 5 Dyslexia Models - classification, symptoms and learning styles

5.1. Introduction

As we have already established, dyslexic individuals exhibit a diverse range of symptoms (Section 2.5). As such, it is important to conduct a formal investigation into the support strategies that can be employed to assist dyslexic learners. To this end, an extensive review of the existing support techniques that are used to help dyslexic computer users are explored in Section (0). This leads to the development of three central research models: dyslexia symptoms and classification, dyslexia assistive technology, and dyslexia and learning style model. These models act as the foundation upon which the Dyslexia Adaptive E-Learning Management System (DAELMS) proposed in Chapter 9 can be designed.

The following sections of this chapter³⁰ provide an overview of the origin of the fundamental dyslexia models and the motivation underlying their construction.

5.2. Dyslexia Models

5.2.1. The Dyslexia Symptoms and Classification Model (DSCM)

As described in Section (2.3), many different types and classifications of dyslexia have been proposed in existing literature and, as such, dyslexia itself can be divided into many different categories. Each theory defines dyslexia symptoms very differently, describes the key signs and symptoms in different ways, and proposes different means of facilitating effective learning experiences for dyslexic learners. The lack of consensus on dyslexia categories entails that it can be very difficult to classify dyslexia into different types. The model proposed in this section is based on Ingram's (1964) classification because this has been commonly employed in existing literature and is generally acknowledged to represent an effective method of categorisation. In 1964, Ingram described how dyslexics exhibit different symptoms. On the basis of his observations, he recommended dividing dyslexia into three categories: visuo-spatial difficulties, speech-sound difficulties, and correlating difficulties. The definition of each of these categories was described in detail in Section (2.3). However, while he highlighted appropriate categories, he did not describe the symptoms associated with each classification; as such, this represents a challenge for this thesis, which seeks to develop personalised learning experiences in accordance with dyslexia type. To overcome this issue, the author has identified the dyslexia symptoms associated with each of three dyslexia classifications that Ingram proposed. These are as follows:

³⁰ This chapter is based on the following peer-reviewed papers:

Alsobhi, A., Khan, N. & Rahanu, H. 2014, Toward Linking Dyslexia Types and Symptoms to The Available Assistive Technologies, in *Proceedings of the 14th IEEE International Conference Advance Learning Technologies (ICALT 2014)*, Athens, Greece.

Alsobhi, A., Khan, N. & Rahanu, H. 2015, Personalised learning materials based on dyslexia types: ontological approach, in *Proceedings of the 19th International Conference on Knowledge-Based and Intelligent Information & Engineering Systems (KES 2015)*, Singapore.

- (1) *Visuo-spatial difficulties (vs)* symptoms are: reading, writing, memory and mathematics.
- (2) *Speech sound difficulties (ss)* symptoms are: reading, writing, memory and speaking.
- (3) *Correlating difficulties (c)* symptoms is: writing.

In order to develop an enhanced understanding of the dyslexia classifications and their accompanying symptoms, a Venn diagram was developed using the following mathematical operation:

Let U be the universal set for all individual dyslexia symptoms, U is defined as {reading, writing, memory, mathematics, speaking}

Let be $vs = \{\text{reading, writing, memory, mathematics}\}$,

$ss = \{\text{reading, writing, memory, speaking}\}$, and

$c = \{\text{writing}\}$

Writing is the most common of the dyslexia symptoms among Ingram's three classifications. Writing difficulties sit at the intersection of the three classifications.

$$vs \cap ss \cap c = \{\text{writing}\}$$

If the student's dyslexia symptoms manifest themselves as reading or writing difficulties, he/she is considered to exhibit a severe form of dyslexia, and this sits at the intersection of visuo-spatial and speech sound difficulties.

$$vs \cap ss = \{\text{reading, writing, memory}\}$$

$$vs^c = \{\text{speaking}\}$$

$$ss^c = \{\text{mathematics}\}$$

The resulting Venn diagram is presented in Figure 5.1. This depicts the relationships between the dyslexia classification and the accompanying symptoms.

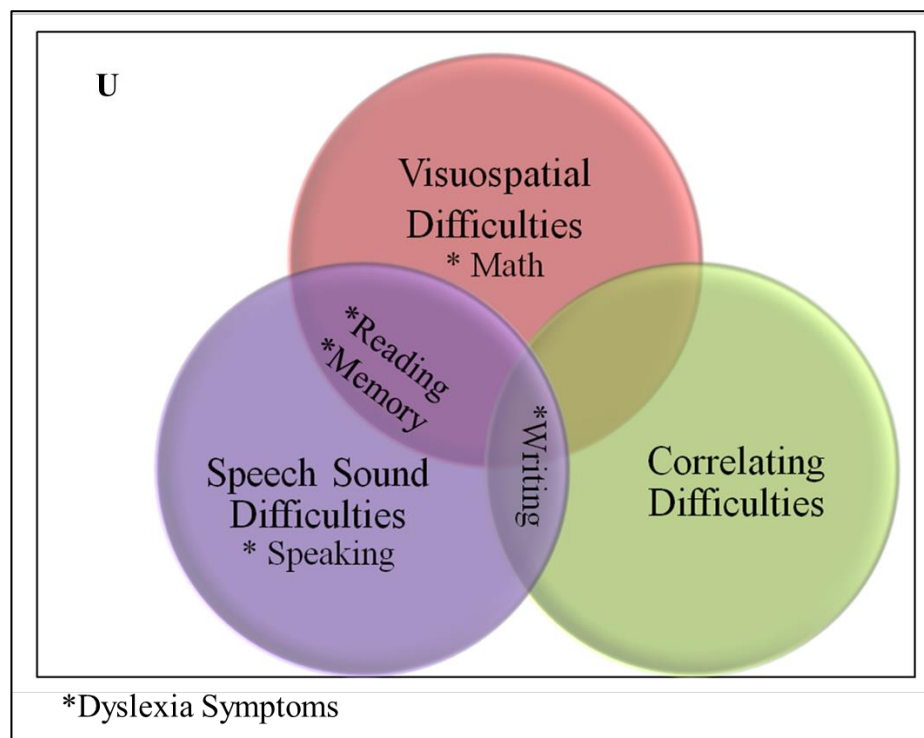


Figure 5.1 The relationships between dyslexia classification and symptoms (Venn diagram)

In Section (2.5) a literature review was conducted to identify the symptoms that subject experts agree are commonly associated with dyslexia, and to examine these in depth. It was apparent

that the authors of the respective studies were unable to agree as to the validity of some dyslexia symptoms. As such, any dyslexia symptoms that remain a subject of major dispute were explicitly rejected from this model and, instead, a consensus-based model of dyslexia symptoms and classification was generated. This model will form the foundation of the internal expert user model of dyslexia symptoms within the DAELMS. It will operate as a checklist that will be employed to identify whether students have dyslexia and will also be utilised at a later date to identify the extent to which learning style can be observed in terms of the dyslexia symptoms that students share. A graphical representation of the system model is presented in Figure 5.2.

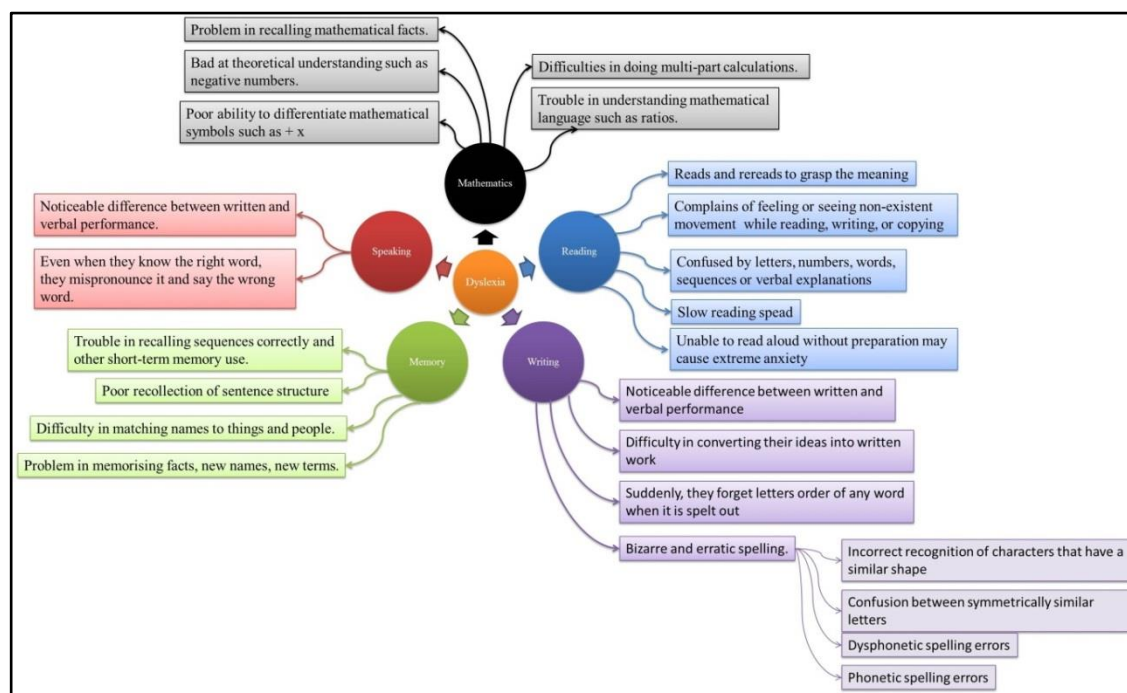


Figure 5.2 The Dyslexia Symptoms and Classification Model (DSCM)

There are a number of significant factors that should be taken into consideration when interpreting the consensus model outlined in Figure 5.2. These are as follows:

- A large number of researchers have examined and described the features that dyslexic subjects commonly exhibit. The works described in the literature review represents only a small proportion of the existing knowledge that is available on the behavioural characteristics that are associated with dyslexia.
- The proposed model is based on a loose notion that 'typical' dyslexia symptoms exist. Given the very complicated nature of dyslexia, it is very unlikely that an individual with dyslexia will exhibit all the symptoms described. In addition, the symptoms themselves will significantly vary from subject to subject in terms of how they manifest themselves and their severity.
- In the event that consensus between theorists could not be established in terms of a given symptom, these symptoms were excluded from the model; for example, poor organisational skills (Miles & Miles, 2004).

5.2.2 Dyslexia Assistive Technologies Model (DATs)

With Once the Dyslexia Symptoms and Classification Model had been developed to represent the existing system expert knowledge of dyslexia symptoms, it was possible to formulate the Dyslexia Assistive Technologies Model (DATs). A decision table was developed to provide an effective means of ensuring the dyslexia types and symptoms were appropriately and effectively linked with the available assistive technology. The initial investigation revealed that at least one assistive technology is available for each recognised dyslexia symptom and, in many cases, there are multiple assistive technologies available. Figure 5.3 presents a pictorial representation of the proposed model. The DATs model took into account the main findings of the literature review presented in Section (0), and was specifically developed to include two essential elements:

- (1) Symptom (as previously identified in the DSCM).
- (2) Dyslexia help via assistive technologies. This aspect of the model aims to identify which of the existing assistive technologies can be effectively embedded (or integrated) into an e-learning system.

According to Vanthienen and Wets (1992), decision tables are capable of “Representing the exhaustive set of mutual exclusive conditional expressions, within a predefined problem area” (p. 28). One of the biggest advantages of decision tables is that they can generate a more compact visual presentation of a problem and, therefore, provide the decision maker with useful insights that will be beneficial in the decision-making process. Furthermore, one of the biggest advantages of decision tables it that they make it easier for the user to verify the completeness, correctness and consistency of the information input. The Venn diagram in Figure 5.1 provides an overview of the three different classifications of dyslexia. These three classifications were applied as the conditions for the decision table employed within this research. The simple Boolean values of Y and N represent the alternatives for these conditions. Figure 5.3 presents the DAT model with the three conditions such that $2^3=8$ different alternatives. As discussed in Chapter 3, and as can be seen in Table 3.1, there are 17 different assistive technologies. These were all considered as the actions for the decision table and are denoted by check marks that represent which of the actions in a given column are to be performed. This decision table will help e-learning developers when they are in the process of producing plans or designs for assistive technologies that incorporate adaptive learning. This table provides an overview of the functional or technical requirements of the proposed adaptive e-learning system and takes into consideration the requirements and limitations associated with students with dyslexia, the policies that govern education, and the environment within which interventions are delivered.

			Rules								
Conditions	Dyslexia classification	Visuospatial Difficulties		Y	Y	Y	Y	N	N	N	N
		Speech sound Difficulties		Y	Y	N	N	Y	Y	N	N
		Correlating Difficulties		Y	N	Y	N	Y	N	Y	N
Actions	Assistive Technologies	Reading	Text Readers	✓	✓	✓	✓	✓	✓		
			Optical Character Recognition	✓	✓	✓	✓	✓	✓		
			Reading Pens	✓	✓	✓	✓	✓	✓		
		Writing	Word processor	✓	✓	✓	✓	✓	✓	✓	
			Word Prediction Software	✓	✓	✓	✓	✓	✓	✓	
			Digital Recorders	✓	✓	✓	✓	✓	✓	✓	
			Voice Recognition Software	✓	✓	✓	✓	✓	✓	✓	
			Electronic Dictionary	✓	✓	✓	✓	✓	✓	✓	
			Spellcheckers	✓	✓	✓	✓	✓	✓	✓	
		Memory	Mind-mapping Programs	✓	✓	✓	✓	✓	✓		
			Personal Organisers	✓	✓	✓	✓	✓	✓		
			Map-reading software	✓	✓	✓	✓	✓	✓		
		Speaking	Speech recognition programs	✓	✓			✓	✓		
			Voice Recording Programs	✓	✓			✓	✓		
		Mathematics	Calculators	✓	✓	✓	✓				
			Spreadsheets Programs	✓	✓	✓	✓				
			Speech recognition for Mathematics.	✓	✓	✓	✓				

Figure 5.3 The DATs model as decision table

The decision table can be viewed as an overview of the findings of key research studies that have examined dyslexia and assistive technologies. However, rule-based techniques, which employ basic IF-THEN logic rules, were employed in the proposed model (see Appendix D) to generate appropriate recommendations for the required assistive technologies. Table 5.1 presents an example of the logic rules that could be used to link the required assistive technologies to dyslexia type.

Table 5.1 Example logic rule to link the required assistive technologies to dyslexia type

Example rule to match dyslexia type with the required assistive Technology:*IF dyslexia classification is "Speech sound Difficulties"**AND dyslexia symptoms is "Speaking"**THEN assistive technologies are "Speech recognition programs"**OR "Voice Recording Programs";***5.3. Dyslexia and Learning Styles Model (DLSM)**

There are several benefits associated with investigating the correlation between learning styles and dyslexia type (described in detail in Section 5.3.2). These include acquiring the knowledge required to adapt learning experiences to learning styles, and using the data about learning styles to improve the effectiveness of the process by which experiences are adapted to dyslexia type. Furthermore, information about learning styles and dyslexia type provides more holistic adaptivity in terms of taking into consideration both students' learning styles and their dyslexia type in adaptive educational hypermedia systems.

The interaction between the Felder-Silverman learning style model (FSLSM) and dyslexia type was investigated to further exemplify the relationship between learning styles and dyslexia type. The next subsection presents a comprehensive literature review of existing studies that contain useful insights that enhance understanding of the relationship between the four dimensions of FSLSM and dyslexia type. Following a review of existing works in this area, experiments that employed real data are presented. These involved the learners completing an Index of Learning Styles (ILS) questionnaire, the results of which provided useful information about the respondent's learning styles. The participants were also asked to perform a basic task that was designed to elicit information about their dyslexia type. The results of the analyses are examined in depth and compared with the results of the literature review in Chapter 11. A key focus of this discussion is on the ways in which an understanding of the identified relationship can facilitate adaptive educational hypermedia systems.

5.3.1 The relationship between FSLSM and dyslexia types

The relationship between learning styles and dyslexia type was investigated in depth via a comprehensive literature review in order to generate useful insights that could be employed to improve the adaption process of learning styles. An analysis of the existing studies in this domain was employed to identify the indirect relationships between dyslexia type and the dimensions of FSLSM. The following subsections will present an overview of these studies. The discussion will start by providing a comprehensive overview that will facilitate an understanding of the relationships between dyslexia types and learning styles. Following this, notable studies will be examined to investigate the extent to which there is evidence of a relationship between each learning style dimension and dyslexia type.

5.3.2 Understanding the relationships between learning styles and dyslexia

A study by Simmons and Singleton (2000) compared the reading comprehension of a group of dyslexic university students with their non-dyslexic peers, and established that dyslexic students

exhibited significant impairment in terms of their ability to construct inferences while processing complex text. No significant differences between the two groups were observed when the participants were asked literal questions about information that was explicitly stated in the text. However, significant differences were found when inferential questions were asked that required the students to combine one or more units of information or to use their existing knowledge to interpret an ambiguous statement. Dyslexic students did not perform as well as non-dyslexic students on tasks that involved answering inferential questions, and the researchers attributed this to the fact that dyslexic students have a working memory deficiency (Simmons & Singleton, 2000). Their findings were supported by later research by Calvo (2001), in which the results of reading-span task revealed that working memory plays an important role in the text-integration process and, as such, is critical to elaborative inference. Essentially, inferential ability plays an important role in bridging the gap between the required semantics (Calvo, 2001).

Beacham, Szumko and Alty (2003) examined the effect that different presentation modes had on the outcome of online courses that were provided to dyslexic students. Within this study, key information about the participants' learning styles was elicited through the use of the ILS questionnaire. According to Simmons and Singleton (2000), dyslexics have impaired working memory capacity. The results of these studies support the hypothesis that learners who have lower working memory tend to have a poorer reading ability. Mortimore (2008) suggested that the achievements of students with dyslexia are enhanced when they are presented with multi-sensory learning experiences that use a variety of channels to reinforce learning. Mortimore's research supported an earlier study by Beacham and Alty (2006) that concluded that the learning performance of dyslexic learners can be directly impacted by the different combinations of media through which the learning experiences are presented.

Earlier research by West (1997) suggested that there is a relationship between visuospatial strategies or strengths and dyslexia. However, this hypothetical relationship has yet to be proven through empirical research and, as such, it remains somewhat subjective (Mortimore, 2008). Exley (2003) conducted research in which seven dyslexic students were assessed. She found that five of these students preferred a visual learning approach and suggested that her findings were of significance. In a small-scale study, Mortimore (2008) completed cognitive styles analysis (Riding, 1991) of 30 students, 15 with dyslexia and 15 without, with the intention of identifying the extent to which dyslexic students favour visual processing over verbal approaches. This study also suggested that there is a relationship between visual style labels and dyslexia.

5.3.3 Linking FLSM dimensions and dyslexia types

As described above, it can be more effective and straightforward for students and their teachers to classify dyslexia according to symptoms as opposed to classifications or types. According to the DSCM, there are three types of dyslexia. Each type has different associated difficulties including reading, writing, speaking, mathematics, and memory. The next sections will map each dyslexia symptom against the dimensions proposed by Felder and Silverman (1988).

Reading

A student who has dyslexia reading difficulties tend to think primarily with images and feeling not sounds or words (visual). They struggle to grasp the meaning of words or symbols. Their struggling in translating words puts them at a disadvantage in timed tests: since they may have to read questions several times before beginning to answer them, they frequently run out of time. Their perceiving of the world involves observing, gathering data through the senses (sensory). Learners with reading dyslexia remember much of what they hear and more of what they hear and then say (sensory). They get a lot out of discussion more than reading. Actually, this reflects that the most applicable assistive technologies for them are related to sounds such as “Text to Speech Readers” and “Reading Pens”.

Writing

A study by Brooks and Weeks (1998) concluded that students who have writing dyslexia learn more effectively if instruction is tailored to their visual and semantic strengths. Exley (2003) concluded that dyslexic students who have writing problems tend to attempt to vocalise elements of the word (verbal) while also creating a visual image of it (visual). In his study, he examined the effectiveness with which seven dyslexic students were taught how to spell new words. He found these students learned new words through visual strength providing this ability is combined with auditory channels. The students who participated in the study required a strong visual image of the word that was written in bold on an A3 sheet of paper or on a large whiteboard to utilise the visual channel. Alternatively, they spoke elements of the word aloud while generating a visual image of it (visual/verbal).

Speaking

Learners with speaking dyslexia typically speak with a stutter or in disjointed sentences when under stress, mispronounce long words, or transpose phrases, words and syllables when speaking. As such, these individuals generally avoid situations in which they are required to discuss or explain things to others (reflectively). Reflective learners work better in isolation or in discrete partnerships as opposed to collaborating with larger numbers of people (Felder & Silverman 1988). They find delivering a presentation or public speech particularly stressful. Turner and Hope (2006) advised students who have speaking dyslexia to summarise their thoughts and ideas in the form of a picture or diagram (visual) form to increase their confidence and overcome their fears.

Mathematics

Chinn and Ashcroft (1999) explains that difficulties in mathematics for students with dyslexia may be due directional confusion, sequencing problems, poor short - term and working memory, speed of working, cognitive style, anxiety, stress and self-image. Joffe (1980), in her study of students with dyslexia’s mathematics performance, found that calculation tended to be the major area of weakness, and this she attributed to the students with dyslexia difficulty with verbal labelling and short-term memory. She found that spatial skills (sensory), needed for understanding shape, size and relative size and quantity. The mathematical skills for the students with dyslexia are improved when they try to link the mathematical terminologies with (visual) reminder according to study by (Exley 2003). Mathematical functions should be

illustrated by flow charts and graphs to simplify complex processes or algorithms (visual/sequentially).

Memory

Students with dyslexia have excellent long-term memory for experiences, locations, or faces. However, they have poor memory for sequences or information that has not been experienced. They reasons mainly with images (visual) and with step-by-step progression diagram (sequentially). It facilitates processing and transfers information to the long-term memory. It is fair to argue that learners with severe deficiencies in working memory would have problems in reading, and according to Beacham, Szumko, and Alty (2003) would likely prefer visual learning (visual). Wey and Waugh (1993) argue that learners with low working memory capacity benefit from visual material and therefore prefer a more (visual) learning style.

5.3.4 Constructing Dyslexia and Learning Styles Model (DLSM)

According to Cassidy (2004), an individual's learning style can be interpreted as the way in which he or she perceives, interacts with, and responds to the learning environment. Furthermore, learning styles can be perceived as the forms, methods or strategies that a student prefers to select, process, and work with information. As such, learning style can be broadly viewed as a student's learning preferences. As we have already discussed, the Dyslexia and Learning Styles Model (DLSM) is based on the Felder-Silverman's Index of Learning Styles (ILS) (Felder & Silverman, 1988) and combines learning styles across four dimensions (active/reflective, sensory/intuitive, visual/verbal, and global/sequential) to define the learning styles of dyslexic students (See Figure 5.4).

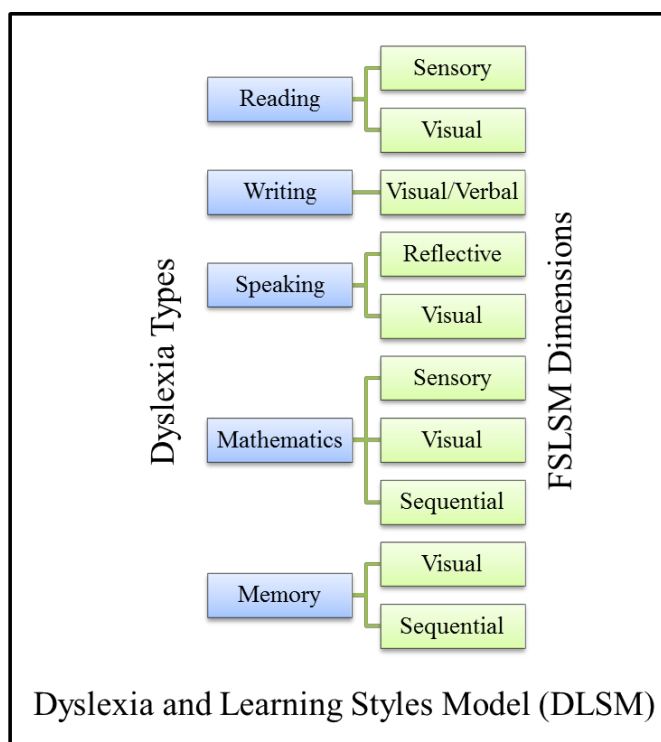


Figure 5.4 Dyslexia and Learning Styles Model (DLSM)

An analysis of the DLSM revealed that, of the learning styles that are recognised, the visual learning style appears to be the most dominant in dyslexic learners and is employed by learners

of all dyslexia types. Beacham, Szumko and Alty's (2003) study agreed with this reasoning, proving that 97% of dyslexic learners are visual learners while the remaining 3% are also positioned in the mild-verbal range. They also discussed how such learning style preference was to be expected since dyslexic people have been proven to exhibit strong talents in the areas of creativity and visual thinking. This finding echoed the earlier conclusions drawn by Wey and Waugh (1993). Both studies revealed that learners who have low working memory benefit from visual material and, therefore, prefer a more visual learning style. To develop a personalised learning experience that is aligned with a dyslexic learner's preferences in terms of learning style, dyslexia type and knowledge level, the author of the current study proposed a new ontological approach to learning experiences that was based on learning style and dyslexia type (see Chapter 8). The DLSSM model was employed to design this system and provided significant input to the formulation of the personalised learning materials. Rule-based techniques that employed simple IF-THEN logic rules were utilised in the proposed model to deliver personalised learning materials (see Chapter 10). An example of this can be observed in Table 5.2.

Table 5.2 Example logic rule to match the dyslexia type with suitable learning style

Example rule to match the dyslexia type with suitable learning style:
<i>IF dyslexia type is "memory"</i> <i>THEN learning style is "visual"</i> <i>OR "sequential";</i>

Appendix D presents a full list of the logic rules that were developed for the FLSM model and dyslexia type. The proposed system will employ these logic rules to develop personalised materials that the system utilises to present learning experiences that match dyslexia type with learning style.

5.3.5 Benefits of understanding the relationship between FLSM and dyslexia types

The relationship between FLSM and dyslexia type that is identified can be employed to generate additional information about the students. This information can enhance the student modelling process. This will, in turn, lead to the development of a more reliable and richer student model that effectively and accurately offers optimised holistic adaptivity. Specifically, the relationship between learning styles and dyslexia types can offer two types of adaptive educational hypermedia systems. The first type of systems are those that are capable of detecting dyslexia types or learning styles in isolation but not in combination. In the case of these systems, the relationship yields additional information about additional characteristics of the user that may be of relevance. As such, a system that can only detect dyslexia types can utilise the identified relationships to acquire further information about the learning styles of each user. This additional information can be subsequently employed to develop a more comprehensive student model and to provide more holistic adaptivity by taking both dyslexia types and learning styles into consideration. In addition, this relationship can be informative for systems that are only able to detect learning styles through providing information about dyslexia types. This, again, enhances the student model and increases the extent to which the system offers holistic adaptivity.

The second type of systems that can benefit from the relationship between learning styles and dyslexia types are systems that incorporate both learning styles and dyslexia types. If the student model includes information about only learning styles or only dyslexia types, it can be extended by including information about the other. In this case, while the student model already includes both learning styles and dyslexia types, explicitly identifying the interaction between learning styles and dyslexia types can result in the construction of a more reliable student model.

As discussed above, explicitly identifying the relationship between learning styles and dyslexia types can generate key information that can be employed to improve the adaption process. In addition to accelerating the process by which learning experiences are adapted to student learning styles, it can also improve the reliability of the student model. Incorporating larger amounts of data in the adaption processes leads to a more accurate and dependable results and, therefore, improves student modelling.

5.4. Chapter Five Summary

This chapter outlined the development of three fundamental framework models: The Dyslexia Symptoms and Classification Model (DSCM), the Dyslexia Assistive Technologies Model (DATs), and the Dyslexia and Learning Styles Model (DLSM). The DSCM model forms the foundation of the internal expert user model of dyslexia symptoms within the DAELMS system. It also operates as a checklist that can be employed to assess whether students have dyslexia or not. The remaining models enhance the student modelling process, leading to the development of a more reliable and richer student model that, again, facilitates more accurate and holistic adaptivity. This chapter has summarised the theoretical requirements for providing adaptivity and personalised learning experiences. The next chapter proposes a new framework that outlines the functional or technical requirements that the e-learning design must meet.

Chapter 6 Dyslexia Adaptive E-Learning Framework (DAEL)

6.1. Introduction

This chapter³¹ presents a comprehensive overview of existing research and theories pertaining to the use of adaptive e-learning systems with students with dyslexia together with the basic requirements of such a system. The Dyslexia Adaptive E-Learning Framework (DAEL) has been specifically designed to meet dyslexic learner's needs across four components: presentation, hypermediality, acceptability and accessibility, and user experience. However, to date, there appears to be a lack of solid research that examines dyslexia type and how dyslexic students' viewpoints can be taken into consideration in system design. This chapter aims to bridge this gap by proposing a framework that has the potential to meet the standards of acceptability and accessibility for dyslexic students. This framework is based on the fundamental hypothesis that dyslexic students will benefit from interacting with adaptable e-learning systems that adjust learning experiences and content to the specific needs of their dyslexia type.

This chapter discusses the relevance and incentive underlying the standards of accessibility and acceptability with respect to the four dimensions of the DAEL framework: presentation, hypermediality, acceptability (including accessibility), and user experience. At present, there are very few systems available that meet the guidelines associated with all four of these dimensions. For example, existing Web Accessibility Initiatives (WAI) and similar accessibility guidelines outline how systems can be adapted to meet the needs of people who are visually impaired or blind; however, very few studies have specifically examined the main issues that people with dyslexia and other specific learning difficulties (SpLDs) experience when interacting with computer-based systems. As such, no specific offerings have been developed. The framework proposed in this thesis aims to bridge this gap by developing a system for dyslexic students that is capable of facilitating their learning experiences as opposed to hindering them.

The remainder of this chapter is organised as follows: first, a description of existing theories that are relevant to the research objectives are presented in Section (6.2). Following that, Section (6.3) provides detailed insights into the DAEL framework and, finally, Section (6.4) summarises the main findings in this area.

6.2. Relevant Theories and Suitable Attributes

It is typical for any research project to start by examining existing theories and using these to form the basis of the scientific knowledge that underpins the development of new technologies or cures for diseases. Over the last ten years, researchers and organisations that specialise in dyslexia have developed a set of generic design principles that should be taken into consideration when developing a computer system that is specifically designed for dyslexic learners (Lovegrove et al., 1980; Molich & Nielsen, 1990; Rello et al., 2012; British Dyslexia

³¹ This chapter is based on the following peer-reviewed paper:

Alsobhi, A., Khan, N. & Rahanu, H. 2015, DAEL Framework A New Adaptive E-learning Framework for Students with Dyslexia, in *Proceedings of the International Conference On Computational Science, (ICCS 2015)*, Reykjavik, Iceland.

Association, 2015; Rainger, 2003). The majority of existing guidelines have been developed through three research phases:

- Evaluation of existing software offerings that have been developed specifically for dyslexic computer users;
- Research into wider universal accessibility;
- Expert opinion on the typical characteristics and symptoms of dyslexia.

The following section presents a comprehensive overview of the domain that is most relevant to the research objectives of this thesis: dyslexia and e-learning. The main findings of this literature review will be employed to develop a sound theoretical grounding of the e-learning requirements of students with dyslexia. This knowledge will subsequently be utilised to inform the development of an effective adaptive e-learning system.

6.2.1 Presentation

Some scholars, such as Guardiola (2001), consider dyslexia to be a cognitive disability, and so cognitive learning theories must be studied before the design of any e-learning system for dyslexic students. Cognitive theory says that the amount of information learned is determined by the learners' ability to process information (Craik & Tulving, 1975). Apart from the amount of effort expended by the learner in the learning process, the depth of the learner's processing (Craik & Tulving, 1975) and the structure of the existing knowledge of the learner (Ausubel, 1960) are considered as other factors for determination.

This in turn implies that when designing e-learning systems the materials must be presented according to some strategies that will enable students to process the materials efficiently. The information on the e-learning system should be organised and presented in small paragraphs, hence facilitating brain processing. This is because dyslexics have a limited capacity in their working memory. Miller (1956) mentioned that information in the classroom should be grouped into meaningful sequences to assist those with short-term memory.

A report conducted by the Disability Rights Commission in the UK (DRC) in 2004 focused on the accessibility of the web for disabled people. The report showed that there were more than 100 Checkpoint violations per page. This demonstrates the scale of the obstacles impeding disabled people's use of websites (Disability Right Commission, 2004). One of the violations that have been expressed by people with dyslexia is the, 'unclear and confusing layout of pages'. Most of the other violations stated were related to the presentation and navigation of the webpage. This highlights the importance of the presentation of e-learning systems for students with dyslexia.

Most of the general presentation aspects of the graphical user interface are concerned with how to make the system more interactive by choosing icons and interaction styles, or by selecting different layout designs (Mayhew, 1992). This framework proposes that e-learning systems should be analysed from general and specific points of view. The presentation dimension refers to the most general point of view common to all interactive systems, while the other dimensions address the appropriateness of design with respect to dyslexic types and the purposes of the system.

6.2.2 Hypermediality

The first appearance of the term 'hypermediality' was in Nelson (1965). It is extended from the terms hypertext and hyperlinks (Brusilovsky, 1996). Hypertext is where graphics, audio, video and plain text are used in designing webpages. These two terms intertwine to create a non-linear medium of information, which is hypermediality. One of the e-learning characteristics of today is hypermediality. Hypermediality facilitates in-depth study and provides deeper insights for taught courses for students. However, research on hypermedia has pointed to two problems, which are cognitive overload and loss in hyperspace (Ardito et al., 2006). This reflects that one of the key distinguishing features in considering hypermedia systems is the notion of navigation, which must be designed (Schwabe, Rossi & Barbosa, 1996).

Referring to dual-coding theory, Paivio (1996) reported that information received in different modes, such as textual and visual, will be better processed than that presented in a single mode, such as text only. Multi-modes would help individuals with dyslexic 'visuospatial difficulties', and those who have difficulties with short-term memory use. Using different modes for delivering information helps dyslexic students to spot their own mistakes, because they are often not good at this skill. Dual-coded information is processed in different parts of the brain. This in turn will result in more information coding or manipulating. Unlike other cognitive theories, dual-coding theory offers an explanation for both reading and writing (Paivio, 1996); it also facilitates processing and transfers to the long-term memory.

Presenting information in different modes also accommodates individual differences in processing, such as dyslexia. This thesis highlights that dyslexia has many forms and barely two individuals share the same symptoms; hence the 'one-size-fits-all' approach to developing e-learning systems is problematic (Beacham & Alty, 2006). Findings from previous studies e.g. (Cobb, 1997) state that poorly designed e-learning systems may increase the difficulties for students with dyslexia. He raised a concern regarding the representation of information, and whether information was represented using media for all sensory forms including touch. Alternatively, different e-learning systems can be designed for different learning tasks.

6.2.3 Acceptability and accessibility

User acceptance is an important primary measure of system success (DeLone, & McLean, 1992). Acceptability is considered to be a new term for adequacy with respect to satisfying the user's needs or complying with requirements or standards. In other words, acceptability refers to the accessibility needs of users (Maguire & Bevan, 2002). There are various models and theories explaining and measuring users' acceptability and predicting the level of user intentions to use a system. One of them is the Technology Acceptance Model (TAM) proposed by Davis (1989). The model provides an adequate foundation for evaluating a student's preparation and readiness before adopting an e-learning system. Usefulness and ease of use convey the level of acceptance for the service or system. These two variables are considered as the base for TAM. Similar attributes could prove to be useful for designing e-learning system for students with dyslexia.

This thesis forms a conceptual model based on pedagogic theory, learning, and individuals with special needs due to dyslexia. This conceptual model has been chosen as the model that directs the identification of attributes. Identifying these attributes will make a user's experience acceptable and accessible.

6.2.4 User experiences

There is a correlation and overlap between usability and user experience. They both relate to how well a product or system is designed. However, usability focuses on the ease of use of the products and on how the users achieve their goals with minimum fuss and without errors. Whereas user experience focuses on making people happier by involving a more emotional dimension in the system, such as desire, joy and meaning. This reflects Nielsen's (2000) user experience theory, which was based on cognitive science. In a similar context, Norman's (2002) theory focuses on emotional design and users' feelings before, during and after using any system.

In most of the existing e-learning systems, usability features that are commonly discussed are included (see Section 3.2). On the other hand, other features such as conventions, user diversity and customisations are not addressed. This is because most of the common systems are developed for just one group of people (i.e. 'non-disabled'), but eventually they tend to fail in accessibility and usability areas for different group of people. Therefore, the term 'user experience' is relatively newer than other domains, such as human computer interaction and usability. This dimension focused on what users' need, on what activities they would perform and on how the system manages with them.

From the perspective of dyslexic students, e-learning materials tend to be primarily developed for non-dyslexics. Hence, this increases 'the inability to provide accessibility and convenience for all learners' (Beacham & Atly, 2006). This will make dyslexic students struggle because they spend even more time and effort learning than they currently do using traditional approaches (Beacham & Atly, 2006). User experience is a very significant factor in measuring the quality of websites or systems' interaction with the user. User experience must be considered before developing any e-learning system. One of the keys to developing a successful e-learning system is to involve prospective students, as stated by Smith (2002). He involved a group of dyslexic students in his design of a Virtual Learning Environment (VLE) Interface and claimed that such an involvement supports the wider deployment of user testing. Section (6.3) presents a broad overview of the framework, while Section (5.3.1) describes some of the key dimensions and attributes in more depth. In Section (6.3.2), the author establishes a link between the proposed framework and the Technology Acceptance Model (TAM). Finally, the framework is finalised in Section (6.3.3).

6.3. The DAEL Framework

The proposed framework (see Figure 6.1) attempts to improve the educational process with the objectives of improving presentation, acceptability and accessibility, as well as user experiences, especially for students with dyslexia. The core of the four dimensions and the 26

attributes are based on the researched theories in the respective domain, as discussed above. Some of the reasons behind dividing according to these criteria are to enable a robust comparison of the frameworks and systems' features, advantages and disadvantages. This would ultimately lead to the development of the proposed framework.

Table 6.1 Chosen Dimensions and attributes for the DAEL Framework

Dimension	Attribute	Label
Presentation	Personalisation	A
	Clarity	B
	Adequacy	C
	Self-descriptiveness	D
	Memorability	E
	Simplicity	F
	Helpfulness	G
	Learnability	H
	Mapping	I
Hypermediality	Technology Variety	J
	Media Channels Variety	K
Acceptability and Accessibility	Accommodate different learning styles	L
	Scaffolding	M
	Incremental Feedback	N
	Constructivist Learning	O
	Linearity	P
User Experiences	User Disability Type	Q
	Controllability	R
	Aesthetics	S
	Attitude	T
	Consistency	U
	Multiple Language Support	V
	Effectiveness	W
	Efficiency	X
	Robustness	Y
	Constraints	Z

The four dimensions with 26 attributes have been identified after conducting an extensive study on the available theories in the respective domain, as discussed above, and supported by (Surjono, 2014; Shi et al., 2013; Beacham & Alty, 2006; Ardito et al., 2006; Norman, 2002; Smith, 2002; Dickinson et al., 2002; Wright, 2001; Cobb, 1997). These dimensions and attributes have been used to design the proposed framework, the Dyslexia Adaptive E-Learning (DAEL). Table 6.1 above summarises the elements of the DAEL framework. The framework will facilitate the structuring of the attributes, which are based on the researched theories of the four dimensions. In the literature, most of the existing frameworks (Baguma & Lubega, 2008) tend to provide general solutions, either by enabling features or providing instructions.

To the best of the author knowledge, no such framework previously existed to cater for the needs of dyslexics. Furthermore, there is no system that responds to their feedback and personalises itself in accordance with the learner's preferences.

6.3.1 DAEL framework dimensions and attribute

The following subsections present more comprehensive insights into each of the four dimensions of the DAEL framework together with their attributes and a justification as to why these attributes have been included in the framework.

6.3.1.1 Presentation attributes

The presentation attributes describe the various system components and features that have been specifically designed for e-learning system interfaces, content organisation and efficient navigation. Each of the presentation attributes is examined in more depth below:

- A. *Personalisation*: Dyslexic students exhibit a range of different symptoms, and no two dyslexic adults are typically the same. As such, dyslexic subjects need to have the ability to adjust basic visual aspects of the system to meet their unique preferences; for example, the font style, size and colour, and the background and foreground colours (Wright, 2001; Dickinson et al., 2002).
- B. *Clarity*: It is a well-known fact that dyslexic subjects experience problems with short-term and working memory. As such, the clarity and usability of navigation mechanisms are of immense importance in any e-learning system that is designed to cater to the needs of dyslexic learners. The material presented on these systems should be structured in an intuitive manner with clear headings and subsections that enhance clarity.
- C. *Adequacy*: Adequacy involves adapting the graphical images that are presented to a user with the context of use. This is of particular importance for dyslexic and SpLDs learners. No limitations should be placed on the adequacy of any learning system.
- D. *Self-descriptiveness*: Dyslexic students typically experience issues with their long-term memory. As such, e-learning systems that are specifically designed for these students should contain features and functionality that reduce a student's need to retain information and, therefore, reduce his or her memory load. A system that incorporates effective self-descriptiveness is essentially able to describe itself in a very simple way that allows students to focus on completing learning tasks as opposed to trying to understand how to operate and interact with the technology (SAP, 2004). Effective self-descriptiveness will allow students to operate in a more effective and efficient manner.
- E. *Memorability*: Memorability entails delivering systems functions and operations that the student can readily memorise. This attribute, again, will help dyslexic students with short-term memory. Memorability is important because, if a student uses the system and later cannot remember how to use it, they may avoid the system in the future.
- F. *Simplicity*: As with memorability and self-descriptiveness, the purpose of simplicity is to offer a solution that the student enjoys working with and, therefore, more likely to be used on a frequent basis. Simplicity, however, does not necessarily equate to lack of functionality. A simple system is one that a student can easily understand, use and interact with within a short period of time (Berkun, 1999).
- G. *Helpfulness*: Context-based help and prompts can help students to use and interact with the system and ensures that users are able to make the most of the various

functionalities that are available. The more helpful a system is, the more likely it is that students will be happy to use it.

- H. *Learnability*: Learnability and usability are closely related. As research completed by Beacham and Alty (2006) pointed out, e-learning systems can take dyslexic students a large amount of time and effort to learn. However, if they can develop a basic understanding of system quickly, this time and effort can be reduced. To enhance the learnability of an e-learning system for dyslexic students, developers should fully understand dyslexic learner's needs, expectation and preferences prior to designing the system and should ensure that the system and its functionality take these into consideration.
- I. *Mapping*: It is important that the system mapping is reflective of the function context, purpose and logic of the system because effective mapping increases understandability. The icons and buttons that are used are particularly helpful to dyslexic subjects because such students often favour images and symbols over words. However, it is important to note that, while there are obvious advantages associated with using icons as opposed to text within e-learning systems that are targeted at dyslexic learners, the majority of research in this area does indicate that icons should not be used in isolation (Haramundanis, 1996).

6.3.1.2 Hypermediality attributes

The second of the key four dimensions of the system is hypermediality. This is reflected in the following areas of the framework:

- J. *Technology Variety*: A study conducted by Fichten et al. (2009) that focused on the problems associated with e-learning that disabled students typically encounter, revealed that more than 50% of disabled students require some form of assistive technology. This is especially true in the areas of reading and writing. Assistive technologies can facilitate dyslexic learners to overcome their reading and learning difficulties; however, even when these assistive technologies are available, disabled students can still encounter problems with them. Such problems are typically associated with lack of knowledge and technical difficulties.
- K. *Media Channels Variety*: Ensuring that sufficient varieties of media channels are available helps to maximise student's access to important learning content. In addition, it also enhances the depth of their studies and provides users with an opportunity to pursue a personalised logical path. This dimension supports and facilitates a further dimension: accommodate different learning styles (see Section 6.3.1.3).

6.3.1.3 Acceptability and accessibility attributes

The third dimension that is included in the framework, acceptability and accessibility, is potentially one of the most important. It includes the following attributes:

- L. *Accommodate different learning styles*: dyslexia manifests itself in many different forms, and it is very rare for two dyslexic adults to exhibit the same symptoms.

Furthermore, different dyslexic types have different learning needs and capabilities. As such, e-learning systems should cater for different learning styles. Accommodating variations in users' learning styles will help to ensure that e-learning systems adequately overcome some of the ineffective processes that are commonly observed in system operations because they will include functionality that is specifically designed for the students who use the system.

- M. *Scaffolding*: Any information that is presented on the e-learning system should be managed in small units. Through providing a solid system or structure by which these units of information are presented, the system can facilitate the user's progress and processing ability. Dyslexic learners are known to have a limited working memory capacity. According to Miller (1956), grouping key information into meaningful sequences can help dyslexic people who suffer from short-term memory problems.
- N. *Incremental Feedback*: Through incorporating the functionality for incremental feedback in an e-learning system, developers can create a continual feedback loop that will enable them to identify areas in which the system can be improved and enhanced while also making the learning process easier for students. Incremental feedback can be secured by asking students relevant questions about their experiences with an e-learning system and the extent to which they found it accessible and useful.
- O. *Constructivist Learning*: Many of the attributes outlined as part of the framework complement and support one another. The constructivist learning attribute is part of the scaffolding attribute and guides the process by which complex processes are separated into simpler functions that the user is more readily able to understand and process.
- P. *Linearity*: A linear system is one that operates through a clear and effective sequence of steps. Students can learn about any process by following these steps in a methodical manner.

6.3.1.4 User experience attributes

The fourth dimension of the framework is user experience. The proposed framework incorporates the following factors as part of this dimension.

- A. *User Disability Type*: Disabled users come in many different forms, and one of the biggest areas in which e-learning systems are ineffective and/or fail to meet the needs of dyslexic learners can be attributed to the fact that developers fail to take disability type into consideration when developing e-learning systems. Through presenting generic systems, developers do not offer learning experiences that are tailored to specific categories of learners. The framework proposed in this research recommends the development of a learning system that can be adapted according to a student's dyslexia type. This will be achieved through the user inputting key information about the specific type of dyslexia he or she has and the system subsequently adjusting its functionality according to this dyslexia type.

- B. *Controllability*: Giving students a degree of control over their own learning enhances their motivation and improves the extent to which they engage with an e-learning system.
- C. *Aesthetics*: Some dyslexic students experience difficulties with visual processing. This can cause slow visual object recognition and issues with visual concentration and/or oversensitivity to light. This entails that the aesthetic qualities of a graphical user interface for an e-learning system are extremely important and can directly influence the readability of the content presented to the learner. In addition, research that was conducted by Jordon (1998) confirmed that aesthetics can directly influence the amount of enjoyment a learner gets from interacting with an e-learning system.
- D. *Attitude*: This dimension focuses on the development of an e-learning system that students find easy to interact with and, therefore, are motivated to use. Through adapting the materials presented according to students' learning styles and dyslexia type, there is a stronger likelihood that users will develop a positive attitude toward the system and are subsequently more likely to use it.
- E. *Consistency*: It is very important that the user interface of any e-learning system is consistent. However, this is particularly important with e-learning systems that are developed for dyslexic students because learners with dyslexia generally have reduced short-term memory processing capabilities (Miles & Miles, 1990; Snowling, 2000). There are a number of different interfaces and on-screen components that should be consistent throughout the system. These include navigational elements, buttons, icons, headers, help facilities, menus, prompts, system outputs, colour and overall theme, fonts, graphics and student feedback. A lack of consistency in terms of these features can have a negative impact on the usability of the interface.
- F. *Multiple Language Support*: It is important that the system is available in multiple languages in order to support student diversity and maximise the number of students the system is available to as opposed to limiting it to a group of students who speak a given language.
- G. *Effectiveness*: The effectiveness of a system refers to the extent to which it is able to achieve its objectives and goals within the target environment. The key attributes that directly influence effectiveness are availability, capability and dependability, and all of these must be present in communication between the functions of the system.
- H. *Efficiency*: Efficiency refers to the speed and effectiveness of the functionality and tasks that are available to the user. Efficiency can be understood as the ratio between work completed by the system and time and effort invested by the user. It is the developer's responsibility to ensure that the system operates in an efficient manner at all times.
- I. *Robustness*: Robustness refers to the system's ability to manage errors and to continue to operate while handling those errors.

- J. *Constraints*: the system constraints should be developed by defining the required student experience and student types. These should then become the chosen standards by which the system operates.

6.3.2 Linking the Technology Acceptance Model and the DAEL framework

Since user acceptance is an important primary measure of system success, many researchers have adopted the Technology Acceptance Model (TAM) framework (Davis, 1989) in their research. The TAM framework has helped many organisations in providing a useful analytical framework, which allowed them to have a clear understanding before the adoption and assimilation of different types of IT innovation. Igbaria and Iivari (1995) state that the contribution made by the TAM framework can be considered to be significant due to its simplicity and ease of use. Many researchers have developed frameworks in different information technology domains based on the TAM framework such as (Squire & Preece 1996). The proposed framework concerns not only the students' 'learning part', but also helps teachers when dealing with dyslexic students i.e. the 'teaching part'. In addition, it provides clear standards and guidelines for developers in understanding the requirements and then designing e-learning systems. The framework will facilitate the structuring and understanding of the attributes that are based on the researched theories of the four dimensions, hence, helping e-learning developers from the early stages and even before making any plan or design. This framework established the functional or technical requirements the design must meet. Moreover, it considers the needs and constraints imposed by students with dyslexia, policies and the environment.

New themes have been added to categorise the attributes in Section (6.3.1) and to incorporate them within the framework. The themes have been allocated on the basis of the factors within the TAM framework, for full description of each attribute see Section (6.3).

6.3.2.1 Perceived ease of use

Davis (1999) defined perceived ease of use as the extent to which users anticipate they will be able to use a given system without needing to invest significant effort (Davis, 1989). Research by Gong, Xu, and Yu (2004) revealed that perceived ease of use can directly influence students' attitudes toward a system and the extent to which they believe it is useful. When designing e-learning applications, designers need to ensure that the materials presented can be processed relatively easily. The DAEL framework attributes that determine "Perceived Ease of Use" factor in aspects of the TAM model as follows:

- *Clarity (B)*
- *Self-descriptiveness (D)*
- *Memorability (E)*
- *Simplicity (F)*
- *Helpfulness (G)*
- *Learnability (H)*
- *Mapping (I)*
- *Aesthetics (S)*

- *Consistency (U)*

The process by which students engage in active learning experiences can be made more straightforward if self-descriptiveness is present; i.e., the system presents itself in a very simple way. However, to be efficient, this self-descriptiveness needs to be coupled with the logical flow of functions and clarity. E-learning systems that combine self-descriptiveness with logical functions and clarity make the learning process easier and, as such, can be defined under a single theme: 'Ease of Use'. The 'helpfulness' attribute facilitates the user's interaction with the system via the most convenient approach. The 'learnability' and 'memorability' functions, as well as 'Mapping' the system functions, allow the student to interact with the system more readily and quickly. Such attributes facilitate the ease with which a student uses the system; hence, these can be grouped under the single theme of 'Ease of Use'.

6.3.2.2 Perceived usefulness

As previously discussed, perceived ease of use directly influences perceived usefulness, which is a fundamental driver of student usage and intention to use. The perceived usefulness of a system refers to the extent to which a student anticipates that interacting with it will have a positive effect on his or her performance (Davis, 1989), which, in the case of the current research, is learning. Many research studies have demonstrated that perceived ease of use and perceived usefulness play a fundamental role in user acceptance and intention to use a system again. For example, a study by Ngai, Poon and Chan (2007) demonstrated that user acceptance of WebCT was determined by its ease of use, and that this, in turn, directly affects usage. Based on this, the DAEL framework attributes that determine 'Perceived Usefulness' factor in aspects of the TAM model as follows:

- *Scaffolding (M)*
- *Incremental feedback (N)*
- *Constructivist Learning (O)*
- *Linearity (P)*
- *Effectiveness (W)*
- *Efficiency (X)*
- *Robustness (Y)*
- *Constraints (Z)*

Each of these attributes contributes to the development of different modes through which an effective learning process can be developed and facilitated. For example, 'scaffolding' specifies the factors that should be developed to enhance the way in which the system functions. 'Incremental feedback' facilitates the continual improvement of the system and the way in which the learning process is presented to the user. 'Constructivist learning' attributes help the student to develop an effective means of interacting with the system. Performance measures are vital for evaluating the system and the service it provides. Common methods by which performance is measured are 'effectiveness', 'efficiency', 'robustness' and 'constraints'. Finally, the effectiveness of the system functions is a measurement of their level of interactivity and the convenience they provide.

6.3.2.3 External variables (system adaptability)

There is a strong positive correlation between the external variables factor and the other factors in the TAM model. Within the DAEL framework, external variables refer to attributes that are related to the adaptability of the e-learning system. Understanding the effect of this factor is fundamental to understanding user acceptance of DAEL. In fact, it is anticipated that, in the future, external variables will govern the importance and usefulness of integrating user experience into any e-learning system. Many researchers have described how adaptability can increase students' learning activity and the extent to which they understand the subject being taught (Jih, 1996; Cantoni et al., 2004). Therefore, it is completely conceivable that these aspects increase the likelihood that students will accept e-learning systems. Specifically, the current research is based on the premise that the benefits that the DAEL framework delivers, such as adapting to a student's dyslexia type and learning style through the use of assistive technologies, will increase the extent to which the student finds the system useful and easy to use. This, in turn, will increase a students' intention to use the adaptive e-learning system through the mediating effect of perceived usefulness and perceived ease of use. As such, the basic hypothesis is that system adaptability is indirectly related to intention to use the adaptive e-learning system as a result of perceived usefulness and perceived ease of use. This hypothesis is supported by the findings of previous studies, such as that by McCormack and Jones (1998), who specified that the extent to which a student will use a given e-learning system is directly related to the extent to which they believe it is useful and offers an acceptable ease of use. Moreover, perceived ease of use has a direct influence on perceived usefulness. The DAEL framework attributes that determine external variables factor in the TAM model are:

- *Personalisation (A)*
- *Adequacy (C)*
- *Technology Variety (J)*
- *Media Channels Variety (K)*
- *Accommodate different learning styles (L)*
- *User Disability Type (Q)*
- *Controllability (R)*
- *Multiple Language Support (V)*

At present, the extent to which e-learning systems take into consideration different types of students needs has been minimal and has been largely limited to adapting to user disability type. It is for this reason that the current research represents a novel approach. The provision of the attributes outlined above will enhance student control and will develop their confidence and level of comfort with using the system and selecting the settings that are appropriate to their needs. Multiple language support will increase the demographic of potential users and will enhance the ease with which the students interact with the system through presenting the available functions and services in a language they can understand. Accommodating for different learning styles will facilitate the process by which students overcome the limitations that are typically associated with system operations when a given e-learning system is generic or intended for a specific set of students. Finally, personalisation will provide the user with an

opportunity to control presentation and information architecture to some extent and will, subsequently, enhance their perceptions of ease of use and usefulness of the system. Having explored the dimensions and attributes of DAEL framework in depth, the next section will integrate the DAEL dimensions within the TAM model.

6.3.3 Constructing the framework

The DAEL framework is developed with the aim of allowing the conceptualisation and development of adaptive e-learning system that facilitates the “Ease of Use” and “Usefulness”. The adaptive e-learning system shall also facilitate accessibility and usability for students with dyslexia. In the framework, the dashed box represents the original TAM model, while the letters denote the attributes for each dimension, as presented in Section (6.3.2).

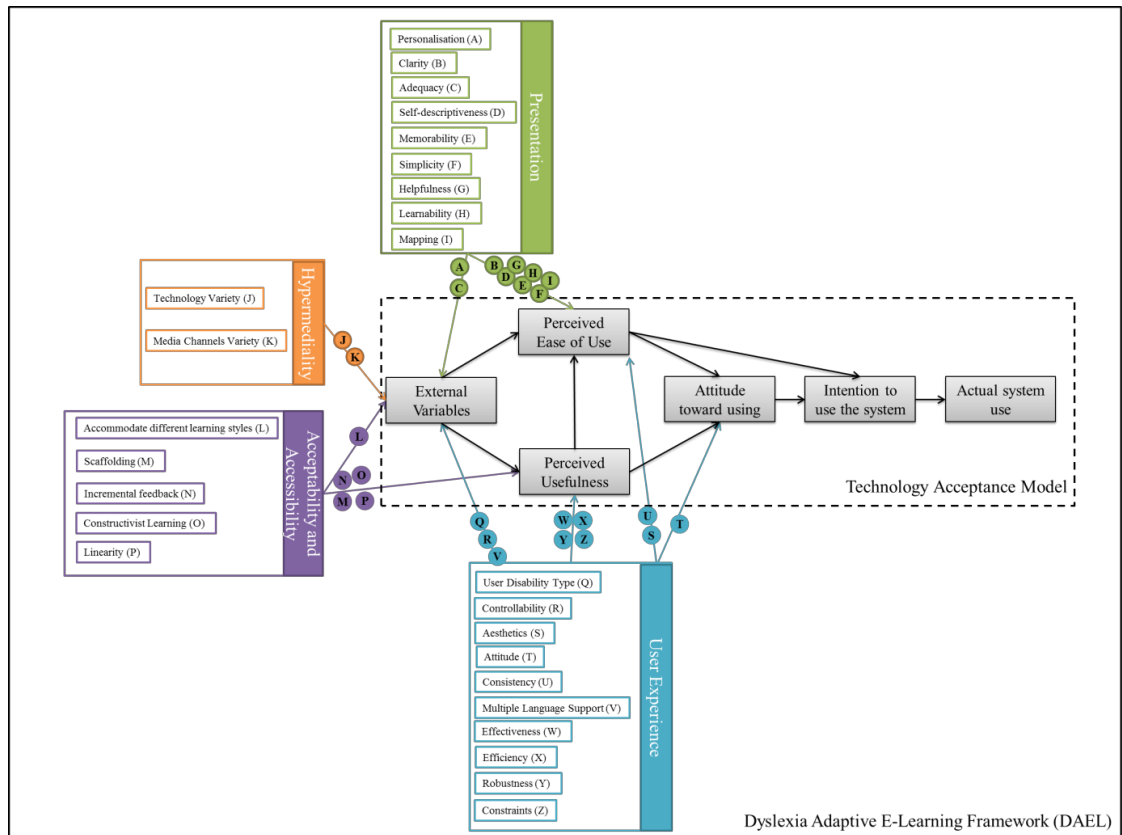


Figure 6.1 The DAEL Framework Based on TAM Model

In Section (6.3.2), the attributes of the DAEL framework were grouped according to the corresponding TAM model factors. The relationships between the relevant factors of the TAM and the DAEL framework attributes (Figure 6.1) can be represented using the mathematical operations outlined below.

- Perceive Ease of use (E) is determined by external variables (SA)

$$E = SA$$

- Perceive Usefulness (U) is significantly affected by various external variables (SA) and Perceive Ease of use (E). This can be represented as follows:

$$U = SA + E$$

If the system offers features like technology variety and clarity this, in turn, increases the likelihood that a given user will perceive the system to be capable of enhancing his or her performance.

- Perceive Ease of use (E) and Perceive Usefulness (U) have direct and positive effect on Attitude toward using the system (A). This can be represented as follows:

$$A = E + U$$

Attributes such as learnability and incremental feedback increase the extent to which the student develops a positive attitude toward using the system. If the student develops a positive view of the system, there is an increased likelihood that the student will use the system again and will recommend it to his or her friends.

- Perceived ease of use (E) and attitude toward using the system (A), therefore, have a direct and positive effect on intentions to use the system (IU). This can be represented as follows:

$$IU = E + A$$

For example, using the DAEL framework attribute as a reference, when certain attributes such as helpfulness existed in the system, student attitude towards using the system is maximised and intention to use the system in the future is increased.

6.4. Chapter Six Summary

This chapter conducts an extensive study of existing frameworks and relevant theories which enabled an understanding of the requirements of adaptive e-learning for students with dyslexia from four different perspectives: presentation, hypermediality, accessibility and acceptability, and user experience. There is no e-learning system currently known that adapts itself according to type of dyslexia. Therefore, the author proposed the DAEL Framework, which would conform to the standards of acceptability and accessibility for different dyslexia types. An expert evaluation has been designed to measure experts' agreement patterns concerning the components of the DAEL Framework. Experts ascertain whether there are some attributes missed and rate the level of importance and conflict associated with each attribute towards the four dimensions. An expert evaluation has been designed to measure experts' agreement patterns regarding the dimensions of the frameworks. Experts' evaluation will determine whether there are some attributes need to be added. It also will rate the level of the importance and conflict associated with each attribute towards these four dimensions. The expert evaluation's steps as well as their results will be presented in following Chapter.

Chapter 7 DAEL Framework Evaluation

7.1. Introduction

Validity can be defined as the extent to which the items of a medium adequately reflect the main concept or domain of content (Rubio et al., 2003). When developing a new measure, the developer has no existing measure available that effectively operationalises the main concept (Rubio et al., 2003); as such, validation is of utmost importance. For example, within any given e-learning system, there may be a number of systems in existence that can effectively measure the presentation, hypermediality, accessibility and acceptability, and usability aspects of the framework. However, at present, as this research has already established, there are no systems in place that can effectively employ all of these in combination to offer learning experiences that are adapted to an individual's specific dyslexia type. To that end, any system that seeks to do so, must first be validated.

When educational developers contemplate the need to validate a system, they typically seek a single global measure of validation. However, this represents an ineffective approach because validation spans different properties and the validity of a given framework cannot be measured along a single linear dimension; i.e., from high to low. For example, the extent to which an educational program is valid cannot be measured in the same way as the validity of a customer service. Furthermore, the validity of a course of education cannot be measured on a single dimension. There is, therefore, the need for a multi-dimensional approach to measure validity that takes into consideration the fact that learning is a multi-faceted and complex process. To effectively measure validity in education, there is a need to develop an understanding of the factors that influence a learner's experience during the learning process and to develop a mechanism by which these can be separately assessed and measured.

It is important to note that a validation method that is employed successfully with a framework in one context will not necessarily be equally effective if the framework is employed in an alternative context. For instance, if a validation method is created to assess the validity of a learning intervention that is taught face to face, it may not necessarily be appropriate for assessing the validity of an intervention that is delivered online. The reason for this is simple: the factors that influence the extent to which an online program is successful are very different from those that impact the effectiveness of traditional face-to-face lessons. In light of this, when developing the system proposed in this research, there is a need to take into consideration the different validation approaches that are available and to assess which of these is the most appropriate to the framework proposed in this study and the context within which it is to be applied.

Very few studies that have attempted to implement multi-dimensional approaches to measuring validity within the higher education setting. This Chapter³² will examine potential validation processes according to the two approaches described by Inglis (2008): validating the framework

³² This chapter is based on the following peer-reviewed paper:

Alsobhi, A., Khan, N. & Rahanu, H. 2015, An Empirical Approach to Validate the Dyslexia Adaptive E-Learning (DAEL) Framework, in *Proceedings of The 10th International Conference on Computer Science & Education (ICCSE 2015)*, Cambridge, United Kingdom.

by reference to the appropriate research literature, and validating the framework by drawing on the knowledge of experts in the field. Section (7.2) of this chapter examines the different ways in which the DAEL framework has been validated and progresses to examine the results of the two different approaches (Section 7.2.1.4). Section 7.2.2 discusses the differences between the validation approaches for the weight that can be placed on DAEL framework and the extent to which it can effectively measure the validity of the DAEL framework (Section 7.3). It is important to note that the goal of this chapter is not to question the validity of existing approaches, but to validate the DAEL framework.

7.2. Validation Approaches

The topic of validity has been extensively researched in existing literature. However, very few studies have focused on the validation processes and, as such, it is difficult to provide a single definition of the concept of validation. For the purposes of this research, in the context of the validity of the DAEL, validation can be considered as a process that includes judgements. Here, those judgements relate to perceptions of the extent to which the DAEL is fit for purpose.

More generally, the purpose of validation processes is to identify the factors that need to be taken into account in the respective framework. Inglis (2008) employed a range of approaches to validate a framework. The following sections contain a comprehensive analysis of these approaches which are:

- 1) Expert Panel
- 2) Refer to Appropriate Literature.

7.2.1 Expert panel

A panel of experts can be employed during a validation activity to provide constructive feedback on the quality of a proposed measure. In the absence of a comprehensive validation study, a researcher will need to use an untested measure to test the approach. For example, if the components of the DAEL framework are used without validation, the model and system that is developed via the application of the framework will need to be revised at a later date, and another round of a pilot study must be conducted. On the other hand, if the components were validated at an early stage, any model or system that is developed based on the framework will require less revision and will not need to be repeatedly evaluated.

Figure 7.1 presents an overview of the expert evaluation process that was used in the development of the DAEL framework. The diagram depicts four main processes. The following sections will explain in detail how the expert evaluation was developed and applied to validate the content of the DAEL.

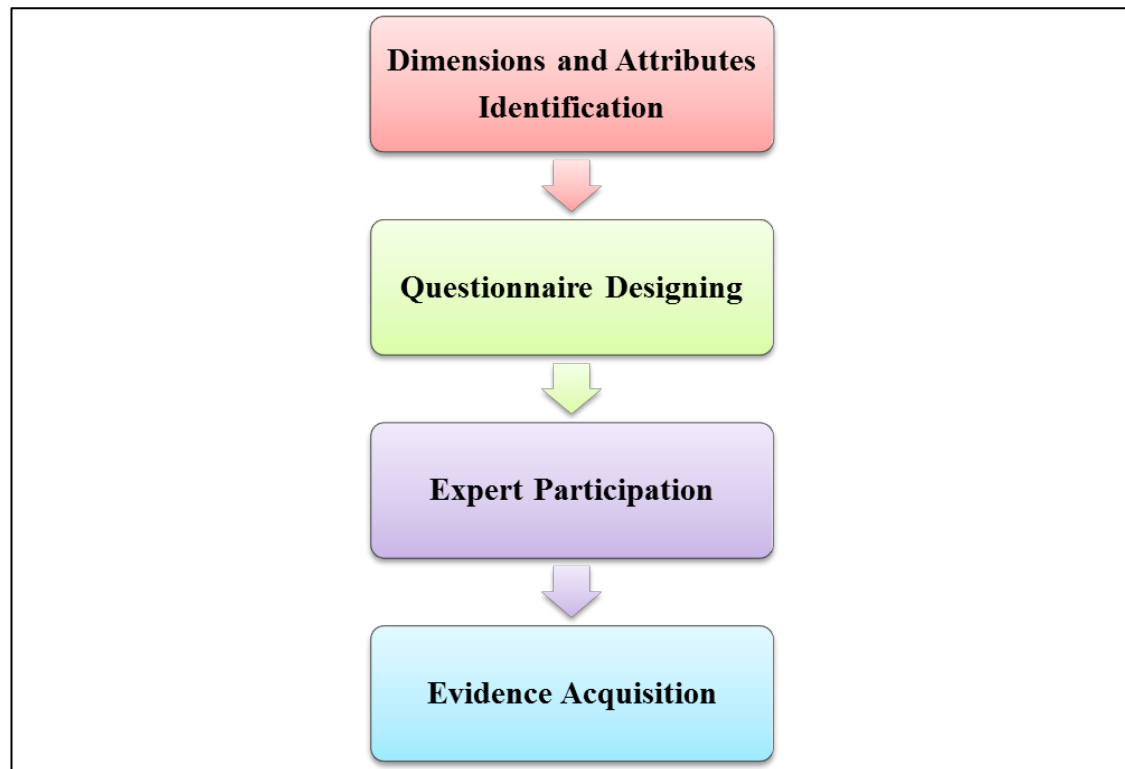


Figure 7.1 Expert panel evaluation process

7.2.1.1 Identify dimensions and attributes

Using the DAEL framework as a source of reference and guide, four dimensions were selected to measure the extent to which the experts agreed that the framework met the requirements of a dyslexia adaptive e-learning system. These were: (1) Presentation (2) Hypermediality (3) Acceptability and Accessibility, and (4) User Experience. For each dimension selected, the appropriate attributes in (Table 6.1, in Section 6.3.1 Chapter 6) were selected for incorporation in the measuring instrument.

A total of three themes were identified. One theme represented the Presentation dimension, the second theme represented the Hypermediality and Acceptability and Accessibility dimensions, and the third theme represented the User Experience dimension. Each question in the questionnaire matches one attributes in DAEL Framework.

7.2.1.2 Design the questionnaire

The research investigation was formulated with the aim of measuring the extent to which experts agreed that the components of the DAEL framework successfully will be in benefit for students with dyslexia and it will improve the learning process. This investigation involved a cross-sectional questionnaire that was performed on a sample chosen from a population of academic practitioners who deal with e-learning systems on a regular basis. Dyslexic students were also included as respondents. The dyslexic participant is an individual who displays the symptoms and difficulties that are typically associated with dyslexia; however, this does not necessarily mean that the participant has been explicitly stated (assessed by an educational psychologist) as dyslexic.

An online questionnaire software application was used to create the questionnaire and distribute it via e-mail. The questionnaire was designed to take less than ten minutes to complete. It constituted of a set of questions that assessed each attribute in the DAEL 4 dimensions. The questionnaire will be divided into five distinct categories as illustrated in Table 7.1, while Table 7.2 illustrates the questions related to the TAM model.

A total of 37 items were created for the instrument. Of these, 9 were designed to evaluate the presentation dimension, 7 the hypermediality and accessibility and acceptance dimensions, and 10 the user experience dimension. The other 11 items used in this study included validated items that have been adapted from prior TAM research (Davis, 1989; Venkatesh & Davis, 2000; Chau, 1996).

Table 7.1 DAEL evaluation questionnaire categories and question examples (DAEL Dimensions)

Question Category	Example Questions
Basic Information about the subject	▪ Age ▪ Gender ▪ Dyslexia Type ▪ Type of Study (Undergraduate/ Postgraduate) ▪ Academic Achievement (Distinction, Merit...)
Presentation Dimension	▪ Every student who deals with e-learning application will have the choice to shape the content and has the control over all settings. ▪ The interface is designed in a way that makes the student grasp the mechanism of the system in short time.
Hypermediality Dimension	▪ The system provides support for the different range of the assistive technologies. ▪ The system should provide the content in different media to meet students' preferences.
Acceptability and Accessibility Dimension	▪ The system should provide the content in different media to meet students' preferences. ▪ The system constantly considers and applies students' feedback and opinion.
User Experiences Dimension	▪ The system adapts itself according to the student's dyslexia type. ▪ The system supports multiple languages in order to support the students' diversity.

Table 7.2 DAEL evaluation questionnaire question examples regarding TAM factors

TAM Model Factors	Example Questions
Perceived Ease of Use	▪ Presentation features make using the system easy for me. ▪ Presentation features make the process of using the system clear and understandable.
Perceived Usefulness	▪ Enhance the effectiveness of my learning. ▪ Improve my learning performance. ▪ Assist me in deepen my understanding in topic learned as I exposed to a multiple perspectives of solution from different learning styles suggested by the system.
External Variables (System Adaptability)	▪ Presents learning contents according to my dyslexia type and learning styles improves my comprehension on the learning topic. ▪ Suggests assistive technologies that give me the possibility to learn with the use of technology.

A Likert Scale was developed and used to evaluate the DAEL. Likert scales are commonly used to measure the extent to which questionnaire respondent's opinions on, and attitudes to, a particular statement are in agreement. The different scales are known as Likert items and are

used instead of numerical scales (Lankes, 2002). The response option adopts a five-point scale format ranging from 'first priority' to 'fifth priority'.

The DAEL framework is relatively new. As such, research and development on this system are limited. Although a great deal of research has focussed on assessing e-learning systems that are designed for students with special needs, no one study has been conducted thus far that examines different dyslexia types from different perspectives. As such, it was important that the questionnaire was aligned with the needs of dyslexics. The British Dyslexia Association (2015) style guide was used to design the questionnaire. The basic structure of the questionnaire is shown in Figure 7.2:

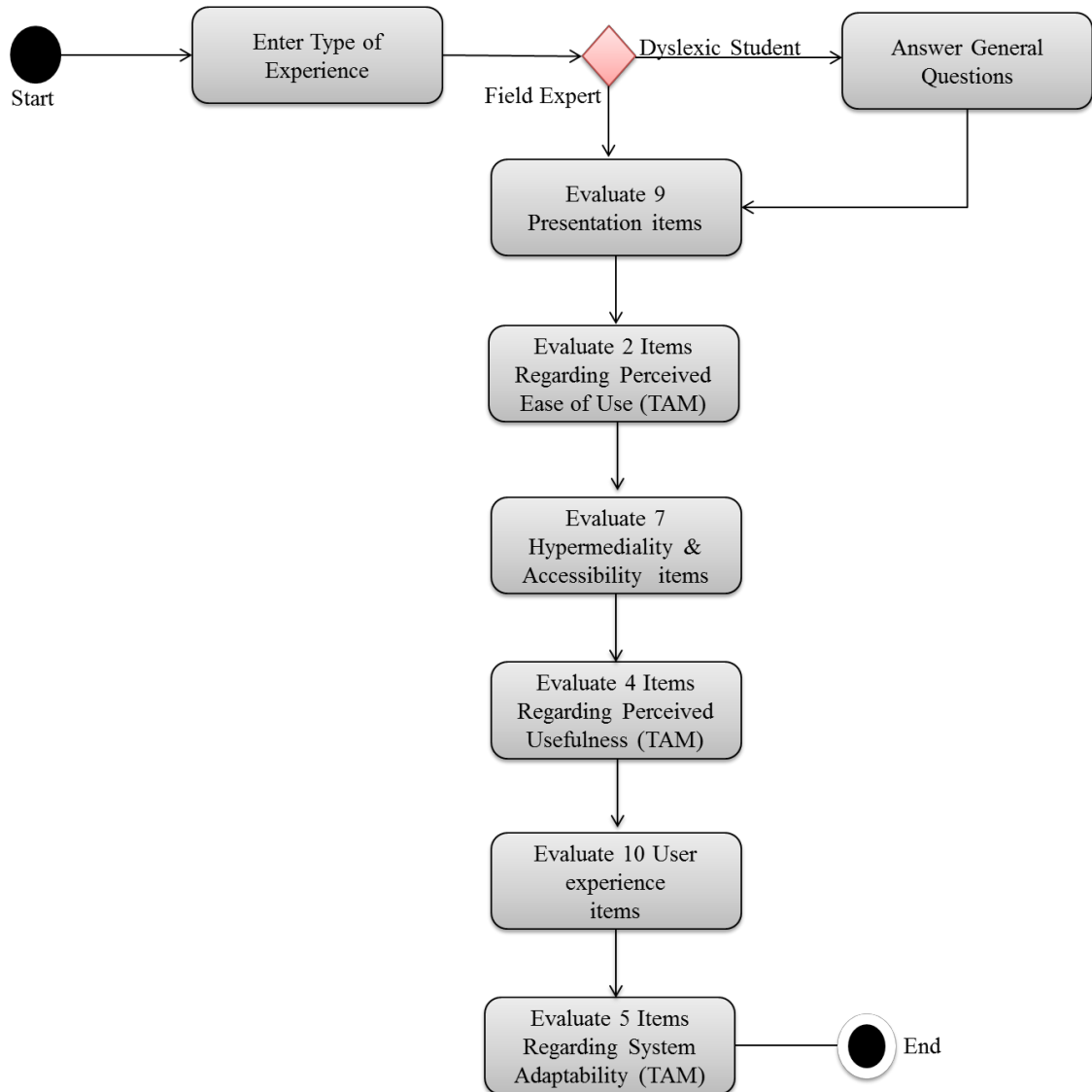


Figure 7.2 Questionnaire's steps

As shown in Figure 7.2, the participant was asked to provide information about whether he or she was a dyslexic student or a field expert. This study was concerned with gaining insights into the learning experiences and challenges of students with dyslexia. However, it was also important to take into consideration the opinions of field experts; e.g., teachers, people who support dyslexic students, and educational developers. This was designed to ensure that the knowledge gained incorporated both teaching and learning perspectives. The author found that

a more focused and purpose-driven questionnaire using a purposive sampling method was more appropriate for the validation procedure (Arber 2001):

1. If the participant selected 'dyslexic students' as the response to question x, a list of demographic questions about gender, age, dyslexia type and the level of academic achievement was presented. For each question, participants were asked to choose the answer that best described their level of agreement. The 37 questions pertaining to the four dimensions were then presented.
2. If the participant selected 'Field experts', they were then asked one question about their main area of experience. Following this, the 37 questions pertaining to the four dimensions were asked.

7.2.1.3 Include expert participation

One method of assessing the validity of a questionnaire is to employ a panel of experts (Saw & Ng, 2001). People who have proven knowledge and experience of a given domain can assess individual questions and the framework as a whole (Rubio et al., 2003). In one useful study, Rubio et al. (2003) suggested a set of criteria that could be employed to select the experts who participate in a panel of this nature. Such criteria may relate to the extent of their knowledge, their research experience and publications in relation to the conceptual framework under scrutiny, and their level of recognition in the field (Rubio et al. 2003). For example, the objective of the research outlined above, is to evaluate the DAEL framework. As such, any panel that was established to assess the validity of a questionnaire employed would need to involve experts who have expertise in the research domain and/or who are familiar with any of the DAEL framework dimensions and have experience of using it. Rubio et al. (2003) recommend the inclusion of two types of experts on the panel; firstly, Lay Experts, who are people for whom the topic is most salient, they help to address issues such as phrasing and unclear terms and recommend other important or significant items. Secondly, Content Experts should be involved. These people are 'professionals who have published or worked in the field' (Rubio et al. 2003). A sample of 111 Lay Experts was selected, 48% of which were postgraduates and 52% of which were undergraduate students. The respondents consisted of 81 females and 30 males who ranged in age from 19 to over 26 years old. The gender distribution of the participants was unexpected, as it is widely recognised that dyslexia affects more males than females. The level of achievement for the dyslexic students who participated in the study was quite impressive, with about 43% classifying themselves as Merit students.

Interestingly, none of the participants had used an adaptive e-learning system that had been designed especially for dyslexic students before; this increases the significance of this research and supports the theory that there is an existing research gap in this field. The biggest difficulties that the dyslexic students faced were writing (32%) and reading (27%). This demographic information as shown in (Figure 7.3) helps us in building a profile for each student. This profile will later be used to design an adaptive e-learning system that incorporates the functionality to modify learning experiences in accordance with the dyslexia type of the student using the system.

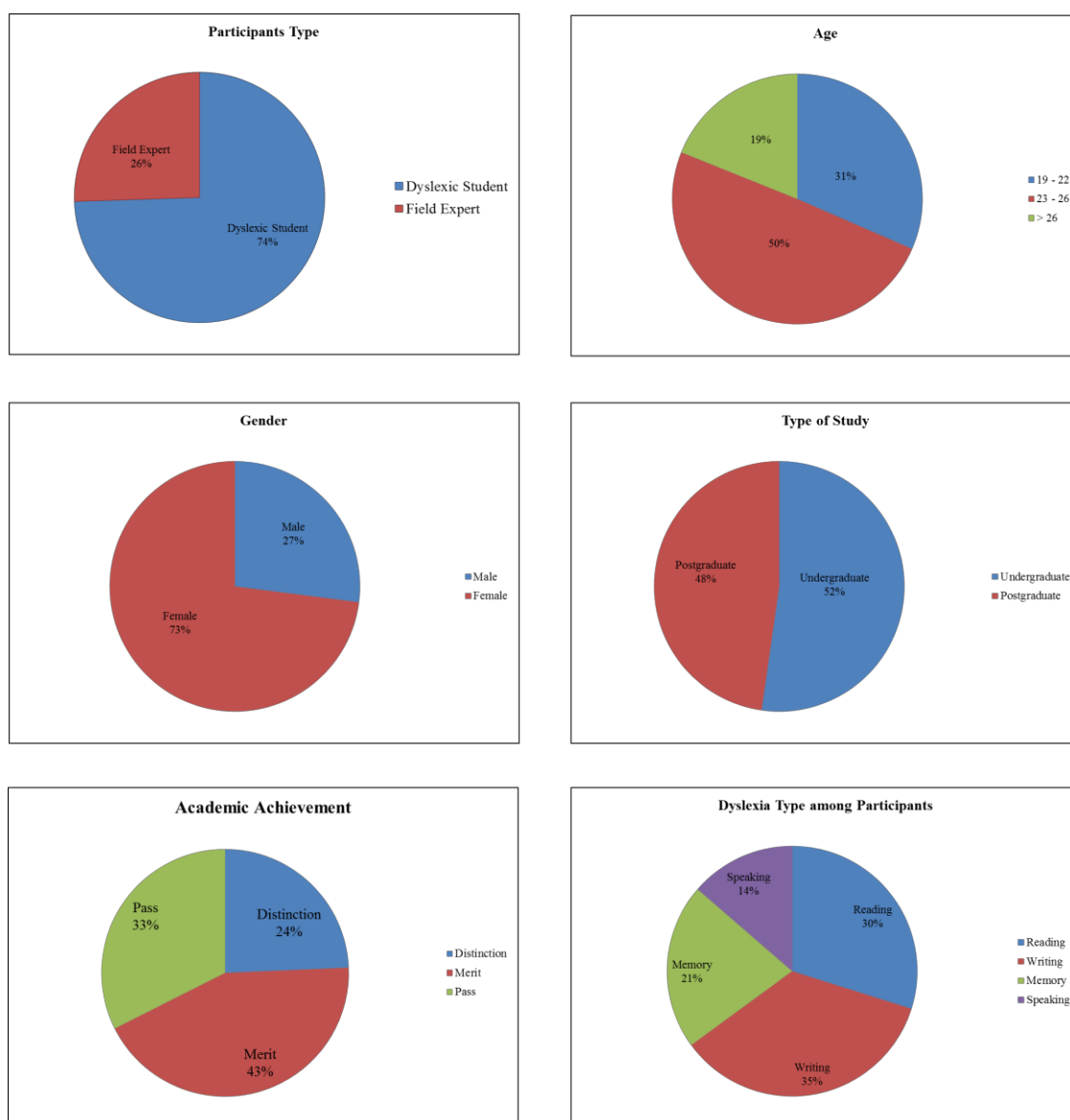


Figure 7.3 Questionnaire participants' demographic information

A total of 38 Content Experts were selected to participate in the content validity study as shown in (Figure 7.4). The demographics of these participants were as follows: 39% teachers, 34% staff from the Supporting Dyslexic Student Unit, 21% educational developers and 2% other. Sample members were recruited based on their interest in the research perspectives. Notice the diverse range of expertise in the field experts' group population; this is useful to evaluate the DAEL from different perspectives.

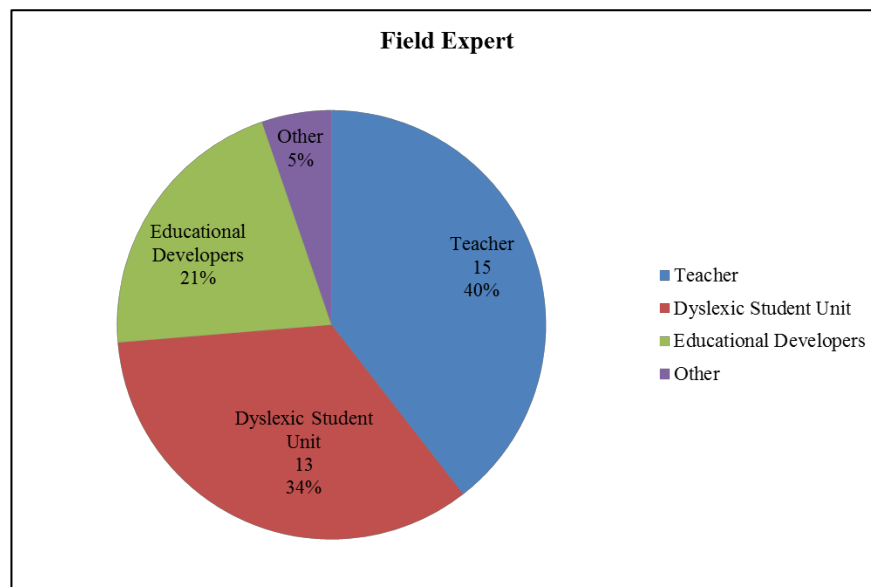


Figure 7.4 Field experts' group population

There are several ways to determine a suitable sample size. Griffin and Hauser (1993) claimed that in order to produce viable qualitative studies, '20-30 in-depth interviews were necessary to uncover 90-95% of all customer needs for the product categories studied.' Accordingly, it was deemed that a sample size of 30 respondents was sufficient for this study and the number of participants included in the research meets the requirement outlined in previous studies; for example, Saiful (2011) stated that sub-samples require at least 30 observations to be applicable. A sample of 149 responses was obtained. Based on the work of Harrington (2009) and others, as outlined above, it was decided that more than 100 participants would represent an acceptable minimum sample size for the purposes of the validation study. Saiful (2011) argued that 30 people should be considered to be the minimum sample size for each category when the sample size is split into sub-samples (Content and Lay Experts in the case of the current study). Therefore, the use of a sample that was about 1/10 of the size of the parent population was required.

Informal pilot study

The purpose of this step was to collate expert's opinions, feedback and recommendations pertaining to the design of the questionnaire. It also provided a mechanism through which it was possible to determine the extent to which the content experts were able to understand the items presented in the context of each dimension. Each lay expert was consulted on an individual basis and their comments, recommendations and inputs were sought in terms of the items that made up the questionnaire. They provided feedback on which items could be deleted, which required modification, and which aspects should be added. Following this process of consultation with the lay experts, the instrument was refined. The final questionnaire consisted of 37 items, 9 of which addressed the presentation dimension, 7 shared the hypermediality and the accessibility and acceptance dimensions, and 10 were related to the user experience dimension.

An invitation email to participant experts

In addition to the consultation with the lay experts, content experts were invited to participate in a review of the instrument. Individuals who were identified as being content experts were contacted prior to the start of the study, giving them sufficient time to respond to the invite. The invitation included an overview of the research objectives and why their input and advice was being sought. The participants were clearly informed that their participation was completely voluntary and that any feedback they gave would be anonymous and confidential. The study itself took place during Spring 2014, and the experts were contacted via email to enhance the efficiency of the communication process and ensure costs were kept to a minimum.

7.2.1.4 Acquire evidence

A total of 149 experts participated in the survey; of these, 111 were students with dyslexia, and 38 were field experts. Data screening was performed to verify reverse coding and identify any missing data. Data screening was deemed to be necessary because the questionnaire contained negatively keyed items, which are items that are worded in such a manner that agreeing with the statement is reflective of a comparatively low level of the attribute being measured. For example, in terms of the hypermediality dimension, the respondents were requested to prioritise a set of statements, such as "*The system provides support for the different range of the assistive technologies*" according to their level of agreement using a 5-point scale (1 = first priority, 2 = second priority, 3 = third priority, 4 = fourth priority, 5 = last priority). When negatively keyed items were employed, the author needed to reverse score these items so that they were recorded in such a way that a high score on the item corresponded to high levels of the attribute being measured and low scores corresponded with low levels of the attribute.

As a means of validating the DAEL framework, a nonparametric one-sample Wilcoxon test was conducted on the data produced from the questionnaire through testing a sample against a given median. Unlike the t-test, the one-sample Wilcoxon test does not require the data to come from a normally distributed population (Higgins, 2003). The one-sample Wilcoxon test is commonly employed when the criterion for parametric tests is violated; i.e., the data is not normally distributed or when the outcome is an ordinal variable or a rank (Hinton et al., 2004). As the data in the current study did not follow a normal distribution and was ranked, the one-sample Wilcoxon test was employed as an alternative to the one-sample t-test. This test was used to determine whether the population median (η) were greater than the hypothesised median (η_0). In this research, "third priority" on the Likert scale was considered to represent the hypothesised median because it was the neutral point on the available scale; as such, (η_0) = 3. A population median greater than the hypothesised median, in the case of this research 4 or 5, was deemed to be indicative that there was some agreement with the statement being tested, while one below the hypothesised median (1 or 2) was indicative that there was some disagreement (Mooney et al., 2012).

This test involved testing the null hypothesis against the alternative hypothesis. The hypotheses employed for testing each item in the four research dimensions were as follows:

- The null hypothesis (**H0**): The population median (η) less than the hypothesised median (η_0).
- The alternative hypothesis (**H1**): The population median (η) greater than the hypothesised median (η_0).

The null hypothesis (**H0**) refers to a theory that has been stated. There as one of these statements is either that it is assumed to be correct or that it is needed as a base for argument, but has not been proved. On the other hand, the alternative hypothesis (**H1**) is a statement of what a statistical hypothesis test will be aiming to prove

- (**H0**) There was no significant difference between using traditional learning and adaptive e-learning systems, which include the attributes from the DAEL framework from a dyslexic student's perspective.
- (**H1**) There was a significant difference between using traditional learning and adaptive e-learning systems, which include the attributes from the DAEL framework from a dyslexic student's perspective.

To use sample data to accept or reject the null hypothesis, the following elements were specified:

- Researchers chose significance levels equal to 0.01, 0.05, or 0.10; however, any value between 0 and 1 could be selected. Therefore, a typical value of $\alpha = 0.05$ was applied. Then:
 - If the *P-value* (for each item) was less than or equal to α , **H0** was rejected; or
 - If the *P-value* (for each item) was greater than α , **H1** was rejected.
- The use of the test method determined whether the hypothesised population proportion differed significantly from the observed sample proportion. Therefore, a One-sample Wilcoxon test was conducted.

Presentation dimension results

Table 7.3 presents a summary of the results of One-sample Wilcoxon analyses of the presentation dimension results. The results in relation to the responses provided by the dyslexic learners and the field experts indicate that the attribute median were greater than the hypothesised median (η_0) = 3. As such, all of the presentation attributes evaluated were of significance within the DAEL framework. The results also revealed that the 'personalisation' attribute has the highest priority among the other presentation attribute with more than 50% respondents ranked it as first priority in adaptive e-learning system. This indicated that the respondents were in agreement that personalisation was significant and is representative of the importance of developing e-learning systems that allow students some degree of control over the content, layout, and navigation of the system. As Section (6.2.1) highlighted, many of the difficulties that dyslexic users experience when interacting with e-learning systems relate to the system's presentation and navigation. As such, personalisation is a key attribute that needs to be taken into consideration within the design of an adaptive e-learning system that is intended to facilitate the learning processes of students with dyslexia. Figure 7.5 revealed that 'Personalisation' and 'Adequacy' attributes were the most important of the presentation

features. The outputs of the One-sample Wilcoxon revealed that the significance value (*P-value*) of all presentation attributes was less than 0.05 ($p < .05$). As such, the null hypothesis (**H0**) was rejected, and the alternative hypothesis (**H1**) for all presentation attributes was accepted.

Table 7.3 Results of One-sample Wilcoxon analyses of the presentation attributes

Presentation Attributes	Median response	Wilcoxon <i>P</i> -value	median >3
Personalisation	5	<0.001	✓
Clarity	4	<0.001	✓
Adequacy	5	<0.001	✓
Self-descriptiveness	4	<0.001	✓
Memorability	4	<0.001	✓
Simplicity	4	<0.001	✓
Helpfulness	4	<0.001	✓
Learnability	4	<0.001	✓
Mapping	4	<0.001	✓

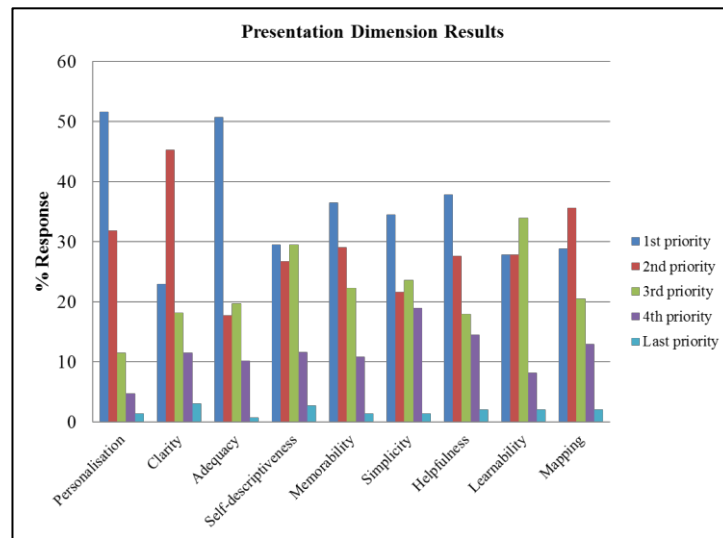


Figure 7.5 Presentation dimension results

Hypermediality and accessibility and acceptance dimensions results

Table 7.4 presents a summary of the results of One-sample Wilcoxon analyses for the hypermediality and accessibility and acceptability attributes, for which two experts evaluated two of the hypermediality attributes: 'technology variety' and 'media channels variety' and five of the accessibility and acceptance attributes (ranging from 'accommodate different learning styles' through to 'linearity'). The outputs of the statistical analysis revealed that the median of all attributes were considerably greater than the hypothesised median except for the 'linearity' attribute with median equals to 3. From Figure 7.6, it became clear that the respondents considered the 'technology variety', and 'accommodate different learning styles' attributes to be among the most significant features. These results confirm that the work proposed in this research study is of importance because it aims to deliver personalised learning materials that are aligned with students' dyslexia type and learning styles. It also supports the research claims that there is a requirement for an adaptive e-learning system that incorporates assistive technologies that can facilitate the learning experiences of students with dyslexia. As indicates, the significance value (*P-value*) for all attributes was less than 0.05 ($p < .05$) even for the 'linearity' attribute; as such, the null hypothesis (**H0**) was rejected, and the alternative hypothesis (**H1**) was accepted for all attributes. If the population median was equal to the

hypothesised median, we look to the (*P-value*) – the case of ‘linearity’ attribute. If this was less than 0.05 ($p < .05$), we rejected the null hypothesis (**H0**). If it was greater than 0.05 ($p > .05$), we accepted null hypothesis (**H0**).

Table 7.4 Results of One-sample Wilcoxon analyses of the hypermediality and, accessibility and acceptability attributes

Hypermediality and Accessibility and Acceptability Attributes	Median response	Wilcoxon <i>P</i> -value	median >3
Technology Variety	5	<0.001	✓
Media Channels Variety	4	<0.001	✓
Accommodate different learning styles	4	<0.001	✓
Scaffolding	4	<0.001	✓
Incremental Feedback	4	<0.001	✓
Constructivist Learning	4	<0.001	✓
Linearity	3	<0.001	×

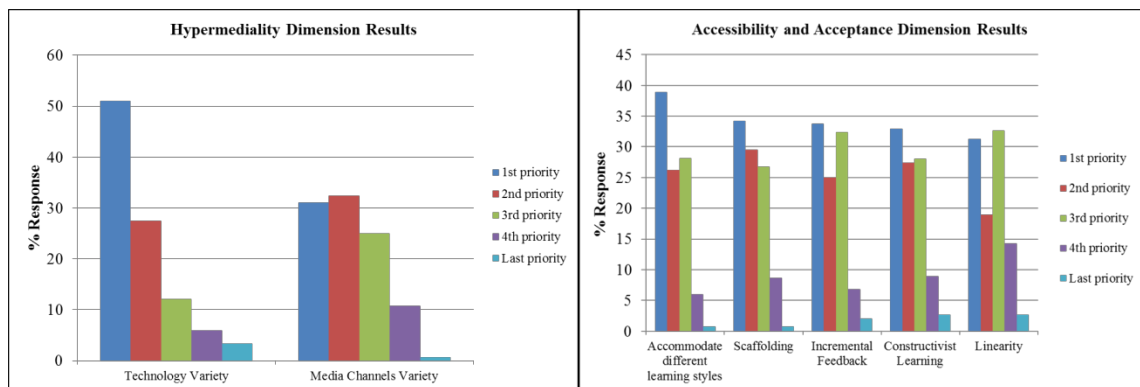


Figure 7.6 Hypermediality and, accessibility and acceptability dimensions results

User experience dimension results

Table 7.5 presents a summary of the results of One-sample Wilcoxon analyses of each of the 10 user experience attributes. As can be seen in the overall statistics, the median of all items was significantly over the hypothesised median except for the ‘Constraints’ attribute with median equals to 3. However, the *P*-value for the ‘Constraints’ was less than 0.05. This indicates that all the user experience experts considered the items that were listed under this attribute to be of importance and that all ten should, therefore, remain within the DAEL framework. Figure 7.7 revealed that the ‘User Disability Type’ and ‘Multiple Language Support’ were consistently considered to be the most important attributes. As Table 7.5 indicates, the significance value (*P-value*) for all attributes was less than 0.05 ($p < .05$); as such, the null hypothesis (**H0**) was rejected, and the alternative hypothesis (**H1**) was accepted for all attributes.

Table 7.5 Results of One-sample Wilcoxon analyses of the user experience attributes

User Disability Type	Median response	Wilcoxon <i>P</i> -value	median >3
Controllability	5	<0.001	✓
Aesthetics	4	<0.001	✓
Attitude	4	<0.001	✓
Consistency	4	<0.001	✓
Multiple Language Support	4	<0.001	✓
Effectiveness	4	<0.001	✓
Efficiency	4	<0.001	✓
Robustness	4	<0.001	✓
Constraints	3	<0.005	×

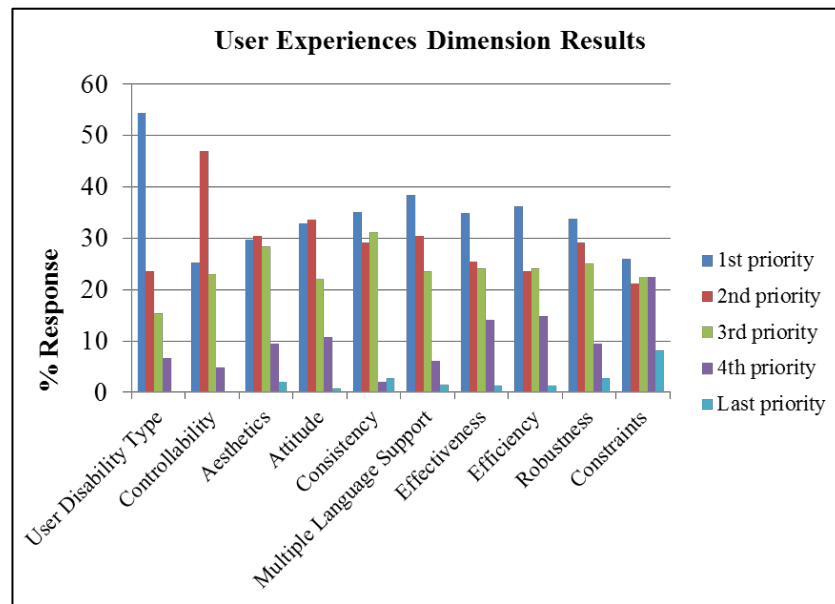


Figure 7.7 User experience dimension results

7.2.2 Refer to appropriate literature

The most obvious way to validate a framework is to refer to appropriate literature. Validating a framework against existing research involves identifying the extent to which factors that impact the effectiveness with which students learn, their perceptions of accessibility or, even more importantly, the effect that factors have on learners' achievements have been proven through empirical research. It is important to note that basing accessibility frameworks on existing research literature alone can be risky because the literature against which the design of a framework is validated may be quite limited and selective. One of the potential risks associated with developing accessibility frameworks through an isolated examination of existing research findings is that the availability of relevant research against which a framework can be validated is relatively limited. While articles may be frequently cited, there is no guarantee that the ideas and concepts they suggest are accurate and of a significant quality. As such, a tendency to rely on the existing literature that is most frequently cited can result in some of the key factors that are pertinent to students' learning experiences being omitted. To prevent this from becoming a

problem, it is important to perform a comprehensive and detailed search; i.e., the more in-depth the literature review, the less likely it is that key attributes are overlooked.

The choice of these frameworks is based on the researchers' previous research in the domain of the usability and quality evaluation of e-learning systems, stressing the importance of evaluating an application from different points of view to obtain more accurate results.

7.2.2.1 Quality improvement framework

Inglis, Ling, and Joosten (2002) provide a quality framework that is designed for managing the improvement of all aspects of delivery of online courses. The framework was originally developed as part of a project funded by the Higher Education Council of the National Board of Employment, Education and Training and is described in (Higher Education Council, 1997). Inglis, Ling and Joosten (2002) republished the framework with a clear set of instructions that outlined how it should be used. As such, the 2002 version provides the most thorough explanation of how the framework should be used to ensure its basic objectives are met, and it is, therefore, this version that the readers are recommended to consult.

The quality improvement framework incorporates ten basic principles that are considered to be important to ensuring that the range of functions that are required to support online delivery are incorporated in a given system.

Table 7.6 maps the DAEL dimensions and attributes against the ten principles of the quality improvement framework as part of the validation process (the letters A-Z denote the DAEL attributes outlined in Table 6.1). When employed in a practical setting, the framework should be contextualised to the institution and the priorities of that institution. In light of this, depending on the situation in which the framework is employed, all ten principles may not always be relevant.

This research describes an approach to validating the quality improvement framework that has not previously published. The framework was first developed by conducting a comprehensive literature review of existing studies and theories on the factors that make a positive contribution to resource-based learning and improve the quality of e-learning systems. Once these factors were identified, they were assessed and categorised in a workshop setting by a panel of experts that consisted of individuals who have featured heavily in existing discourse on distance, open and flexible learning. Following the workshop, a draft framework was produced, and this was, once again, shown to the panel of experts for this review.

In addition to being considered experts in their field, the people who made up the panel of experts were all employed in the tertiary education sector in Australia. As such, the validation process took place within the context of the Australian education environment. This was acceptable because the purpose of the original study was to develop recommendations for a national body of higher education in this setting. However, due to the fact that the framework was validated in the Australian setting, there is no guarantee that it is fit for application within an alternative educational context.

Table 7.6 Matching DAEL framework attributes with the Quality improvement framework ten principles

The Quality Improvement Framework ten Principles	DAEL Framework Attributes
(1) Informed planning and management of resources.	I, Y
(2) Sustained committed leadership.	Y
(3) Improving access for all clients, incorporating equity, and promoting cultural diversity.	L, Q, V
(4) Understanding the requirements of the learner and reflecting stake holder requirements.	L, Q, V, J, K
(5) Design, development, and implementation of programs for effective and active learning.	A, B, C, D, E, F, G, H, I, S
(6) Creating confident and committed staff with new competencies.	T, U
(7) Managing and maintaining the technical infrastructure.	Y, R, W, X, Z, U
(8) Evaluating for continuous improvement.	N
(9) Provision of effective and efficient administrative services.	W, X
(10) Supporting the needs of learners.	L, M, N, O, P

Although the framework that was employed in this study and the DAEL framework are different in terms of their approach and the context of their application, they do share some common characteristics. This is especially true in terms of the core objectives of this research: to consider student diversity and learning experiences that are aligned with students' unique needs. Of the various principles that are outlined within the framework, Principles 3, 4 and 10 specifically focus on supporting the needs of learners and are, therefore, those that are the most aligned with the DAEL dimensions.

7.2.2.2 An Approach to usability evaluation of e-Learning applications

The approach developed by Ardito et al. (2006) aimed to define a methodology that could be employed to evaluate e-learning applications through adapting the e-learning aspect of the Systematic Usability Evaluation (SUE) methodology (Matera et al., 2002). SUE combines a unique inspection technique with user testing to evaluate software applications. What makes this particular approach stand out is the fact that it employs evaluation patterns, which are referred to as abstract tasks (ABTs), to describe the process by which the extent to which the basic application components comply with a set of required attributes and guidelines that have been identified for a particular application task can be estimated. The ABTs guide the inspector's activities and, through doing so, highlight which objects of the application should be present and what actions the inspectors should perform when they assess these objects. These ABTs were designed to conform to a set of guidelines that were defined in accordance with three aspects: (1) the authors' experience with e-learning applications (Roselli, 1995; Roselli et al., 2003), (2) a literature review, and (3) a user study. Through following the SUE methodology, the authors developed a set of specific usability criteria that were deemed to represent an accurate view of the key criteria that the e-learning system should meet. This approach also recognised the importance of assessing the extent to which e-learning applications were accessible. The definition of both ABTs and the usability criteria presented in Table 7.7 refer to the SUE preparatory phase. This table also presents an evaluation of the DAEL framework that was produced by following the SUE methodology (the letters A-Z represents the DAEL attribute as in Table 6.1).

Table 7.7 Usability evaluation for inspecting DAEL framework

ABTs Category	ABTs Type	ABTs Code and Title	DAEL Attribute
Content insertion and content access	Basic	C_1: check of authoring tools	J,K
		C_2: check of the window for requests to repository	J
	Advanced	C_3: reuse verification	W, X
		C_4: check of insertion of alternative learning paths	L
		C_5: check of managing of alternative learning paths	L
		C_6: check of the different access modalities	K
		C_7: check for support to authoring	J,K
		C_8: check for support for flexible content organisation	A,B,D,E,F,G
Scaffolding	Basic	S_1: help verification	G,N,R
		S_2: graphic layout	A,B,C,D,E,F,G,S
		S_3: check of scaffolding presence	M,O
		S_4: check of scaffolding attenuation	M,O
Learning Window	Basic	LW_1: organisation of a course document	A
		LW_2: modality of fruition of a course document	L,O,J,Q
	Advanced	LW_3: suitability of formats of a course document	Q,V
		LW_4: check of assessment test availability	N
		LW_5: check of assessment test presence	N
		LW_6: check of presence of communication tools	K
		LW_7: check of usage of communication tools	K
		LW_8: check of presence of alternative learning paths	L
		LW_9: check of learning tools	J
		LW_10: adequacy of learning tools	C
		LW_11: advanced personalisation verification	A,B,D,E,F,G,Q,V

It is good to mention that the evaluation patterns, ABTs, have not inspected all 26 DAEL attributes. The following attributes are not inspected: H, I, P, U, W-Z. The aim of this validation was to satisfy the above criteria. One important aspect is learning window, since in any interactive system the appearance of the user interface plays an important role especially for dyslexic students. This aspect is reflected in the presentation dimension. The other aspect to evaluate is the structure of the hypermedia and its dynamic behaviour due to the use of different media. This aspect is reflected in the hypermediality dimension. The other two dimensions emerge from considering the two interacting actors and their expected activities: the e-learning application, which should support the user either the student learning the content or the lecturer designing the content. Besides, anticipate to the users' needs which are reflected in the 'learning style' and 'disability type' attribute.

7.3. Chapter Seven Summary

This chapter validates that the DAEL framework can meet the needs of the standards of acceptability and accessibility for learners with different types of dyslexia. The expert validation was designed to measure the extent to which experts agreed that the components of the DAEL

framework met the pre-determined requirements. Experts ascertained whether some attributes were missing from the framework and rated the level of importance and conflict associated with each attribute in terms of the four dimensions. An expert evaluation study was conducted with 111 students who have dyslexia, and 38 field experts consisting of academic researchers and educational developers. The results suggested that there is a statistical significance between the experts' agreement on the extent to which the components/attributes of the DAEL framework meets the four dimensions. The analytical results indicated that the DAEL framework provides sufficient perspective of learners' with dyslexia. The findings provided evidence that the DAEL framework is based on sound theoretical foundations from research with respect to all four research perspectives. The DAEL framework was further validated by identifying the extent to which factors that impact the effectiveness with which students learn, their perceptions of accessibility or, even more importantly, the effect that factors have on learners' achievements have been proven through existing empirical research. The evidence suggests that the DAEL framework has additional criteria, especially with respect to user diversity and usability. The output of this research will be valuable for both academics and developers of e-learning systems.

This chapter presented a comprehensive evaluation of the DAEL framework proposed in Chapter 6. While this DAEL framework provides a detailed overview of the functional or technical requirements that an e-learning system must deliver, no analysis has been performed as to the techniques by which personalisation and adaptation can be achieved. As such, Chapter 8 describes the process by which the ontologies can be modelled in a manner that provides students with dyslexia with access to personalised learning experiences.

Chapter 8 Ontology Engineering

8.1. Introduction

In recent years³³, more and more researchers have attempted to develop an understanding of how technology can enhance the effectiveness of teaching and learning interventions. E-learning has evolved into a key tool that can facilitate and enhance the progression of student's knowledge, skills and understanding. The web, in particular, has gained increasing importance as a teaching tool and is more and more frequently employed within contemporary classrooms. While it is readily acknowledged that technology can positively facilitate a teacher's ability to deliver the key elements of the curriculum, the interventions that are currently utilised in classrooms often fail to take into consideration the needs and behaviours of students with disabilities. As such, these students are often denied the benefits of technology that are available to their mainstream counterparts. This is certainly true in the case of students who have dyslexia. Research by Beacham and Alty (2006) found that the e-learning tools that are employed in many modern-day classrooms do not take the needs and requirements of dyslexic learners into consideration, resulting in materials that have an 'inability to provide accessibility and convenience for all learners' (p. 90). Furthermore, their research also indicated that the e-learning materials that are in use in contemporary classrooms fail to offer learning experiences that are aligned with student's individual preferred learning approaches and, as such, hinder, as oppose to facilitate, dyslexic students' learning.

The following sections employ the Methontology proposed in Section (3.5.4) to develop an ontology that can deliver learning technologies that can adapt to the needs and learning styles of learners with dyslexia. The discussion starts by providing an overview of the ontology concept (Section 8.2), and the steps involved in the construction of a conceptual model (Section 8.3), before formalising the proposed conceptual model in Section (8.5.1). Finally, in Section (8.6), the author validates the proposed ontology.

8.2. Ontology Concept Description

As a result of recent developments in semantic web technologies, ontology is being increasingly used to create adaptive learning systems. The semantic web makes it possible for data to be accurately and logically read, processed and understood by machines. As an explicit formal specification of a conceptualisation (Grubber, 1993), ontology is the most effective method of representing knowledge because of its extensibility and the fact that it can be flexibly applied during the process of designing concepts and defining their relationships. Ontology makes it possible to formally and explicitly define the various concepts that exist within a domain and the relationship between them. Furthermore, an ontology can simplify the complex structure of knowledge that makes up a domain in a manner that facilitates reasoning about knowledge

³³ This chapter is based on the following peer-reviewed paper:

Alsobhi, A., Khan, N. & Rahanu, H. 2015, Personalised learning materials based on dyslexia types: ontological approach, in *Proceedings of the 19th International Conference on Knowledge-Based and Intelligent Information & Engineering Systems (KES 2015)*, Singapore

domains (Chandrasekaran et al., 1999). As such, ontologies have proven their worth as mechanisms for representing knowledge across a multitude of domains, in particular, those that are prevalent in the field of education.

This thesis is concerned with how ontologies can be employed to generate personalised learning experiences and development plans that are directly linked to a learner's preferred learning style and dyslexia type. To deliver such a personalised learning path, the ontology needs to meet the following criteria:

- **Flexible:** The ontology needs to be sufficiently adaptable so that the developers can incorporate adaptivity components that effectively influence the adaptive process.
- **Extensible:** The ontology should provide the authors with the option to introduce further elements of adaptivity.
- **Semantically rich:** The ontology needs to be capable of logically expressing adaptation decisions.
- **Independent:** The ontology should assist the explicit definition of every adaptivity component without having an impact on the system implementation code.
- **Maintainable:** The ontology should be sufficiently modifiable to facilitate effective personalisation options.

As part of this thesis, multiple ontologies and accompanying rules were specifically designed to deliver an annotating knowledge domain that is capable of meeting the criteria outlined above. To achieve this, the process commenced by classifying and differentiating those ontologies that are of relevance to the domain of e-learning as follows:

1. User Ontology
2. Learning Ontology
3. Dyslexia Type Ontology
4. Learning Style Ontology
5. Assistive Technology Ontology

8.3. Building Conceptual Model

There is no one, universally accepted approach to building ontologies, and several methodologies have been utilised with great success to design and build ontologies. The extent to which an approach is effective relates directly to the objectives of the application and any future extensions that may be anticipated. According to Millard et al. (2006), a number of different stages are involved in the construction of an ontology: knowledge acquisition, knowledge modelling, knowledge annotation and reuse. In practice, the development of an ontology is very much an iterative process. The key concepts of the ontology should be close to the main objects (physical or logical) and relationships in the domain of interest. In the sentences that describe the domain, these are typically nouns (objects) or verbs (relationships) in sentences. The ontologies presented within this thesis were developed by following the approaches suggested by Millard et al. (2006) and Noy and McGuinness (2001). This stage of the research aimed to develop a set of resources that adequately describe the ontology's objects, purposes, scope and granularity. The appropriate activities are outlined below.

8.3.1 Step 1: Determine the domain and scope of the ontology

Within the software design methodology employed, the author should develop a comprehensive overview of the scope of the domain(s) to be captured and described in the proposed ontology, regardless of whether that domain consists of a single or multiple domains. Stipulating the ontology is an important step in the process of recognising and understanding the domain boundaries that require investigation. During the specification phase, the designer should identify the key questions pertaining to the purpose of the ontology and should subsequently seek to answer these; for example, in the case of the current research, the designer should ask: For what purpose is the Ontology of Dyslexia Adaptive E-Learning (ODAEL) being built? What are its planned uses? Who are the end users? Furthermore, it is important that the boundaries pertaining to the domain that the ontology will cover are identified and clearly delineated.

The process at this stage involves pinpointing the domain ontology that the ontology will be employed for and where it will be implemented. This involves identifying the main features of the ontology and assessing how it relates to other domains. The scope of the ODAEL employed in the current research is presented in Table 8.1, while Figure 8.1 provides an overview of the domain scope of the proposed ODAEL.

Table 8.1 The Scope of Ontology of Dyslexia Adaptive E-Learning (ODAEL) domain

Domain	Adaptive E-Learning for students with dyslexia
Date	2014-2015
Built by	Research student at Computer Science department in School of Science and Technology – Middlesex University.
Purpose	To develop a consensual knowledge model of the adaptive e-learning domain. The model should be fully accessible and usable by scholars and, ultimately, domain users. The domain ontology will be employed to create assistive learning technologies that can be directly aligned with the needs and capabilities of learners with dyslexia. Two fundamental aspects were of interest: the learning styles that people with dyslexia exhibit, and how assistive technologies can be adapted in such a manner that they support and foster these learning behaviours. It is anticipated that the ontology developed can be employed for a multitude of different purposes and can potentially be extended to facilitate the learning experiences of individuals who have general usability issues because the problems associated with dyslexia are generally also exhibited by people who have alternative forms of special needs.
Scope	Within the semantic model, the scope reflects the domain knowledge. The ODAEL ontology is domain specific and covers the dyslexia type, learning styles and assistive technologies branches.
Sources of knowledge	• ISO 9999:2011³⁴ (Assistive products for persons with disability -- Classification and terminology) • FIPA Device Ontology Specification³⁵ • Solutions and Content ontology³⁶ • IEEE (2002)³⁷ (Learning Object Metadata) • Gascuena et al., (2006) (Domain ontology for personalised e-learning in educational systems). • The researcher also scanned several materials, websites, assorted books, and online courses' curriculum to grasp an idea about the named domain.

³⁴ <https://www.iso.org/obp/ui/#iso:std:iso:9999:ed-5:v1:en>

³⁵ <https://www.fipa.org/assets/XC00091D.pdf>

³⁶ https://wiki.gpii.net/w/Solutions_and_Content_ontology

³⁷ http://129.115.100.158/txlordocs/IEEE_LOM_1484_12_1_v1_Final_Draft.pdf

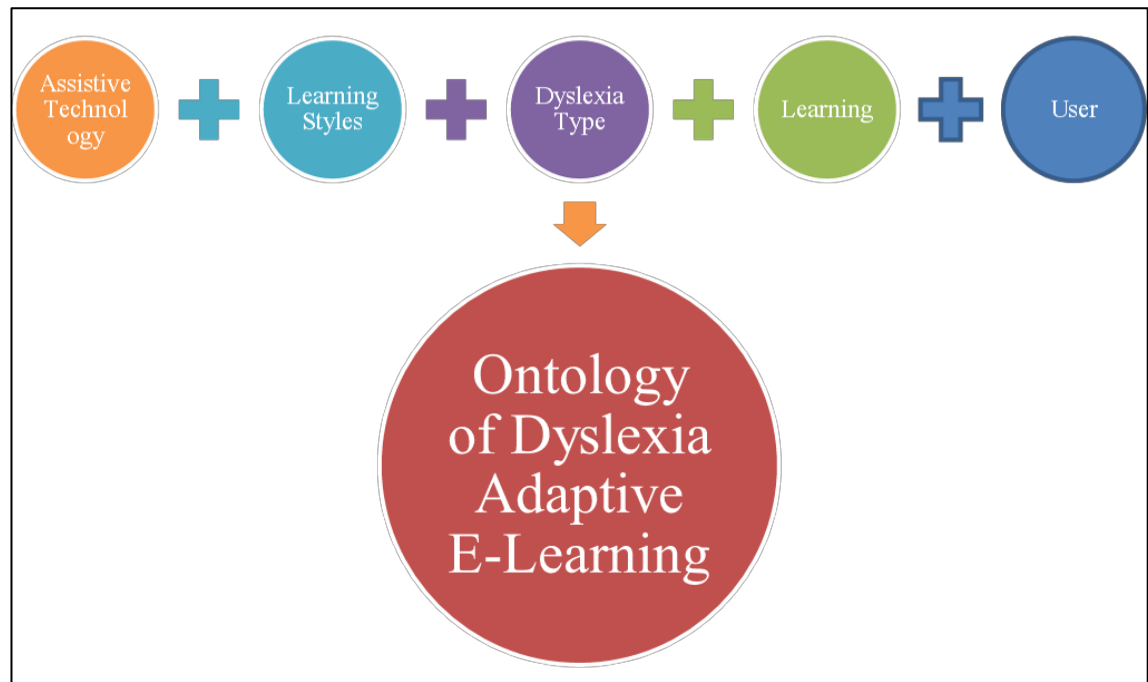


Figure 8.1 The Main components of Ontology of Dyslexia Adaptive E-Learning (ODAEL) domain

8.3.2 Step 2: Consider reusing existing ontologies

Before commencing the process by which the ontology is modelled and built, it is first important to identify whether any existing ontologies are available that can potentially be employed to develop an e-learning system that meets the objectives of this thesis. Existing ontologies can be identified through a number of processes. These include searching ontology libraries, such as the DAML ontology library³⁸, and the Protégé ontologies³⁹, using semantic search engines such as Swoogle⁴⁰ and OntoSearch⁴¹, or consulting ontology portals such as ONTHOLOGY⁴².

An initial search of these three sources was unable to identify any matching ontologies that were aligned with the domains of interest in this thesis; i.e., 'dyslexia type' and 'learning style'. However, a number of useful candidate ontologies related to the learning domain and assistive technologies were identified. These will be discussed in more depth in due course in this chapter. In light of the lack of existing matching ontologies for the domains of interest, ontologies were constructed from scratch for the 'dyslexia type' and 'learning style' domains, and some aspects of the 'assistive technology' domains. These ontologies underpinned the development of conceptual approaches by which personalised learning materials for students with dyslexia could be delivered.

8.3.3 Step 3: Knowledge acquisition

In order to construct a conceptual model, it is first important to gain sufficient knowledge to describe the key domains associated with the concept. A solid research and design process needs to be followed by which knowledge is acquired, analysed and interpreted, before being

³⁸ <http://www.daml.org/ontologies/>

³⁹ <http://protege.stanford.edu/download/ontologies.html>

⁴⁰ <http://swoogle.umbc.edu/>

⁴¹ <http://www.ontosearch.org/>

⁴² <http://www.onthology.org/>

developed into a machine representation. In the case of this thesis, the purpose of knowledge acquisition is to encapsulate the domains of dyslexia, learning styles and assistive technologies, and to organise them into a hierarchical structure-based ontology competence. The approach that is typically employed by the artificial intelligence (AI) community involves domain experts eliciting knowledge at a preliminary stage before the knowledge is formally coded.

The three models described in Chapter 4 represent key aspects of this step. Through completing a formal and informal text analysis of the domain literature, the researcher extracted the knowledge of the three respective domains: dyslexia type, learning styles and assistive technologies. The main concepts and information that needed to be described was identified before the core relationships between the key concepts were identified. As such, the knowledge that had been acquired was transferred into models that adequately represented the relationships between the domains. The knowledge acquisition process that was employed in this thesis helped to frame the ontology structure and develop the main set of concepts that guided the development process. As knowledge representation is procedural, developing the ontology represented a significant challenge.

8.4. Conceptualisation of ODAEL Entities Ontology

According to Methontology described in Section (3.5.4), conceptual models identify the tasks associated with constructing information in a logical model. The conceptualisation process commences when the majority of the required knowledge has been acquired and is in need of organisation. Once the author has accumulated sufficient knowledge pertaining to the respective domains (Chapter 4), he or she can develop a conceptual model that describes the problem and its solution.

The process of developing a conceptual model commences with identifying the components of the ontology: concepts, relationships, individuals, attributes, constants, formal axioms and rules. Figure 8.2 depicts how these components are constructed as part of the conceptualisation activity. Given that this research focused on the use of domain ontologies that have a light-weight level of expressiveness, which exclude axioms and constraints, Step 9 of the conceptualisation activities, *describe formal axioms*, was deemed to be out of the scope of this thesis.

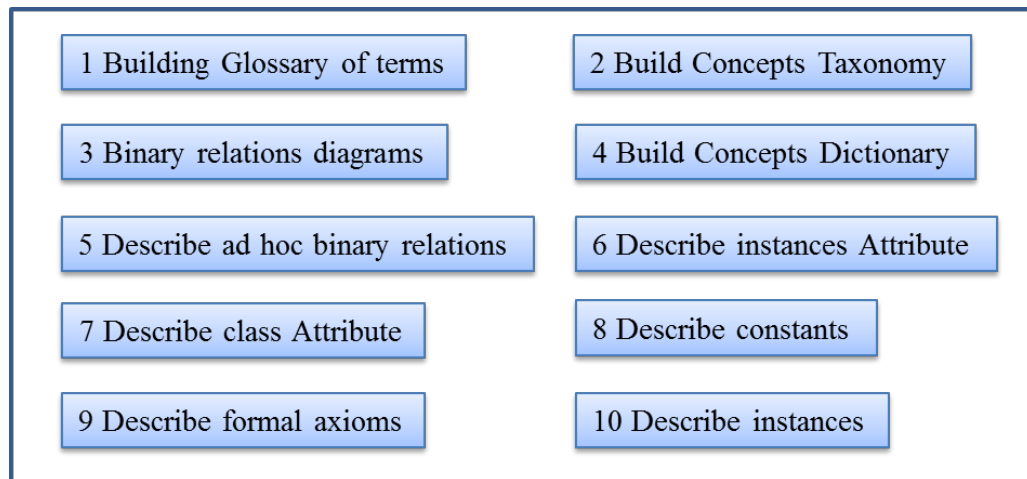


Figure 8.2 Conceptualisation activities

8.4.1 Step 4: Building glossary of terms

The development of a glossary of the ODAEL terms commenced with integrating all the relevant terms of the field. A conceptual model of the ontology was then constructed that was based on this glossary of terms, which included synonyms, acronyms and a simple description for each term included in the ontology. Table 8.2 shows a sample of the glossary of terms of the ODAEL entity ontology. In this study, the three models described in Chapter 4 were used as the source through which this glossary was generated.

Table 8.2 Part of the glossary of terms of ODAEL ontology

Class Name	Synonyms	Acronyms	Description	Type
Course	Module	-	Describes number of lessons and lectures to cover a materials in a curriculum	class
isDescribedBy <i>Concept, Resource</i>	-		Provide a detailed description for the class Concept by class Resource	Relation
Student	Learner	-	Describes the person who is enrolled or attends classes at a school, college, or university.	subclass
Concept	-	-	Describes the smallest grain of learning object	class
conceptName	-	-	The concept name	Instant Attribute
DyslexiaType	Dyslexia Difficulties	-	Describes the difficulties encounter by students with dyslexia	subclass
AssistiveTechnologies	-	ATs	Describes the hardware or software designed to facilitate the use of computers by people with impairments	class

8.4.2 Step 5: Building concepts taxonomy

The construction of the concepts taxonomy could commence once the glossary of ODAEL contained a large amount of domain terms. Before the development of a computational model became fundamental, natural language was employed to generate and define unambiguous and precise classes that are structured in a semi-formal hierarchy.

Constructing a concept taxonomy of the domain generates the concepts, classifications and descriptions that are to be described in a hierarchy. Ontology construction approaches are employed to develop the concepts taxonomy. These methods can be both top-down and bottom-up. This facilitates the identification of the first concept to control the level of details, such as Classes –Subclasses of – Partition-of.

Several different approaches to developing a class hierarchy can be employed. These were described by Uschold and Gruninger (1996) as follows:

- A top-down development process: This commences by defining the most general concepts in the domain and then drilling down to more specialised concepts.
- A bottom-up development process: This commences by defining the most specific classes in the domain and the leaves of the hierarchy. The classes are then grouped into more general concepts.
- A combination development process: A combination of the top-down and bottom-up approaches through which general concepts are identified, and these are matched with specific classes.

It is important to note that none of the three methods described above are necessarily more effective than the others. The approach that is most suitable for a given project will very much rely on the objectives of that project and the personal view of the domain. If an author has a systematic top-down view of the domain, the top-down approach will generally be the most appropriate. Many ontology developers favour a combination approach because the concepts that typically sit “in the middle” of the domain tend to be the more descriptive concepts (Rosch, 1978). The approach to the construction of the ODAEL ontology in the current research was based on a top-down approach, the reasons for this are provided below.

8.4.2.1 ODAEL Top-Down Approach

To develop a more comprehensive understanding of the ODAEL domain, after building the glossary of terms, the high-level structure of the ontology was defined according to the three research models described in Chapter 4. A top-down approach to designing the taxonomy of the ODAEL was deemed to be the most appropriate for this research because it allowed an accurate and readable expression of the domain knowledge. The top-down approach that is represented in Figure 8.3 depicts the ontologies that compose the ODAEL as opposed to the hierarchy of these ontologies. A number of research studies have indicated that information can be more readily classified in a multidimensional hierarchy than it can in a one-dimensional classification (Sawsaa & Lu, 2013). The multidimensional hierarchy of the ODAEL can be observed in Figure 8.3.

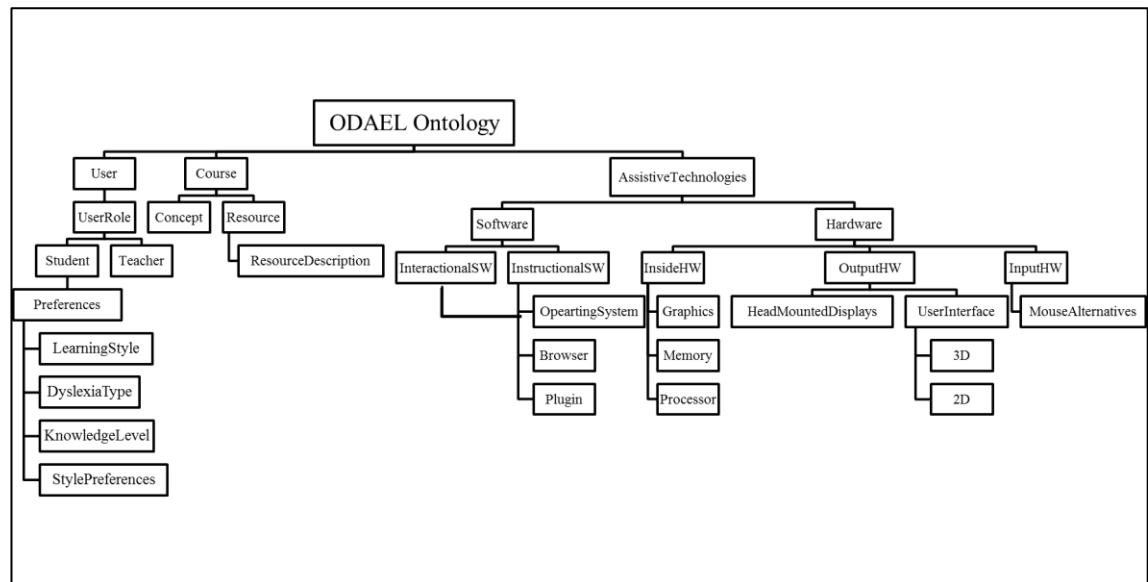


Figure 8.3 ODAEL top-down approach

Four taxonomic relations were used, according to the Methontology (Section 3.5.4): Subclass-Of, Exhaustive-Decomposition, Disjoint-Decomposition and Partition.

- Class *B* is a subclass of Parent class *A* if, and only if, every instance of *B* is also an instance of *A*. The *A* class may have multiple superclasses and subclasses. Subclass-of has a transitive meaning; i.e., If *B* is a subclass of *A* and *C* is a subclass of *B*, then *C* is a subclass of *A*.

For example, the author defined the *AssistiveTechnologies* (*ATs*) class and then defined the *Software* class as a subclass of *ATs*. The author then defined the *InteractionalSW* class as a subclass of *Software*. The transitivity of the subclass relationship means that the *InteractionalSW* class is also a subclass of the *AssistiveTechnologies* class. Sometimes the developer may distinguish between direct and indirect subclasses. A direct subclass is deemed to be the “closest” subclass of the class because there are no classes between the class and its direct subclass in a given hierarchy. That is, no other classes exist in the hierarchy between a class and its direct superclass. In terms of the example outlined above, *InteractionalSW* is a direct subclass of *Software* and is not a direct subclass of *AssistiveTechnologies*.

- The Exhaustive-Decomposition relation of the *C1* class is a subclass of *C2*; as such, they share common subclasses and instances.

For example, if the *InteractionalSW* and *InstructionalSW* classes are Exhaustive-Decomposition relations of the *Software* class, these classes share common instances, such as *Browser*, *OperatingSystem* and *Plugin*.

- If class *B* and class *C* are subclasses of class *A*, and there are no common instances between them, the relation is disjoint-Decomposition.

For example, the *AssistiveTechnologies* class was defined, and this has two subclasses: *Software* and *Hardware*. There are no common instances between the *Software* and *Hardware* classes; as such, the relation is disjoint-Decomposition.

- If a class *B* is a subset of class *A*, they do not have common instances; however, if *B* covers part of class *A*, a Partition relation exists.

For example, the *Student* and *Teacher* classes form a Partition relation of the *User* class because every user is either a *Student* or a *Teacher*. Figure 8.4 outlines the concept taxonomy of the ODAEL ontology.

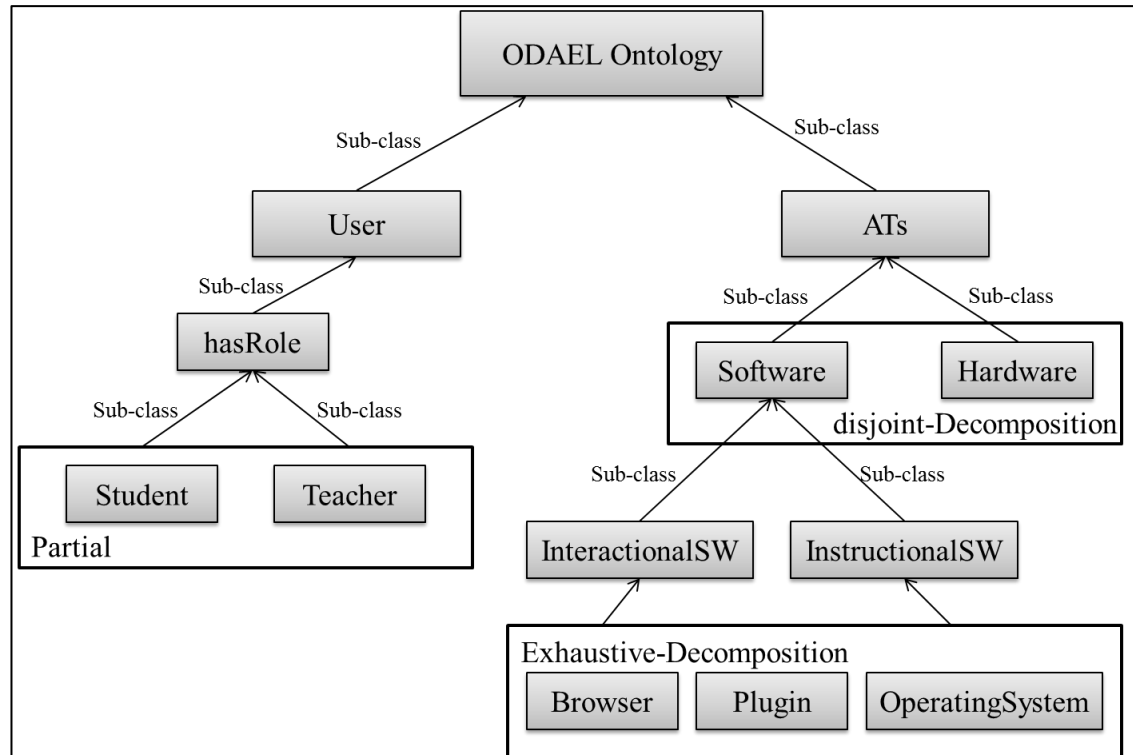


Figure 8.4 Concept taxonomy of ODAEL ontology

8.4.3 Step 6: Building ad hoc binary relation

Once the concepts taxonomy has been constructed, the binary relations should be developed. These binary relations are designed to establish ad hoc relations between the same or different classes that are already included in the concept dictionary. Figure 8.5 presents the ad hoc binary relations of the ODAEL ontology with the relations Has-A and Is-A, and their inverse relations isPartOf and haspartA; these relations connect these classes. Before progressing, the ad hoc binary relations should be verified to ensure there are no errors. This is of particular importance if the domain and ranges axiom is applied.

In the current research, the relationship between the *Resource* class and *ResourceDescription* was named Has-A, and the inverse relationship was referred to as is-Part-Of.

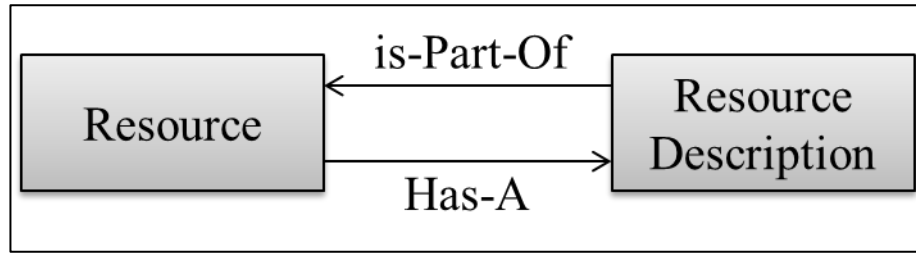


Figure 8.5 ODAEL ad hoc binary relations

8.4.4 Step 7: Build the concept dictionary

The ontology distinguishes between the relationships and instance attributes of each class. The classes should be outlined in an ODAEL dictionary that describes the domain concepts together with key information such as class name, class attribute and relations. Table 8.3 presents a sample of the ODAEL concept dictionary employed in the current research.

Table 8.3 ODAEL concept dictionary

Class Name	Instances	Class Attribute	Instance Attribute	Relations
User	Student, Teacher	hasRole,	userId, userName, password	hasRole,
Course	Programming Language	hasConcept, hasStudent, Teacher	courseName, courseDescription, numberOfStudents	hasConcept, hasStudent, taughtBy

8.4.5 Step 8: Define ad hoc binary relation

Defining the ad hoc binary relation is critical to developing a solid understanding of the binary relationships that can be observed in the classification tree. Table 8.4 presents a sample of the ad hoc binary relation of the ODAEL ontology employed in the current research. To identify the correct binary relations, the relations of the ODAEL ontology were sorted in a table format according to relation name, names of source, target class, cardinality and inverse relationship for each ad hoc relationship.

Table 8.4 Part of the ad hoc binary relation of ODAEL ontology

Relation Name	Source Class	Cardinality	Target class	Inverse relation
enrollinCourse	Students	M:N	Course	hasStudent
isDescribesBy	Concept	M:N	Resource	describes

8.4.6 Step 9: Define instance attributes

The instance attributes table expands on the descriptions of the instance attributes that were outlined in the concepts dictionary. Within the instance attributes of the ODAEL ontology table, the instance attribute takes the same form as that described in the dictionary; however, additional information relating to the value of the attribute it also included. The table contains the following fields: instance attributes name, the class name that belongs to it, value type, value range (numerical value), and cardinality (min, max). Table 8.5 depicts a sample of the instance attributes of the ODAEL ontology.

Table 8.5 Part of instance attributes of ODAEL ontology

Instance Attributes Name	Class Name	Value Type	Value Range	Cardinality
Programming Language	Course	String	-	(1,1)
StudentID (A0003)	Student	String	-	(1,1)

8.4.7 Step 10: Create class attributes

The class attributes table describes the class attributes in more detail than that presented in the concepts dictionary. When developing the class attributes table, the ontologist should include the following fields: class attributes name, defined class name (where the attribute is defined), value type, and cardinality (min, max), and value. Table 8.6 presents part of the class attributes table for the ODAEL ontology.

Table 8.6 Part of class attributes of ODAEL ontology

Class Attributes Name	Defined Class	Value Type	Cardinality	Value
hasRole	User	String	(1,N)	String
createdBy	ResourceDescription	String	(1,N)	String

8.4.8 Step 11: Define constants

Each of the constants that are outlined in the glossary of terms needs to be described in detail. The define constants table presents a detailed description of each constant and presents the following: names, value type (a number, a mass, etc.), value, and measurement unit for numerical constants. The attributes can be extrapolated according to the constants. Table 8.7 presents a sample of the constants of ODAEL ontology.

Table 8.7 A Section of constants table of ODAEL ontology

Name	Defined Class	Value Type	Value	Measurement Unit
numberOfStudent	Course	Cardinal	min 5 students	students

8.4.9 Step 12: Define instances

Following the development of the conceptual model of the ontology, the ontologist may progress to define relevant instances of the concept dictionary through the use of an instance table. This table will include the following information: instance name, concept name, attribute and values (if known). Table 8.8 provides a sample of some of the instances that are included in the instance table of the ODAEL ontology.

Table 8.8 Part of the instance table of the ODAEL ontology

Instance Name	Class Name	Attribute	Value
Mr.X, A0001, "n12345", Student,	User	Username	Mr. X
		userId	A0001
		Password	"n12345"
		hasRole	Student

8.5. Conceptual Model of ODAEL Ontology

At this stage of the process, the list of core basic terms should be elaborated upon by following the Methontology presented in Section (3.5.4). The conceptualisation process will result in a conceptual model that visualises and expresses the theoretical constructs of the ODAEL domain.

Conceptual models represent reflections of the computational model; for example, in the current study, they represent assistive technologies that students with dyslexia will use in the domain. The conceptual model was developed using ArgoUML⁴³ software. It contains the entity classes, attributes and their relationships in the ODAEL ontology. It will be useful at this point to elaborate further on the primary relationships between the classes defined in the ODAEL ontology.

The first entity, *User*, covers all people who use the Dyslexia Adaptive E-Learning Management System (DAELMS), and represents relationships with other subclasses, as depicted in Figure 8.6. The study assumes *User* is a single person; however, it could also be a group of people. Every *User* in the proposed system *hasRole*, which is *Student* or *Teacher*.

Another example is the *Resource* class, which is related to the *ResourceDescription* class by *has-A* description. The *Resource* is *createdBy Teacher*, *helpsToAchieve conceptObjective*, and *hasA resourceKeyword*. In the majority of cases, the user who creates the resources will be the *Teacher*; however, in some cases, it may also be a *Student* who has achieved an “expert” classification in the *knowledgeLevel*. In order to achieve the level of adaptivity required to meet the objectives of the system, the *Resource* incorporates multiple parameters: *knowledgeLevel*, *language*, *dyslexiaType*, *learningStyle* and *interactivityType*. Each user *hasA userId* and *password* to access the system. It is the combination of these that allows us to express the relationship between these classes. The data involved in the system is complex and large-scale; as such, it is only possible to discuss some of the results here.

⁴³ <http://argouml.tigris.org/>

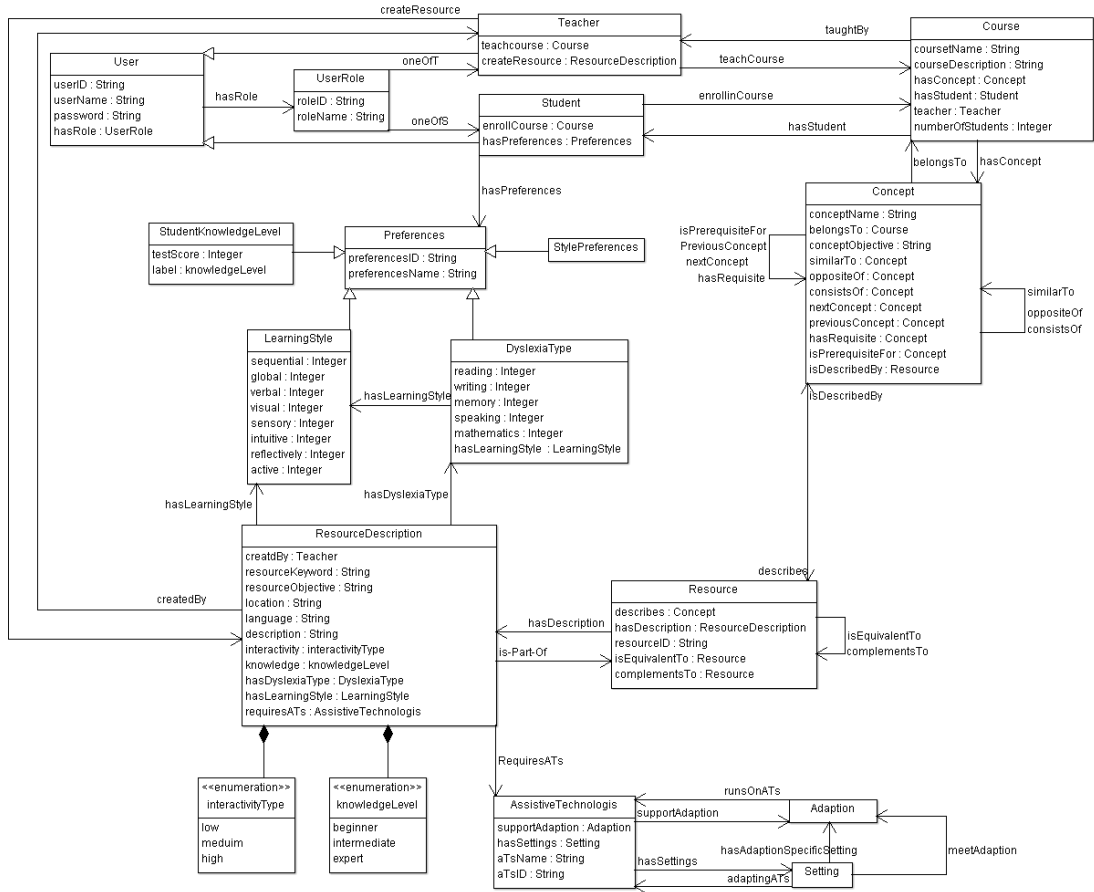


Figure 8.6 Part of conceptual model of ODAEL ontology

8.5.1 Building computational model – formalisation

It is important to develop a conceptual model of the Dyslexia Adaptive E-Learning domain in natural language. The primary output of this stage is the ODAEL ontology, which is structured in natural language that is suitable for data modelling and knowledge representation using an appropriate ontology editor such as Protégé. Protégé allows the expression of unambiguous and complete specifications of domain concepts with relations between them, and organises them in an appropriate hierarchy that consists of super-types and sub-types. Furthermore, an ontology that is produced in Protégé can be exported to different formats such as RDF and XML. Figure 8.7, presents the ODAEL ontology in OWL language.

```

1 <rdf:RDF
2   xmlns="http://www.semanticweb.org/aishaalsobhi/ontologies/2014/10/ODAEL#"
3   xml:base="http://www.semanticweb.org/aishaalsobhi/ontologies/2014/10/ODAEL#"
4   xmlns:dc="http://purl.org/dc/elements/1.1/"
5   xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
6   xmlns:owl2xml="http://www.w3.org/2006/12/owl2-xml#"
7   xmlns:owl="http://www.w3.org/2002/07/owl#"
8   xmlns:xsd="http://www.w3.org/2001/XMLSchema#"
9   xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
10  xmlns:ODAEL="http://www.semanticweb.org/aishaalsobhi/ontologies/2014/10/ODAEL#"
11
12  <!-- OWL Header Example -->
13
14  <owl:Ontology rdf:about="http://www.semanticweb.org/aishaalsobhi/ontologies/2014/10/ODAEL#"
15    <dc:title>ODAEL ONTOLOGY</dc:title>
16    <dc:description>Ontology that describe the domain of Dyslexia Adaptive E-Learning.</dc:description>
17    <dc:creator xml:lang="en"> Aisha Alsobhi </dc:creator>
18  </owl:Ontology>
19
20 </rdf:RDF>
21

```

Figure 8.7 ODAEL ontology is written by OWL

The user can explore the structure of the ODAEL ontology by browsing the upper level of the tree. The upper level provides a comprehensive overview of the adaptive e-Learning domain. From there, deeper levels can be examined by navigating through the multiple levels of the tree. The root class in OWL is thing (owl: Thing). This is the root of all classes such as Resources in RDF (rdfs: resources). Figure 8.8 presents a simple hierarchy of the main classes of the ODAEL ontology in OWL coding; some classes of the ODAEL ontology are as shown in Figure 8.8 as well.

```

1 <rdf:RDF
2   xmlns="http://www.semanticweb.org/aishaalsobhi/ontologies/2014/10/ODAEL#"
3   xml:base="http://www.semanticweb.org/aishaalsobhi/ontologies/2014/10/ODAEL#"
4   xmlns:dc="http://purl.org/dc/elements/1.1/"
5   xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
6   xmlns:owl2xml="http://www.w3.org/2006/12/owl2-xml#"
7   xmlns:owl="http://www.w3.org/2002/07/owl#"
8   xmlns:xsd="http://www.w3.org/2001/XMLSchema#"
9   xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
10  xmlns:ODAEL="http://www.semanticweb.org/aishaalsobhi/ontologies/2014/10/ODAEL#"
11
12  <!-- OWL Class Definition - UserRole -->
13  <owl:Class rdf:about="http://www.semanticweb.org/aishaalsobhi/ontologies/2014/10/ODAEL#UserRole"
14    <rdfs:label>User Role</rdfs:label>
15    <rdfs:comment>The class of all user roles.</rdfs:comment>
16  </owl:Class>
17
18  <!-- OWL Subclass Definition - Student -->
19  <owl:Class rdf:about="http://www.semanticweb.org/aishaalsobhi/ontologies/2014/10/ODAEL#student"
20    <!-- Student is a sub-classification of UserRole -->
21    <rdfs:subClassOf rdf:resource="http://www.semanticweb.org/aishaalsobhi/ontologies/2014/10/ODAEL#UserRole"/>
22    <rdfs:label>Student</rdfs:label>
23    <rdfs:comment>Student As system User</rdfs:comment>
24  </owl:Class>
25
26  <!-- OWL Subclass Definition - Teacher -->
27  <owl:Class rdf:about="http://www.semanticweb.org/aishaalsobhi/ontologies/2014/10/ODAEL#teacher"
28    <!-- Teacher is a sub-classification of UserRole -->
29    <rdfs:subClassOf rdf:resource="http://www.semanticweb.org/aishaalsobhi/ontologies/2014/10/ODAEL#UserRole"/>
30    <rdfs:label>Teacher</rdfs:label>
31    <rdfs:comment>Teacher As system User</rdfs:comment>
32  </owl:Class>
33
34 </rdf:RDF>

```

Figure 8.8 Some of ODAEL ontology classes is written by OWL

The next subsections define the interrelations between the classes of the ODAEL ontology and their classifications through the use of the OWL property and the ontological definition. Section (8.5.2) presents an overview of the ontology that is designed for a learner who has dyslexia. Additional classes and concept instantiation can be employed to extend this ontology through inheritance. This will make it possible for the system to take the requirements of a specific application or the type of disability that the user exhibits into consideration.

8.5.2 User ontology

The *User* class is an abstract entity that is employed to describe the person who uses the system. It is the main component of the ODAEL ontology. This upper category is important because it stresses and embodies the relationships and their roles in the system. The *User* class is connected to the *UserRole* class via the *hasRole* object property, which describes the role of the *User* in the system. Regarding the user class, data type properties such as *userName*, *userId*, and *password* are of string type. The *User* class has two main subclasses: *Teacher* and *Student*. The *Student* class is applicable to an individual who is interacting with the system with the intention of achieving a set of learning goals. This class has two main object properties: *enrollinCourse*, which provides a list of the courses that a student is enrolled in, and *hasPreferences*. The object property *hasPreferences* connects the *Student* class with *Preferences* class and it is considered to represent the main object property of the system because it delivers the required adaptation through taking into consideration the learning style ontology and dyslexia type ontology along with the student knowledge level and style preferences. The *Teacher* class is applicable to the individual who teaches or instructs the *Course* (*teachCourse* object property). In addition, the *Teacher* creates the appropriate resources and the learning materials via the *createResource* object property.

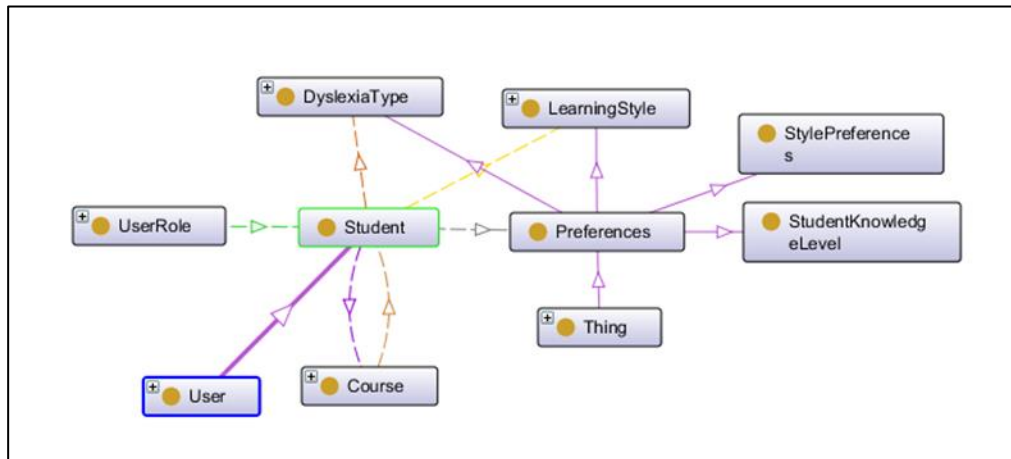


Figure 8.9 Class *Students* and its relationships with other classes

8.5.3 Learning ontology

The learning ontology describes all aspects related to learning, from the course through to the relevant learning materials. This indicates where the name “Learning Ontology” came from.

8.5.3.1 Course class

The *Course* class represents the subjects being taught in a given educational system. An instance of the *Course* class, for example, could be *Programming Language*. The class contains several properties: *courseName* and *courseDescription*, which refer to the name of the course and a brief description of its content respectively. *hasConcept* (*belongsTo* is its inverse) relate to the set of concepts of which a course is composed. The number of students enrolled on the course and the list of all enrollees is represented by two properties: *hasStudent* and *numberOfStudents*, which is a data type property with integer type. The *teachCourse* object

property links the *Course* class to the *Teacher* class and specifies the name of the person who is teaching this course.

8.5.3.2 Concept Class

The *Resources* and *Concept* classes described by Gascuena et al. (2006) were adopted in this research as they were deemed to represent appropriate learning concepts and resources. The ontology was then developed using relevant metadata relating to the learning concepts involved. The concepts that the students are learning at the point of interaction are stored in the *Concept* class, which is represented as a collection of concepts within the *Course* class. The resources are separated from their associated concept in order to allow a higher degree of reuse; i.e., different resources can point to the same concept allowing the given material to be reused within an alternative course. It is possible for concepts to have hierarchical relations between themselves; for example, “Basic Java Syntax” and “Creating (Declaring) Java Variables”. This relation will be employed for the purposes of facilitating adaptation; for instance, to show the resources related to the concept “Basic Java Syntax” before “Creating (Declaring) Java Variables”.

As described previously, the knowledge of the treated domain is reflected in the concepts and is, therefore, collected in the *Concept* class. This class contains the *conceptName* data type property, and this is employed to identify the concept and other object properties that make it possible to establish different relations between domain concepts as follows:

- 1) *consistOf* defines a concept hierarchy and, therefore, establishes a relation between a given concept and its sub-concepts. The sub-concepts continue to the point at which an atomic concept is reached; that is, from the point of view of the teacher, no further decomposition is required;
- 2) *similarTo* and *oppositeOf* allows the author to map a concept to other concepts that have the same or different semantic meanings respectively;
- 3) *nextConcept* and *previousConcept* indicate the concepts through which it is possible to progress/return to a given concept. The browsing possibilities that these two properties allow do not impose any constraint in terms of whether the mapped concepts are known or not; and
- 4) *hasRequisite* and *isPrerequisiteFor* (its inverse) indicate which concepts must be known before starting to study a concept, and the concepts for which they are a prerequisite respectively. In this case, some conditions need to be fulfilled before a learner can be provided with access to the concepts.

The data property *conceptObjective* describes the collection of objectives associated with the study of a concept. The object property *isDescribedBy* (*Concept* class) points to digital resources that explain a concept or assess the stored knowledge pertaining to it. The capacity of a learning concept to achieve a high degree of reusability is largely a function of the granularity of the collection of concepts contained within it. In the current thesis, the learning concepts that have a very low granularity are treated as resources; for example, learning concepts at the level of paragraph, image, table, diagram, and so on. Thus, in real time, an e-learning system is able to add/remove contents at this level to produce tailor-made learning

materials that are aligned with the learning preferences and styles of the user. Also, this facilitates the use of didactical materials in those assistive technologies that some students with dyslexia require to learn effectively.

Learning concepts that have a larger degree of granularity are constructed from those that have a smaller degree of granularity. For instance, Course consists of one learning units. Each of these learning units can, in themselves, consist of one or more chapters. Each chapter includes one or more learning concepts and these learning concepts can be of several types according to the resources sub-ontology.

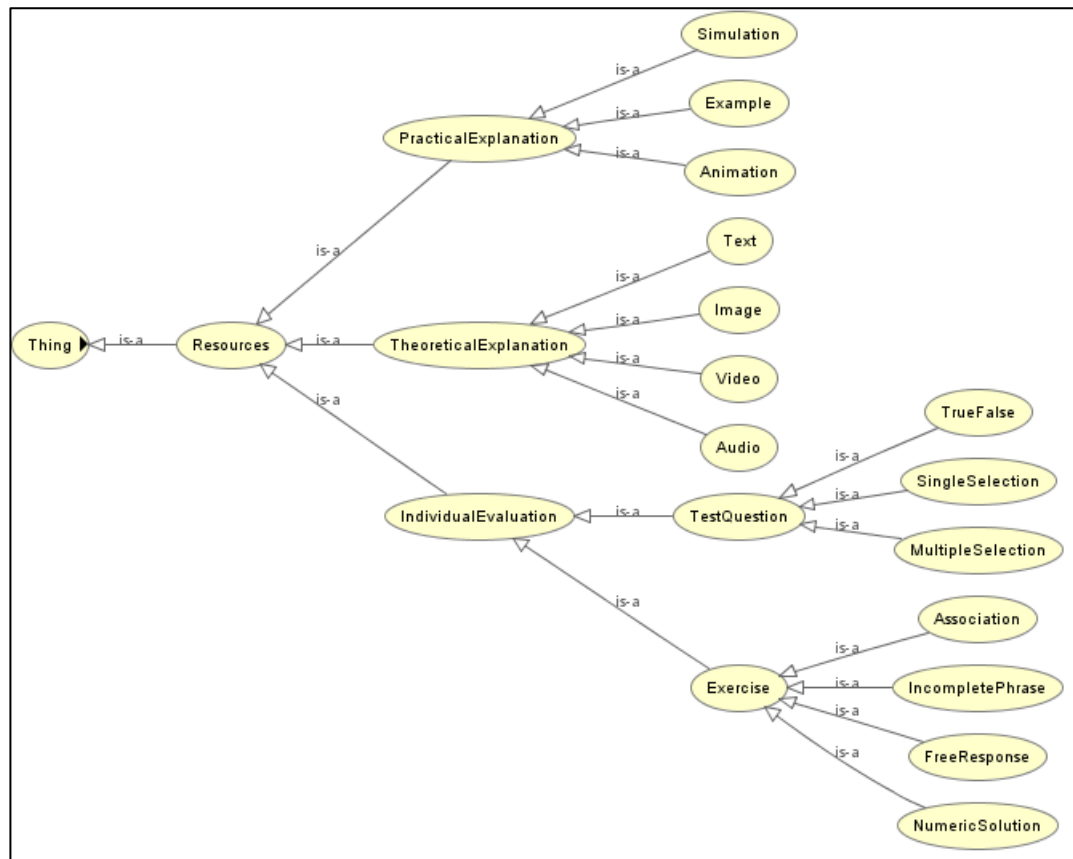
8.5.3.3 Resource sub-ontology

A resource can reference several concepts (object property *describes* – *isDescribedBy* is its inverse). The *Resource* class also includes the object properties *isEquivalentTo* and *complementsTo*. The purpose of *isEquivalentTo* is to facilitate the identification of resources that have the same semantic meaning, whereas *complementsTo* allows the reuse of any resources that the author perceives to be necessary to group together within one course. For example, the written text or audio that describes a diagram should be grouped with that diagram; a simulation should be reused in combination with the text that explains the concept of the simulation, etc..

The *Resource* class contains the data type property type string, which is the *resourceId*. Furthermore, the *Resource* class includes an object property *hasDescription*, which points to the description of the *ResourceDescription* class, where further metadata that describes a resource are provided. A resource has many object and data type properties as described below:

- 1) It is created by one or several authors who are all connected to the *Teacher* class (property *createdBy*),
- 2) it is described by a set of keywords (*resourceKeyword* property),
- 3) it facilitates the achievement of multiple objectives (*resourceObjective* property),
- 4) it is sited in a certain location (*location* property),
- 5) it is written in a given language (*language* property),
- 6) it includes a brief description (*description* property),
- 7) it incorporates a type of interactivity through low, medium and high values (property *interactivityType* property),
- 8) it describes a grade that is aligned with knowledge level: beginner, intermediate, or expert (*knowledgeLevel* property), and
- 9) in order to provide the aimed level of adaption, the object properties *hasLearningStyle*, *hasDyslexiaType* and *requiresATs* respectively, are introduced.

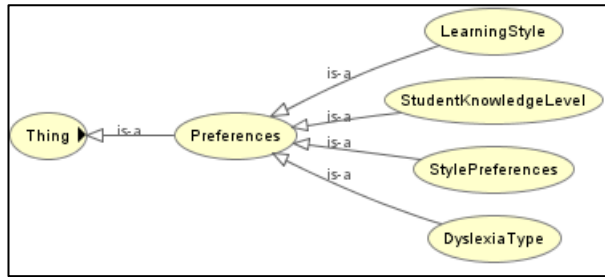
The type of interactivity in *interactivityType* relates to the extent to which the user interacts with the material; for example, where the student interacts and/or performs operations, such as simulations, exercises, and test questionnaires, the type of interactivity is “high”. On the contrary, where the objective is to present material that the student does not need to interact with, such as plain text, images and sound, the type of interactivity is “low”. Figure 8.10 depicts the subclasses of the *Resource* class.

Figure 8.10 Class *Resource* with its subclasses in Protégé

8.5.4 Ontology of dyslexia type

It is necessary to determine students' dyslexia types within the dyslexia type ontology. To achieve this, the student is required to answer multiple questions that directly relate to each type of dyslexia described in the Dyslexia Symptoms and Classification Model (DSCM) (Section 5.2.1). The dyslexia type test (see Appendix C) employed in the current research was designed and constructed using the free online evaluation that was published by Davis Dyslexia Association International⁴⁴ as a reference. To create a mechanism by which student's learning styles could be taken into consideration in the proposed system, attempts were made to match each dyslexia type to the dimensions of the FSLSM (see Section 5.3.3). The *DyslexiaType* class in the ontology reflects the types of dyslexia and their associated learning difficulties that should be included in the learning concepts. It incorporates five properties that correspond to the five types of dyslexia: reading, writing, speaking, memory and mathematics. The *DyslexiaType* and *LearningStyle* classes are connected via the *hasLearningStyle* property object; both classes are subclasses of the *Preferences* class (Figure 8.11).

⁴⁴<http://www.testdyslexia.com/>

Figure 8.11 Class *Preferences* with its subclasses in Protégé

8.5.5 Ontology of learning styles

The learning style ontology was produced using the techniques proposed in Felder and Silverman's Learning Style Model (1988), which uses 44 questions to attempt to implicitly determine a student's learning style⁴⁵. Given that it would not be practical to incorporate all 44 questions from the ILS questionnaire into the proposed system, the number of questions needs to be reduced. The ILS questionnaire has been analysed to add semantic information (Graf et al., 2007); however, if only a subset of questions is selected from the ILS questionnaire, a new criterion needs to be developed as a means of selecting the most appropriate questions. Latham et al. (2009) analysed the ILS questionnaire with the intention of identifying which questions best predict an individual's learning style. The results of their study can be employed as a useful starting point for developing a set of questions that provide an accurate and efficient indication of overall learning style tendencies. For the purpose of the current thesis, the six most representative questions for each dimension of the ILS were selected (Appendix B) in accordance with the frequencies analysis published by Graf et al. (2007) and Latham et al. (2009). The *LearningStyle* class of the ontology represents the learning styles that the learning concepts can include, and it offers eight properties of type integer that correspond to the dimensions of the FLSM: (*active-reflective*, *visual-verbal*, *sensing-intuitive*, *sequential-global*).

8.5.6 Ontology of assistive technology

As describing the characteristics of assistive technologies was deemed to be critical to this project, an ontology was produced that was based on key elements of the technical category of the Foundation for Intelligent Physical Agents (FIPA) Device Ontology. The FIPA Device Ontology is a frame-based structure that can be applied to describe devices. The purpose of this structure is to facilitate agent communication as a means of facilitating content adaptation via a range of different devices, including iPads, PCs and PDAs. Within the realm of assistive technologies ontology, FIPA provides an ideal starting point from which modifications and additions can be implemented while taking into consideration the key aspects of assistive technologies. The assistive technology employed in this thesis ontology consists of three sub-ontologies: *AssistiveTechnologies*, *Setting*, and *Adaption*. Each of these sub-ontologies contains a semantic description of different aspects of assistive technology. For instance, "*Adaption*" is a semantic representation of adaption according to the domain; "*Setting*" is a semantic representation of all adaptations, or of device-specific aspects that can be adapted, etc.

⁴⁵ <https://www.engr.ncsu.edu/learningstyles/ilsweb.html>

8.5.6.1 The Assistive Technology (ATs) sub-ontology

The *AssistiveTechnologies* class (see Figure 8.12) encompasses those technologies that have the potential to improve learning outcomes for students with learning disabilities. This class is not limited to students with dyslexia; it can be effectively applied to a wide range of disabilities. A fundamental requirement of providing learning materials in a form that meets the learning styles of students with dyslexia is the use of appropriate technological offerings. As such, the *Hardware* and *Software* classes are required as part of the *AssistiveTechnologies* class. This allows the offering to incorporate both hardware and software. The *Hardware* Class incorporates three subclasses: *InputHardware*, *InsideHardware* and *OutputHardware* classes. These represent the input and output systems that the students will employ. The *InsideHardware* class is further divided into additional subclasses: *Memory*, *Processor* and *Graphics*.

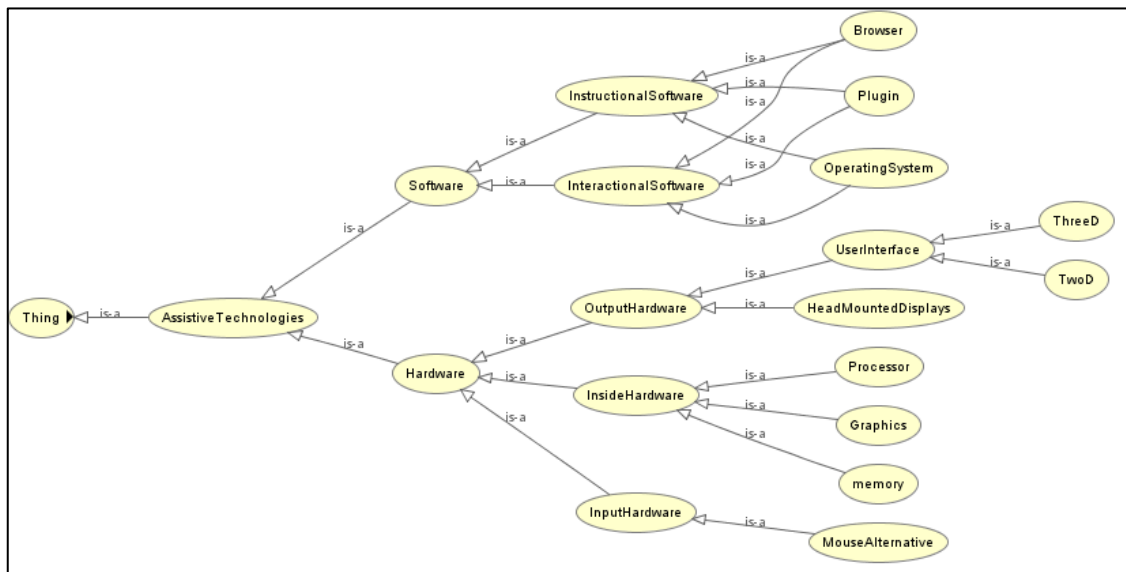


Figure 8.12 *AssistiveTechnologies* sub-ontology with its Subclasses in Protégé

The assistive technologies involved in the ontology each incorporate flexible settings that can be altered in accordance with the learning needs of the student who is using the system. The way in which these settings are fixed and adapted is determined in the *AssistiveTechnologies* class, which incorporates the *Settings* and *Adaption* classes via the *hasSettings* and *supportAdaption* object properties.

The *Software* class incorporates two subclasses: *InstructionalSoftware* and *InteractiveSoftware*. The *InstructionalSoftware* class describes computer software that does not readily interact with the student; for example, a program that employs photographs or plays sounds to support an individual's learning experience. The *InteractiveSoftware* class describes programs that interact with the learner as he or she is in the process of learning; for example, multiple-choice quizzes or multifunctional games. Both the *InstructionalSoftware* and *InteractiveSoftware* subclasses can incorporate the software types of *Browser*, *OperatingSystem* and *Plugin*.

8.5.6.2 The settings sub-ontology

It is important that the system developed offers reusable personalised learning experiences. As such, the *Settings* class (see Figure 8.13) is required as a separate entity to the *AssistiveTechnologies* class. The “Solutions and Content ontology” was employed as a basis for developing the *Settings* class. The *Settings* class allows the user to select options in accordance with his or her learning needs and capabilities and semantically captures the various settings that are available within the technology. The *Settings* class incorporates four semantic classes: *AudioSettings*, *PersonalSettings*, *CommunicationSettings* and *VisualSettings*. The semantic classes can be further segregated into the subcategories of the *AssistiveTechnologies* class via the *hasSettings* object property; the inverse object property is *adaptingATs*. In order to deliver settings that meet the user’s needs, the *Settings* class connects with the *Adaption* class via the *meetAdaption* object property.



Figure 8.13 *Settings* sub-ontology with its subclasses in Protégé

8.5.6.3 The adaption sub-ontology

The *Adaption* sub-ontology (Figure 8.14) aims to present a semantic description of the adaptations available by categorising them according to their functionalities. Thus, the *Adaption* sub-ontology classifies the available adaptations and applications to semantic classes. For instance, the first semantic level of adaptations classifies the adaptations according to eight classes: *Communication*, *Hearing*, *Mobility*, *Organisation*, *ShortMemory*, *Vision*, *Reading* and *Writing*. In order to classify the available adaption in more detail, these classes are refined as we progress deeper into the ontology. In the event that a new adaption needs to be incorporated into the ontology, and none of the existing classes meet the developer’s proposed classification, a new class can be created. This can be a generic class or a class that modifies an existing class. If necessary, a whole hierarchy can be added to classify a new application/adaption. The instance of each *Adaption* participates in the following object properties: *runsOnATs* *hasAdaptionSpecificSetting*. The *runsOnATs* property creates a link

between an *Adaption* instance and the appropriate ATs on which it runs. If an *Adaption* is supported by more than one AT, it also relates an *Adaption* to multiple ATs. On the other hand, the *hasAdaptionSpecificSetting* property relates an *Adaption* to the settings that can be adapted. Figure 8.14 represents the relationships between the three sub-ontologies that, in turn, create the assistive technology ontology.

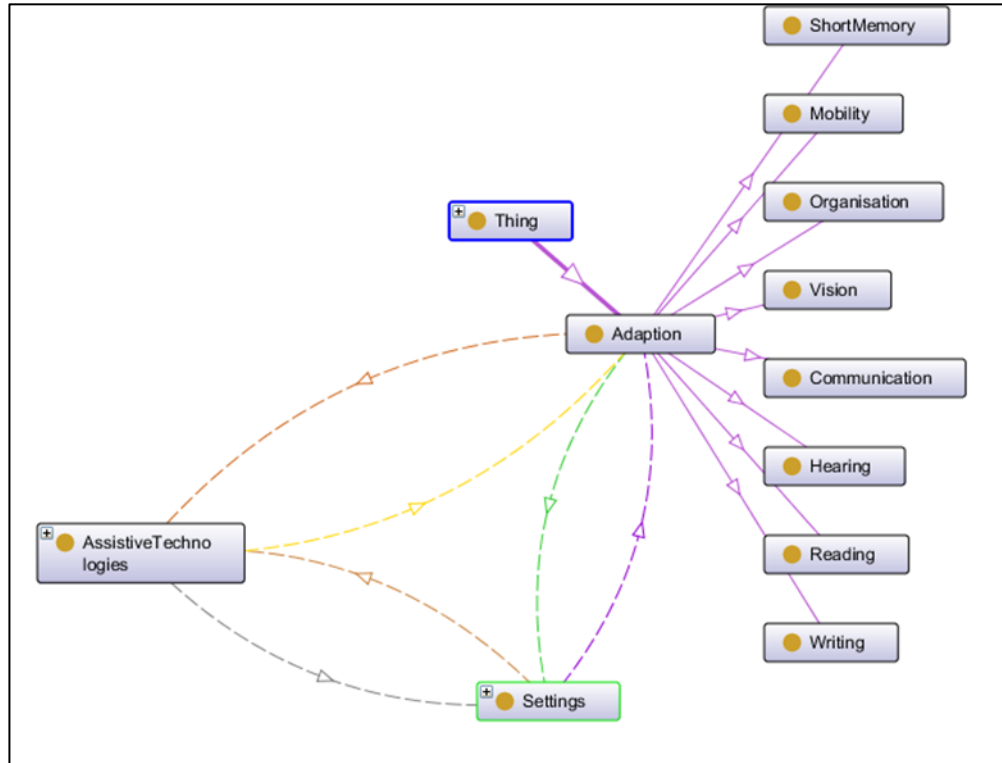


Figure 8.14 *Adaption* sub-ontology with its subclasses in Protégé and the relationships between the three sub-ontologies

8.6. Ontology Validation

One key challenge associated with ontology development relates to evaluation. Formal ontologies need to be guided and evaluated, and objective criteria need to be developed that directs this process. Developing predefined criteria can help ontologists to evaluate ontologies in an effective and objective manner. According to the existing literature, many different approaches have been employed to evaluate ontologies (Brewster et al., 2004, Lozano-Tello & Gomez-Perez, 2004, Maedche & Staab, 2002, Porzel & Malaka, 2004). As such, no single preferred approach to ontology evaluation has been developed. The evaluation approach that is most suitable for a given ontology depends on the purpose and type of ontology being developed. The evaluation process is always necessary, even when an ontology for a particular domain is being developed from scratch, or an existing ontology is being modified (Gómez-Pérez et al., 2006).

The validation of the ODAEL ontology was conducted from three perspectives, and these were designed to assess the way in which the ontology was written and to ensure that it did not contain any errors and anomalies. As such, this research sought to ensure the richness and complexity of syntactic issues of the ontology, not just the correctness.

8.6.1 Validation by ontology reasoner

HermiT⁴⁶, a reasoner for ontologies that was written using the Web Ontology Language (OWL), was employed to test the coherence of the modelled knowledge. Given an OWL file, HermiT can determine the consistency of the ontology entities, relationships, and restrictions, and verifies the extent to which the statements and class definitions are consistent. In the current study, the HermiT reasoner was employed as a plug-in for Protégé and was applied during the process by which the ODAEL ontology was developed to check the consistency of the ontology. The HermiT reasoner infers classification and class hierarchy in the ontology. This can be of use when attempting to correct any errors and inconsistent classes in the ontology classification. In fact, checking the consistency is necessary to identifying any contradictions, to ensure the modelling constructs are being used accurately, and to avoid the formulation of any incorrect inferences.

In Protégé, there are two structures of taxonomy: the computed method is called inferred hierarchy, and the manual method is referred to as asserted hierarchy. If there is any error, the HermiT reasoner will highlight the affected classes in a red colour, and this will be reflected in the OWLVis. During the current research, the reasoner was run many times to ensure the inferred and asserted taxonomies were consistent. The tool did not indicate that there were any tasks that needed to be completed or semantically validated. As can be observed in Figure 8.15, the ODAEL ontology passed the HermiT reasoner.

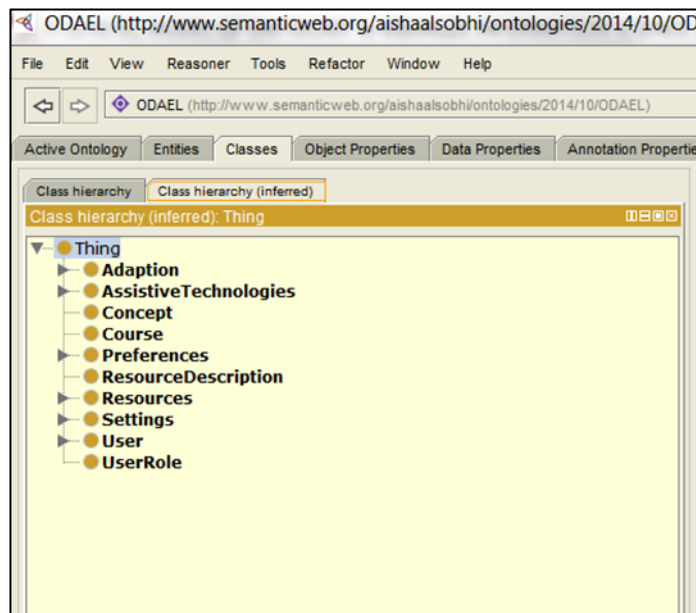


Figure 8.15 ODAEL inferred class hierarchy

8.6.2 Validation by OWL ontology validator

To ensure there are no confounding and contradictory concepts, and to verify terms have consistent meaning and clarity, an ontology should provide mapping according to the meaning of its contents. The consistency and the syntax of the generated OWL file can be verified using an OWL ontology validator. In addition to being validated using the HermiT reasoner, the ODAEL ontology was verified using an OWL validation tool. The most recent tool for validating

⁴⁶ <http://hermit-reasoner.com/>

an ontology was employed, the OOPS! Pitfall Scanner (Poveda-Villalón et al., 2012). OOPS! is designed to identify potential pitfalls that could lead to modelling errors. The pitfalls OOPS! identifies are not of equal importance; their impact on the ontology will depend on multiple factors. For this reason, each pitfall has an importance level attached to it that indicates how important it is. OOPS! identifies three levels of pitfall:

- **Critical:** It is crucial to correct the pitfall. Otherwise, this issue could have a negative effect on the consistency, reasoning, applicability, etc. of the ontology.
- **Important:** Though not critical to the function of the ontology, the pitfall should be corrected.
- **Minor:** The pitfall is not really a problem; however, correcting it will improve the ontology.

OOPS!⁴⁷ is used by ontology developers during the process of ontology validation, particularly during the diagnosis task. Its main functionality is to analyse ontologies (a) via the URL at which an ontology is located or (b) via text input containing the RDF code of the ontology. The author validates ODAEL by text input using the RDF code.

The OOPS! validation tool was employed to analyse the ODAEL using the process outlined above, and the results of the validation exercise revealed a number of minor pitfalls, as shown in Figure 8.16. Pitfalls that fall into the minor category do not affect the overall quality of the ODAEL ontology, since this research is focused on the use of domain ontologies that have a lightweight level of expressiveness.

The screenshot shows the OOPS! Ontology Pitfall Scanner interface. At the top, it says "OOPS! (Ontology Pitfall Scanner!)" and provides a brief description. Below this, there are two input methods: "Scanner by URI" and "Scanner by RDF". The "Scanner by URI" field contains the example URL: `http://data.semanticweb.org/ns/swc/swc_2009-05-09.rdf`. The "Scanner by RDF" field contains the following RDF code:

```
<?xml version="1.0"?>
<!DOCTYPE rdf:RDF [
  <ENTITY owl "http://www.w3.org/2002/07/owl#" >
  <ENTITY xsd "http://www.w3.org/2001/XMLSchema#" >
  <ENTITY rdfs "http://www.w3.org/2000/01/rdf-schema#" >
  <ENTITY rdf "http://www.w3.org/1999/02/22-rdf-syntax-ns#" >
  <ENTITY ODAEL "http://www.semanticweb.org/aishaalsobhi/ontologies/2014/10/ODAEL#" >
  <ENTITY untitled-ontology-5 "http://www.semanticweb.org/aishaalsobhi/ontologies/2014/10/ODAEL#" >
]
```

Below the input fields, there is a checkbox labeled "Uncheck this checkbox if you don't want us to keep a copy of your ontology." and a link "Go to advanced evaluation".

The "Evaluation results" section shows the following:

It is obvious that not all the pitfalls are equally important; their impact in the ontology will depend on multiple factors. For this reason, each pitfall has an importance level attached indicating how important it is. We have identified three levels:

- **Critical** : It is crucial to correct the pitfall. Otherwise, it could affect the ontology consistency, reasoning, applicability, etc.
- **Important** : Though not critical for ontology function, it is important to correct this type of pitfall.
- **Minor** : It is not really a problem, but by correcting it we will make the ontology nicer.

Below this, there is a table showing the results for various pitfalls:

Pitfall	Results	Importance
P08: Missing annotations.	164 cases	Minor
P13: Missing inverse relationships.	28 cases	Minor
P22: Using different naming criteria in the ontology.	ontology	Minor
SUGGESTION: symmetric or transitive object properties.	9 cases	

On the right side, there is a "Want to help?" section with links to "Suggest new pitfalls" and "Provide feedback". Below this is a "Documentation:" section with links to "Pitfall catalogue", "User guide", and "Technical report". At the bottom right, there is a "Related papers:" section.

Figure 8.16 ODAEL validation results using OOPS!

8.6.3 Validation by metric-based approaches

Alongside the growth in the number of ontologies, there have been some attempts to study the different approaches and tools that are available for ontology evaluation and validation. Metric-

⁴⁷ <http://oops.linkeddata.es/>

based approaches to evaluate ontologies offer a quantitative perspective of the quality of an ontology. Such approaches divide the metrics into two related categories, as follows:

- Schema metrics: Schema metrics address the design of the ontology. Although we cannot definitely know if the ontology design correctly models the domain knowledge, metrics in this category indicate the richness, width, depth, and inheritance of an ontology schema design.
- Instance metrics: Instance metrics evaluate the placement of instance data within the ontology and the effective use of the ontology to represent the knowledge modelled in the ontology (Tartir et al., 2010).

Table 8.9 depicts the summary results of the schema and instance metrics for ODAEL using OntoQA metrics that were developed by Tartir et al., (2010), where H , P , C and C' represent the number of inheritance relationships, the number of non-inheritance relationships, the number of classes and the number of non-empty classes respectively.

Table 8.9 The summary results of schema and instance metrics for ODAEL

Category	Metrics	Equations	Values
Schema	RR (Relationship Richness)	$RR = P / (H + P)$	$RR = 36 / (80 + 36) = 0.310$
	IR (Inheritance Richness)	$IR = H / C $	$IR = 80 / 92 = 0.869$
Instance	CR (Class Richness)	$CR = C' / C $	$CR = 92 / 92 = 1$

An RR that is close to zero indicates that most of the relationships in the ontology are class-subclass (i.e. ISA) relationships. As indicated in Table 8.9, many of the relationships in the ODAEL are inheritance relationships and the data in the knowledge base represents the majority of the knowledge in the schema. An IR value that is close to zero indicates that the ontology is horizontal and shallow and is perhaps more representative of general knowledge, while values close to one represent a vertical ontology that covers a specific domain in a detailed manner. In the current research case, the ODAEL ontology describes detailed domain knowledge. Class Richness gives a general idea of how well the Knowledge Base (KB) utilises the knowledge modelled by the schema classes. Thus, if the KB has a very low Class Richness (CR) that is close to zero, the KB does not incorporate data that exemplifies all the class knowledge that exists in the schema. On the other hand, a KB that has a very high CR close to 1 would indicate that the data in the KB represents most of the knowledge in the schema. The CR of the ODAEL ontology is equal to 1. This indicates that the ODAEL ontology does not have any empty classes and that it utilises most of the knowledge that is available in the domain.

8.7. Chapter Eight Summary

This chapter examined the use of domain ontology to develop assistive learning technologies that can adapt to the needs and learning styles of learners with dyslexia. Two key areas were of interest in the developed ontology: the learning styles of people with dyslexia, and the ways in which assistive technologies can be employed to align learning experiences with these learning behaviours. The learning objects that formed part of the ontology were developed by taking dyslexia type into consideration. This made it possible to develop an e-learning system that is

capable of adapting the learning materials and resources presented to the user with his or her dyslexia type, learning needs and capabilities. To deliver adaptive materials, it was necessary to create a link between the *Adaption* class and the *AssistiveTechnologies* class. This provided the levels of adaptation that were necessary to ensure that the e-learning software incorporated the assistive technologies required to deliver adaptive learning experiences that are aligned with a student's needs. Within the developed ontology, the *Settings* class is separate from the *AssistiveTechnologies* class. Separating the classes in this manner makes it possible for the proposed ontology to be reused and employed with a wide variety of different users with different needs. In light of the fact that the difficulties that people with dyslexia typically encounter also commonly affect people with special needs, it is envisaged that the proposed ontology can be employed for a variety of purposes and can potentially be extended to people who exhibit general software usability problems.

The ODEAL ontology will underpin the DAELMS system and will facilitate the development of a platform that can support the e-learning experiences provided to students with dyslexia. In addition to verifying the ODAEL ontology through the use of HermiT and OOPS! in automatic mode, the ODAEL ontology was evaluated through a metric-based approach in manual model. The outputs of these evaluations revealed that many of the relationships in the ontology were inheritance relationships and that the data in the knowledge base adequately represents the knowledge in the schema.

The next chapter will describe the methodology and system architecture of DAELMS and how the ODAEL ontology will be integrated into the system architecture.

Chapter 9 Methodology and Architecture for Developing DAELMS

9.1. Introduction

Through harnessing the benefits of the Internet, e-learning systems provide flexible learning opportunities that can be delivered at a fixed cost at a time and place to suit the user. As such, e-learning systems can allow students to learn at their own pace while also being suitable for both distance and classroom-based learning activities. As previously described in Chapter 3, Adaptive Educational Hypermedia Systems (AEHS) are e-learning systems that employ artificial intelligence (AI). They deliver personalised online learning interventions that extend electronic learning experiences beyond a mere computerised book through the use of intelligence that adapts the content presented to a user according to a range of factors including individual learning style and existing knowledge. Chapter 2 of this thesis provided an overview of the role that learning styles play in the learning process in terms of how a student receives and processes information. In the physical world, teachers are able to accommodate differences in the learning styles and abilities of the student population by presenting different types of learning material and instructional methods (e.g. tutorials, labs, lectures). AEHS seek to replicate this flexibility and adaptiveness by catering to different learning styles in a manner that enhances the effectiveness of a learning experience (Chapter 3).

This chapter⁴⁸ describes a novel adaptive e-learning system called DAELMS. The DAELMS incorporates the functionality to detect a student's dyslexia type and learning style and to subsequently adapt the learning materials, navigation and structure in accordance with these factors. For the purpose of this thesis, the term DAELMS will be employed to describe the overall e-learning system that incorporates the required functionality to adapt to students' learning styles and dyslexia type.

Section (9.2) of this chapter will present an overview of the DAELMS, and Section (9.3) will recommend a methodology by which this system can be developed. Section (9.6) will propose a generic architecture for the DAELMS. To simplify the development and maintenance process, this system will be modular based and will incorporate the functionality required to deliver flexible learning experiences relating to the learning styles model and learning domain.

9.2. Dyslexia Adaptive E-Learning Management System (DAELMS)

The Dyslexia Adaptive E-Learning Management System (DAELMS) is an innovative adaptive e-learning system that operates by detecting a user's dyslexia type and the preferred learning style associated with it and subsequently adapting the material presented in accordance with this learning style. The pedagogical objective of the DAELMS is to enhance the effectiveness of learning experiences and the depth of learning by presenting educational material that is directly

⁴⁸ This chapter is based on the following peer-reviewed paper:

Alsobhi, A., Khan, N. & Rahanu, H. 2015, Dyslexia adaptive e-learning system based on multi-layer architecture, in *Proceedings of the IEEE International Conference on Science and Information (SAI 2015)*, London, United Kingdom.

aligned with a given user's learning style. The DAELMS is not designed to sense the user's learning style; rather, through the use of the DLMS described in Section (5.3), the system correlates each given dyslexia type with its associated preferred learning style and subsequently adapts the learning material presented to the student. As such, the DAELMS represents an adaptive e-learning system that incorporates a number of personalisation options including navigation, structure of curriculum, presentation, guidance and assistive technologies that are designed to ensure the learning experience is directly aligned with the user's dyslexia type and associated preferred learning style. As DAELMS is a generic technology, it facilitates a free choice in terms of the learning styles model and the subject domain. The next section will describe the basic construction of the DAELMS. The discussion will commence by providing an overview of the proposed generic methodology that could be employed to develop the DAELMS before progressing to examine the generic architecture involved in the construction of the system.

9.3. A Generic Methodology for Developing DAELMS

The DAELMS is a complex system that will require a significant amount of time and expertise in knowledge engineering and formatting (i.e. dyslexia type, learning styles, domain knowledge) to develop. One of the most effective methods of approaching this complex task is to formalise the development of a DAELMS that can be applied to different learning styles models and education domains. Four distinct phases of development are proposed for creating the DAELMS. An overview of these is presented in Table 9.1. Section (9.4) of this chapter described the first phase of the methodology. This phase involves identifying the specific requirements of the DAELMS system before progressing to the second phase, during which any potential issues will be ascertained in relation to the design itself and the system architecture (9.5). The outputs of Phases 1 and 2 will be employed to create the DAELMS system in Phase 3 of the development process. Finally, during Phase 4, experiments will be conducted to investigate the extent to which the DAELMS can successfully improve the learning experiences of students with dyslexia. Phase 1 and Phase 2 will be described in this chapter, Phase 3 will be described in Chapter 10, and Phase 4 will be described in Chapter 11.

Table 9.1 3-Phase methodology for developing DAELMS

Phase 1: DAELMS requirements

- 1.1 Identify the research gap
- 1.2 Understand different dyslexia type and classification
- 1.3 Select Learning Style Model
- 1.4 Map Learning Style Model and Dyslexia Type
- 1.5 Collect the Technical Requirements for DAELMS

Phase 2: Design the DAELMS

- 2.1 Select a technology for adaptivity
- 2.2 Design the personalised materials
 - 2.2.1 Determine the course materials scope
 - 2.2.2 Design the course structure
- 2.3 Construct the DAELMS Architecture

Phase 3: Implement the DAELMS

Phase 4: DAELMS Evaluation

9.4. Methodology Phase 1: DAELMS Requirements

This thesis has been organised in a sequential manner that aims to describe the linear process by which the DAELMS was developed. Chapter 1 to Chapter 8 outlined the requirements of the system and the technologies required to deliver these requirements. This chapter describes how the outputs of the previous chapters were employed to generate the DAELMS architecture. Phase one of the methodology involved the outputs from Chapter 1 to Chapter 7 of this thesis.

9.4.1 Step 1.1: Identify the research gap

A large amount of existing research has examined the process by which universally accessible e-learning systems can be developed that meet the needs of a wide range of user groups (Goette, et al., 2006; Keates, 2006). However, the vast diversity in disabilities that exists has rendered it very challenging to develop one universal solution that is capable of adequately meeting the needs of different types of disabled users (Maybury, 2001). One solution to this problem is the development of individual e-learning systems that cater specifically to the learning needs of different groups of users. Such offerings are of particular importance when the absence of a system that can provide appropriate support mechanisms has the potential to significantly disadvantage specific disabled user groups. One group of learners that is readily acknowledged as being at a disadvantage when utilising conventional e-learning systems is students with dyslexia. The very nature of dyslexia entails that the operations that are common to an e-learning system interface, such as text interpretation, data entry and system navigation, represent a challenge for dyslexic users. As such, the development of the DAELMS is entirely justifiable. Further information about the current gaps in knowledge that exist in this domain is presented in Chapter 1.

9.4.2 Step 1.2: Understand different dyslexia types and classifications

Dyslexia manifests itself in a variety of forms and no two dyslexic learners typically exhibit the same symptoms. This entails that dyslexic students each have unique needs, and these needs should be served by learning experiences that are aligned with those needs. When developing the DAELMS, it is imperative that the developer recognises that each dyslexic user represents a unique individual who has very specific and distinctive learning needs. However, before commencing development activity, it is first important to develop in-depth insights into the nature and manifestations of dyslexia. Such an understanding will allow the developer to ensure that the functionality and adaptability of the system maximises its benefit to dyslexic students. Section (2.6) summarised the key findings of existing research into the nature of dyslexia, while Section (5.2.1) proposed a Dyslexia Symptoms and Classification Model (DSCM) that was developed through a comprehensive analysis of the conditions and symptom characteristics of different types of dyslexia. The DSCM forms the basis of the understanding of dyslexia that was employed in this thesis and represents the foundation upon which the Dyslexia Type ontology was created (Section 8.5.4).

9.4.3 Step 1.3: Select learning style model

The first step in the process of developing an appropriate learning styles module involves selecting the learning styles model upon which it will be based. As previously discussed, the Felder-Silverman (FSLSM) model (Felder & Silverman, 1988) was selected for the purposing of the application described in this thesis for a number of reasons (see Section 2.7.5). The FSLSM is a complex model. As such, it was deemed appropriate to simplify it so that the main and relevant aspects contained within it could be implicitly incorporated into the adaptive e-learning system proposed in this research. As described in Chapter 8, Section (8.5.5), Graf et al. (2007) and Latham et al. (2009) successfully simplified the FSLSM model. Their experiments revealed that 17 questions could effectively predict a user's overall learning style in at least 75% of cases. Furthermore, the top three questions predicted the result in 84% of cases. Their findings were incorporated in the current research, and their proposed subset of the most effective ILS predictor questions formed the basis of the learning styles assessment model contained within the DAELMS (Appendix A).

It was then appropriate to extract the typical learner behaviour characteristics for each learning style from the model. For the purposes of clarity and ease of analysis, the behaviour characteristics were extracted from the FSLSM model, and a summary of the common learner preferences was developed. This is summarised in Table 9.2.

Table 9.2 Typical learner characteristics extracted from the FSLSM model

	Active	Reflective
Content	The most important knowledge	Lesson objective, Case studies, Lectures, Conceptual map
Media format	Liner text	Text and liner text
Navigation	All available navigation	
Communication and collaboration	All communication tools	Just email
Activities	Guessing possible questions and answering them with other students	Write short summaries about the already learned material
	Sensory	Intuitive
Content	Data and facts as well as learning from examples	Abstract material such as concepts and theories.
Media format	Slide shows, hypertext, the response system, the digital library, and media clips such as movies, graphics and audio objects	The learning objectives, slide shows, the response system, and media objects are recommended.
Navigation	All available navigation	
Communication and collaboration	All communication tools	
Activities	An example is presented first and then the explanation is given	Intuitive learner is first provided with the explanation and then with an example.
	Visual	Verbal
Content	Case studies and a focus on synthesis	Lectures
Media format	Visual learners with visual material such as graphics, diagrams, flow charts, images, videos, demonstrations, conceptual maps, colour notes with highlighters, slides with multimedia, and animations	Text-based
Navigation	All available navigation tools	
Communication and collaboration	All communication tools	
Activities	Use visual walkthroughs exercise	Write summaries about the learning material and work in groups
	Sequential	Global
Content	Relating the topic to already learned material, present the learning material step by step in a logical order.	Table of contents, objective, a summary, diagrams, an overview of information, and so on. These elements are presented in order to facilitate learners to get the overall picture of the topic
Media format	Small chunks of text-only and Hypertext as well as video and audio	Hypertext as well as video and audio
Navigation	Hides all links apart from the next and back buttons for navigation in order to provide a more structured path	Open navigation with several links within the text
Communication and collaboration	All communication tools	
Activities	They like guidance through activities	Open answer questions

Table 9.2 provided a reference source that could be employed when developing the required learning materials in the subject domain. It provides a summary of the preferences for each learner according to the FSLSM dimensions in terms of navigation, communication, activities, media formats and content. Given the complexity of this table, it was recognised that it was important to further simplify the data by identifying those characteristics that were common across the various FSLSM dimensions. For example, in terms of the communication and collaboration activities, with the exception of reflective learners, all types of learners can benefit from all communication tools, including chats, participating in forums and group discussions, while the reflective learners prefer communicating by email alone and do not typically like participating in discussions.

9.4.4 Step 1.4: Map learning style and dyslexia type

Step 1.2 generated in-depth insights into the differences between dyslexia type and classification, and Step 1.4. provided learning preferences for each of the FSLSM dimensions. A combination of the information gained through each of these steps subsequently facilitated the acquisition of information that could be employed to associate each dyslexia type identified in the DSCM described in Section (5.2.1) with the learning style dimensions of the FSLSM model presented in Section (2.7.4.3). This resulted in the development of the Dyslexia and Learning Style Model (DLSM) (Section 5.3), in which each dyslexic type was mapped with the associated preferred learning styles to deliver a personalised learning experience for dyslexic learners based on his/her learning style.

The final step in Phase 1 of the methodology was to convert the information contained within the model into a set of logic rules that could be employed to ensure that the system adapts the learning material presented to a user according to his or her dyslexia type and associated learning style. An analysis of the DSCM model described in Section (5.2.1) resulted in the development of these logic rules (Appendix D). The generic logic rules should be adapted in accordance with the appropriate style model and, where required, extended to incorporate additional relevant learner behaviour defined by the chosen model. Algorithm 1, which is presented in Section (10.4.3), demonstrates the use of these logic rules to provide personalised learning materials that are aligned with dyslexia type and learning style.

9.4.5 Step 1.5: Collect the technical requirement

Chapter 6 describes the technical requirements that were collected for the DAELMS. These requirements contributed to the development of the Dyslexia Adaptive E-Learning (DAEL) framework. The DAEL is a generic framework that can be readily applied to develop adaptive e-learning systems that cater to any type of disabilities. In Chapter 7, the framework was validated from the perspective of students with dyslexia. The DAEL framework was subsequently employed as a reference by which the DAELMS was developed.

9.5. Phase 2: Design the DAELMS

Phase 2 of the methodology involved selecting an appropriate technology that was capable of developing a sufficiently flexible and extensible adaptive system. It also involved utilising the

learning ontology described in Chapter 8 to design personalised learning experiences. Phase 2 also involved the development of a proposed generic architecture for the DAELMS that was based on a modular structure, the components of which can be readily reused.

9.5.1 Step 2.1: Select a technology for adaptivity

As previously discussed, traditional e-learning systems have a number of inherent disadvantages. To overcome these, ontology can be employed to explicitly represent adaptation components. Ontology allows machines to read, process and understand data in a precise and intelligent manner. Furthermore, ontologies make it possible for the concepts of a domain and their relationships to be formally and explicitly defined, and they can clarify a domain's structure of knowledge in a manner that facilitates reasoning about knowledge domains.

Ontology can be used to represent abstract views of concept sequencing and learning content. As such, using a specific ontology to represent each component of adaptivity makes it possible to separate the adaptivity components, thus facilitating the development of e-learning systems that are flexible and extensible and that incorporate adaptation components that can be reused. Integrating these discrete adaptation components at runtime delivers flexible, personalised learning experiences. Furthermore, through the use of logic rules and adaption algorithms to facilitate the flexibility and extensibility of the system in implementing different adaptive effects, it becomes possible to enhance the extent to which the adaptation rules are reusable and modifiable. As such, developers and designers can readily enhance or alter the adaptation techniques employed within given courses of study without having any major impact on the overall system. Logic rules also represent a transparent map of the underlying functionalities behind the system and provide sufficient flexibility such that instructional designers can quickly and easily modify the adaptation rules.

Chapter 8 described the process by which the Ontology for Dyslexia Adaptive E-Learning (ODAEL) was designed to overcome the limitations of the existing e-learning systems that were surveyed as part of this research to achieve both the properties and technical requirements described above.

9.5.2 Step 2.2: Design the personalised materials

This step of Phase 2 of the methodology involved capturing the course material requirements from expert human tutors and books. It also involved iteratively developing suitable course materials for dyslexic learners using the input provided by human instructors.

9.5.2.1 Determine the course materials scope

The first step in designing relevant course material for the purpose of this thesis was to acquire a comprehensive overview of the relevant knowledge of the courses through consulting course materials, textbooks and human tutors. This process commenced by taking into consideration the scope of the material in combination with its length, the associated syllabus and the desired learning outcomes. To identify the key components of the material syllabus, interviews were conducted with undergraduate-level course tutors who had subject expertise in the given domain. Two courses were designed for the purposes of this thesis: "Fundamentals of Computation" and "An Introduction to Programming in Java". These particular courses were

deemed to be suitable for the objectives of this thesis because basic Java and computation instruction is typically delivered in the form of several units and assessed via examinations; however, programming is a skill that can be easily forgotten if it is not actively used on a regular basis. As such, an online revision system that delivers personalised learning experiences that assist students to revise their basic Java and computation skills at a time and place to suit them, such as during the examination period when formal teaching has ceased, could be advantageous.

Having extensively reviewed the Java and computation skills taught in several unit syllabuses, a revision syllabus was developed that covered some of the basic Java principles and concepts that were critical to these courses. The main source of information for the materials to be included in the “Fundamental of Computation” course was a book by Wolf (2012) entitled *Computers as Components: Principles of Embedded Computing System Design*. The source of information for the “Introduction to Programming in Java” course materials was a book by Pohl and McDowell (2000) called *Java by Dissection*. A test consisting of ten multiple-choice questions was developed for each course (see Appendix F). This was designed to cover the learning outcomes of the course materials and to assess students’ knowledge prior to completing the e-learning course. The same test was subsequently employed at the completion of the course to assess the extent to which the participating students’ knowledge had improved as a result of interacting with the system.

9.5.2.2 Design the course structure

The learning ontology described in Section (8.5.3) was developed on the assumption that every course consists of one learning unit, each of which incorporates one or more chapters. In turn, every chapter includes one or more learning concept(s) that can be presented in various forms according to the resources (see Figure 8.10). Each concept resource (Section 8.5.3.3) has meta-data that outlines knowledge level, learning style and dyslexia type, and this is employed to deliver the required level of adaptation.

Several different concepts for each topic involved in both courses were developed. These concepts incorporated the use of different media types to support different dyslexia types, and accompanying learning style preferences in accordance with the FSLSM model. In addition, as a means of extending the level of personalisation the system offers, the learning concepts were also developed in varying difficulty levels to ensure that the system met the learning requirements of students with different abilities.

Concept includes text or other forms of multimedia material that represent the content of the course. They can also contain external links to additional information about the current concept or to related topics. These links make it possible for (global) learners to actively seek out further information about the topic they are studying, or to form connections between the materials they are currently learning and associated topics. In the case of sequential learners, these links can be hidden to ensure that the course is presented in a linear style (Section 10.4.6) that is most closely related to their preferred learning styles. In addition, multimedia objects can be integrated with content objects. For example, an audio object may be employed that plays a short statement from an individual who is an expert on a given topic, or interactive animations

can be presented that allow the learner to visualise a given topic. Multimedia objects of a variety of forms can supplement the key learning experiences presented in textual form to appeal to the preferred learning styles, be it visual, verbal, active or sensing, of a variety of learners.

The *Resource sub-ontology* (Section 8.5.3.3) contains some additional examples that better illustrate the way in which the system works. Each example describes one or more specific concept objects. Examples are especially important for sensing learners; as such, these should be presented to sensing learners in advance of any other types of learning concepts (Section 10.4.6). The *Resource sub-ontology* (Section 8.5.3.3) also includes exercises. These practical experiences provide learners with opportunities to put what they have learned into practice, and they consist of a number of questions pertaining to the interpretation of predefined solutions or the development of new solutions. These exercises also provide a mechanism by which the level of knowledge that the students have acquired can be calculated (Section 10.4.2). If a user answers the questions in an exercise correctly, his/her knowledge level will increase accordingly. These exercises are of particular relevance for active and sensing learners. However, they should not be presented to reflective, sensing, and global learners in advance of concept objects that teach them the required material and topic because it will frustrate them.

The system incorporates pre- and post-tests that are designed to test a student's knowledge level. Each question is related to certain learning concept(s). They can be about facts or concepts, represent broad overviews or in-depth concepts, be graphical or text-based, deal with interpreting information or developing solutions, etc. Once the students have completed and submitted the test, the system provides them with feedback about their performance.

As described in the previous steps, communication is of utmost importance, especially for active and verbal learners who benefit from having an opportunity to work collaboratively, discuss topics and ideas and seek explanations and clarification from their peers and their teachers. To facilitate the delivery of learning experiences that appeal to these types of learners, group discussions and chats are considered in the course structure within the e-learning system but it vary according to the student's learning style (Section 10.4.6).

As described above, the structure of each course will vary according to each individual user's preferred learning style. Figure 9.1 illustrates the general course structure of the DAELMS in accordance with the learning ontology described in Chapter 8. Appendix J presents the course structure in XML.

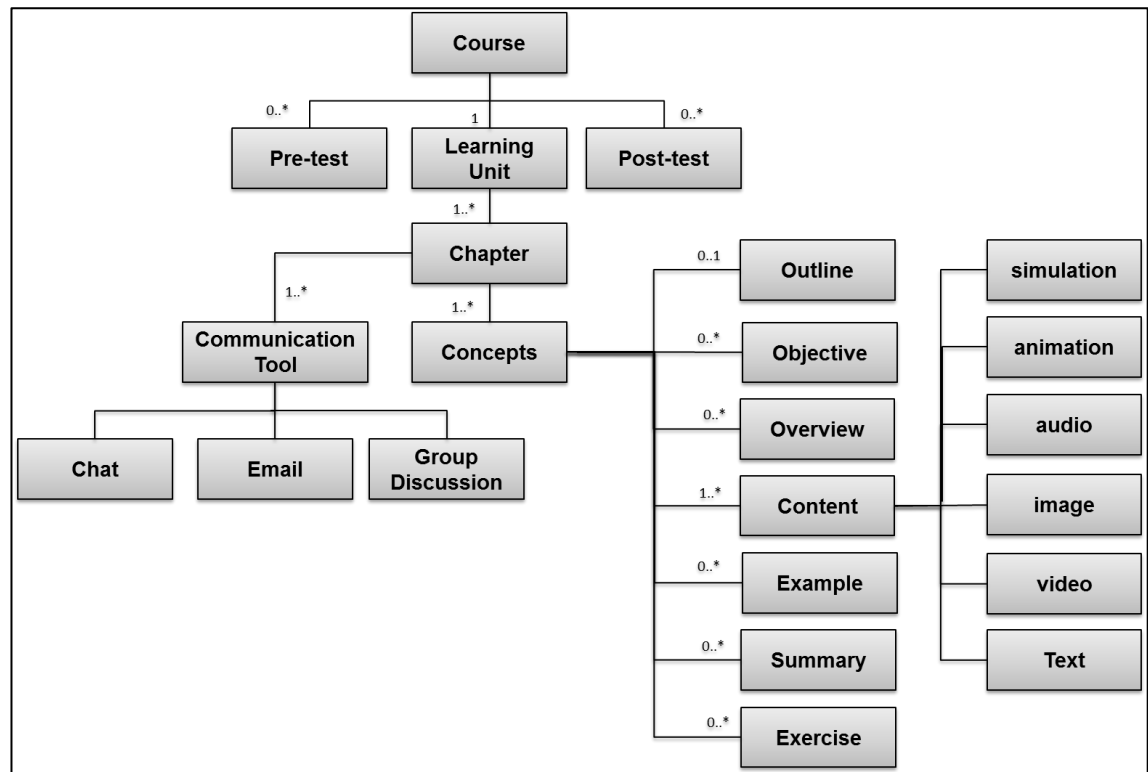


Figure 9.1 General structure of each course in DAELMS

9.5.3 Step 2.3: Construct the DAELMS Architecture

Once the domain model and the course materials have been designed, they can be incorporated into the architecture of the DAELMS. The DAELMS incorporates a number of layers including a *Presentation*, an *Adaption*, a *Learning Management System*, an *Application Server* and a *Database*. Each of these components will be described in more depth in Section (9.6), which outlines a standard, generic DAELMS architecture that incorporates all required components.

9.6. The DAELMS Architecture

The architecture of a system represents the conceptual description of the design, content, structure, behaviour, and all other key aspects (Jaakkola & Thalheim 2010). It consists of the system components, the properties of those components, and the mechanisms by which human users interact with them. It also represents the relationships between each component and how they work in combination with each other to form the overall system. Jaakkola and Thalheim (2010) argued that system architecture supports reasoning about the structures of the system. The system architecture for the proposed DAELMS system is depicted in Figure 9.2.

The system architecture of the DAELMS system has a clear structure that delivers many distinct advantages. It consists of a multilayer application architecture that facilitates a model by which system architects can develop flexible and reusable applications. Essentially, each separate layer can be modified, or additional layers can be introduced without a requirement for the entire application to be reworked (Buschmann et al., 1995). Within an effective architecture, each layer will have very specific responsibilities and can be easily expanded and identified. When

new functionality is developed, this will be added to a specific layer without any work being required on the other layers. As such, a multi-layered architecture makes it straightforward to add and change functions. Furthermore, the layers that form the architecture can be reused in alternative application systems (Qin et al., 2006). Application systems are typically developed through the use of C/S (Client/Server), B/S (Browser/Server) basic two-layer or three-layer architectures. Client-server applications follow a two-tier architecture; however, web server applications can be based on an architecture that consists of any number of tiers. It is generally accepted that the B/S structure is more beneficial than the C/S structure in terms of openness, ease of integration and the ability to uninstall client software. Furthermore, the basic B/S three-layer architecture can be improved for the purposes of software reusability (Qin et al., 2006; Wei et al., 2006). As such, the system architecture selected for the purpose of the DAELMS system was based on B/S multi-layer architecture.

The DAELMS operates entirely independently of a given learning style model and of the subject domain being taught. As such, it is important that the DAELMS architecture keeps the system knowledge separate from the functionality so that the learning styles model and learning domain can be modified. Furthermore, to enhance the rate of adoption of the DAELMS, it is important that the time it takes to develop or modify course materials is minimised. For these reasons, a modular architecture represents the most appropriate system architecture because it facilitates the introduction, modification and replacement of modules as and when required.

The DAELMS was based on a general expert system architecture that was designed with component reuse in mind. Figure 9.2 depicts the generic architecture of the DAELMS. This generic architecture makes it possible for any alternative course materials that have been developed according to Step 2.2 of the methodology to be “plugged in” to the system in order to develop new subjects or to enhance existing subjects. Furthermore, additional learning styles can be applied by replacing the learning styles ontology (see Step 1.3 and 1.4), and different disability types can be taken into consideration by implementing a new disability type class in the ODAEL ontology or by modifying or replacing the dyslexia type ontology (see Step 2.1).

The architecture was designed in a manner that aimed to maximise the use of ontologies for representing knowledge through the following mechanisms:

- Promoting a clear separation of the personalisation components.
- Improving the flexibility of the system through enabling authors to update different personalisation components.
- Improving the extensibility of the system by employing multilayer architecture that allows developers to create new courses without modifying the computer code.
- Exploiting all the benefits of semantic technologies to develop a personalised e-learning system.
- Increasing the interoperability and reusability of the various components that form the system.

There are two distinct groups of users of the DAELMS system: students and teachers. As can be seen in Figure 9.2, the DAELMS system consists of five layers and each layer has very specific roles. Each of the layers and their specific roles will be described in detail in Sections (9.6.1 to 9.6.5).

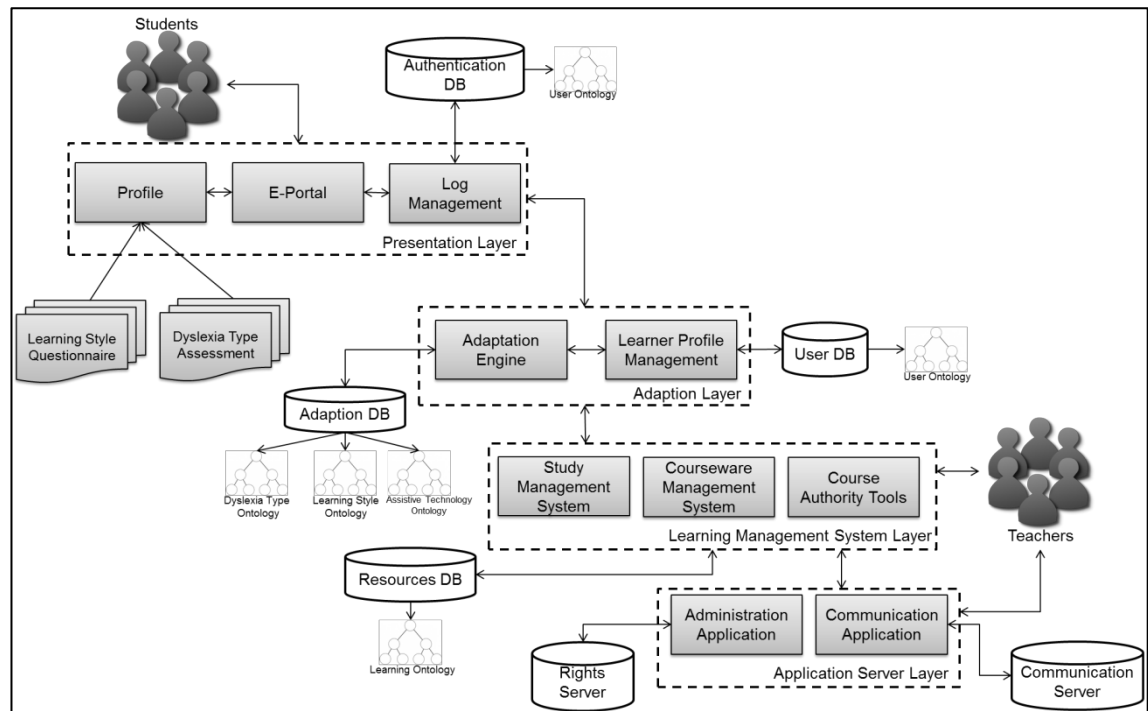


Figure 9.2 DAELMS multi-layer system architecture

9.6.1 Presentation layer

The *Presentation* layer sits at the top of the architecture, and it represents an accessible and user-friendly interface through which the user can directly interact with the system. The *Presentation* layer includes the user interface, which is responsible for the display, managing events (such as clicking buttons, etc.) and sending communications to and from the user. The display consists of a webpage that provides instructions, a chat area through which the user can communicate with other users and an interface that displays questions, tests, images, documents and interactive movies.

It is through the *Presentation* layer that the learner creates an account on the system by providing the appropriate registration details and creating a login and password. Once these details have been provided, the user can log in through the 'Log Management' and access his or her profile. The system will then store the preferences of each user and use them to adapt the information presented and the navigation structure in accordance with the distinct characteristics of each student. In addition, it will also record the responses that the learner gives during the interactive activities and will then transfer them to the *Adaption* layer. This layer is responsible for acquiring the identity of the user and transferring the acquired information to the *Database* layer for authentication.

9.6.2 Adaption Layer

The *Adaption* layer will create the different presentations specified by the *Presentation* layer in accordance with a combination of items from the other layers and the 'Learner Profile Management'.

Learner Profile Management contains information about the learners. The system then uses this information to adapt the information presented and the way in which it is presented so that it is

aligned with the learner's individual needs. The system gradually updates the *Learner Profile Management* throughout the learning process in order to keep track of learner's actions and progress and as a means of potentially guiding the learner. The *Learner Profile Management* retrieves the characteristics of a particular learner, makes the necessary changes and communicates these to the *Adaptation DB* by interacting with the other layers. The system also receives critical information about new learners from the *Presentation* layer and stores it in the *Learner Profile Management*. *Learner Profile Management* is updated in response to new information about the learner that is sent from the *Adaptation Engine*.

9.6.2.1 The Adaption Engine Architecture

The *Adaptation Engine* is at the heart of the system, and it is this area of the system that is responsible for generating personalised learning experiences. Figure 9.3 shows the internal architecture of this key component. Although it does include the computations that are required for personalisation, it does not contain the strategies or knowledge for any particular learning domain, or for concepts sequencing. The knowledge about the domain and the learners are all stored in their respective ontologies. This separation results in a highly modular system architecture that has a high level of abstraction. It consists of three sub-modules: user information collection, adaption filtering, and resource (or information) sending. The statuses of all the students are stored in the *User DB* through the *Learner Profile Management*. The process by which the adaptation technique operates is as follows:

- First, the user information collection module collects a range of information relating to the learning status of the user;
- Second, based on the user information collected, the adaption filtering module reads the learning preferences, such as which algorithm to apply according to the student preferences;
- Third, the resource sending module selects the relevant resource from the library using the resource ID and sends it to the user.

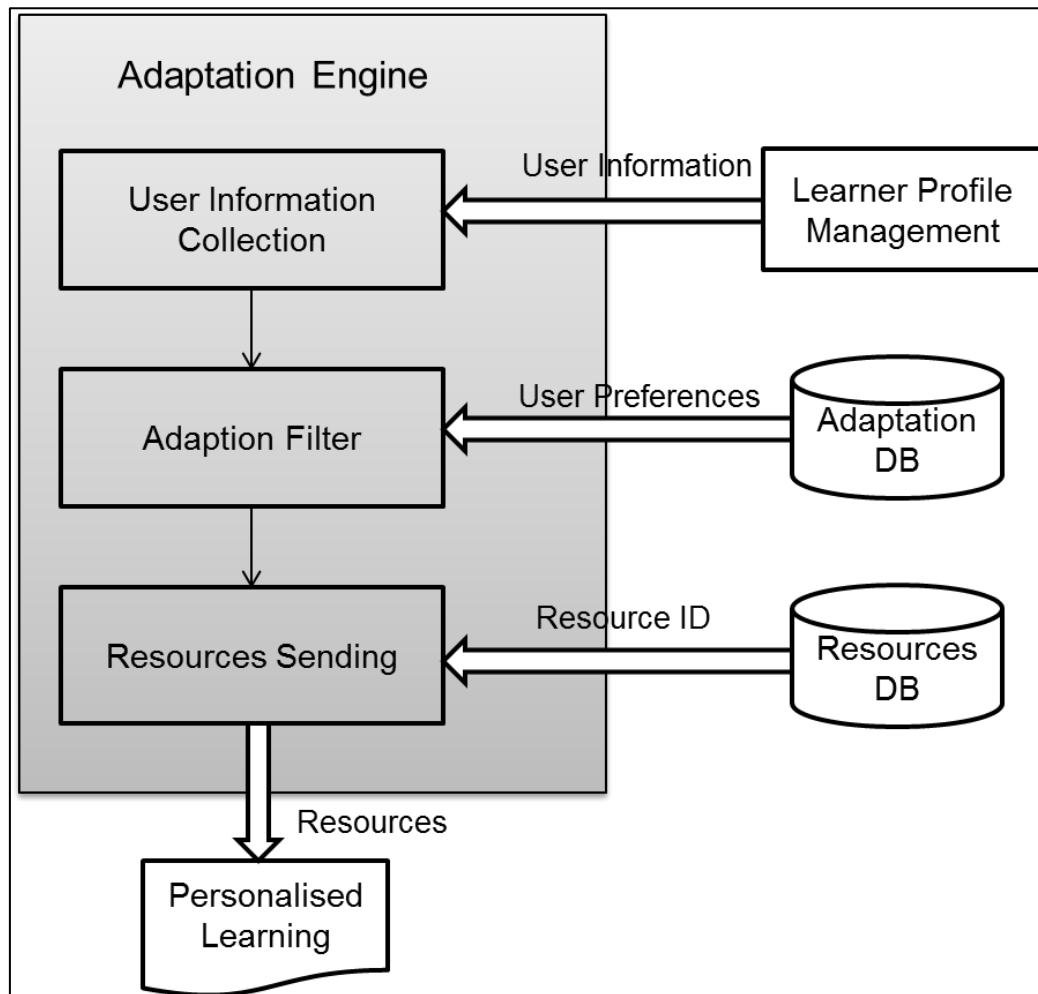


Figure 9.3 Adaptation Engine Architecture

As Figure 9.3 illustrates, the filter can provide personalised information to each and every user by intelligently and automatically filtering the required information from the system's comprehensive resources. Having created an account on the system, each user is required to complete the learning style and dyslexia type assessment test. The information that they provide during this test will be stored in the *Learner Profile Management* along with any additional information relating to the user's personal requirements, and this data will be used to personalise each user's learning experience as he or she interacts with the system. The profile can be reused by any other Learning Management System. By using the information in the *Learner Profile Management*, the system can recommend learning experiences according to the students' knowledge level, dyslexia type or preferred learning style.

9.6.3 Learning Management System Layer

The *Learning Management System* layer represents the essence of the teaching process, and it offers a set of tools that facilitates the management of courses, lessons and teaching materials. Furthermore, the *Learning Management System layer* allows courses to be previewed and published to the students. To effectively develop this layer of the architecture, the developer needs to be aware of the required needs and preferences of learners during each step of course creation, from analysis to evaluation.

The *Learning Management System* layer is responsible for managing course information, such as topics and their breakdowns, related tests and the teaching materials that are accessed from the *Resources DB*. All materials information will be categorised according to learning style and dyslexia type. The *Learning Management System* layer will receive information and instructions from the *Adaption* layer, which, in turn, will send the required information to the *Presentation* layer.

9.6.4 Application Server Layer

The application server sits in between the browser-based front-ends (the first three layers) and the back-end *Database* layer. The *Administration Application* handles the capabilities and permissions for each user through referencing the information stored in the *Rights DB*. For example, it will detail whether a given user has access rights to modify or update the content of the course. This layer also provides communication, such as by email and chat, and it supports both synchronous and asynchronous communication.

9.6.5 Database Layer

The *Database* is one of the proposed system layers. It stores data, including the database of learning resources, authentication, mail server, and access rights server. The *Adaption DB* records the learning status of each student and stores the main data used to filter each user's personalised information.

9.7. Chapter Nine Summary

This chapter described the novel DAELMS adaptive e-learning system that can personalise the learning experiences presented to students in accordance with their knowledge level, dyslexia type and learning style. An original, generic methodology was described by which the DAELMS can be constructed. Thus, four-phase methodology operates independently of the learning styles model, dyslexia type and learning domains selected. Phase 1 of the methodology involved the collection of the main requirements of the DAELMS. In Phase 2, a generic architecture was proposed for the DAELMS. This architecture is modular based; as such, it allows components to be reused and facilitates efficient development and maintenance. The architecture also operates independently of the choice of learning styles model, dyslexia type and learning domains applied.

An experimental study was conducted to validate the proposed generic methodology and the architecture of the DAELMS. Phase 3 of the proposed methodology involved the implementation of the DAELMS. This will be described in the next chapters. In Phase 4 of the methodology, experiments were conducted to investigate the extent to which the DAELMS can successfully improve the learning experiences of students with dyslexia.

Chapter 10 Implementation of DAELMS

10.1. Introduction

Having developed the essential system models and mechanisms by which adaptable e-learning experiences that are aligned with the preferred learning styles of dyslexic learners can be delivered, it was necessary to create a working prototype system that would allow the effectiveness of the system and the validity of the process upon which it was constructed to be tested. It was readily acknowledged that it would not be possible to develop a standalone prototype that could adequately fulfil all the proposed system requirements; however, the development of a working prototype did facilitate the generation of valid insights into the suitability and effectiveness of the overall adaptive e-learning system and the models, framework and architecture upon which it was developed.

As described in Chapter 9, a generic methodology and architecture were developed by which a DAELMS could be created that acts independently of learning style and subject domain with the intention of delivering a system that is capable of providing dynamic learning experiences that can be adapted to the preferred learning styles and dyslexia type of students. This chapter will describe how the proposed methodology, architecture and ontological approach proposed in Chapter 8 was employed to create the DAELMS. In this case, the prototype DAELMS was designed to deliver adaptive e-learning experiences for the “Introduction to Programming in Java” and “Fundamentals of Computation” subject domains. The DAELMS incorporated a learning styles model that was derived from the Felder-Silverman Learning Style Model (FSLSM) before the proposed methodology and architecture of the prototype DAELMS was empirically tested. This will be described in Chapter 11.

The remainder of this chapter will describe the process by which the DAELMS prototype was developed in more detail. An overview of the technology employed to develop the system will be provided in Section (10.2), before the discussion progresses to provide detailed insights into the adaptation algorithms and personalisation features in Section (10.4) together with screenshots of the key user interfaces of the DAELMS. Finally, the implementation of the DAELMS will be summarised in Section (10.5).

10.2. The Required Technologies for the DAELMS

DAELMS is hosted on a web-based server that was deemed to be suitable to the project requirements. The site itself was tested on Microsoft Internet Explorer, Chrome, Safari and Mozilla Firefox independent from any operating system. A number of applied technologies were employed to support the implementation of the DAELMS system, and these are described in more detail below:

- The Bootstrap⁴⁹ front-end web framework was utilised to develop the front-end of the DAELMS. HyperText Mark-up Language (HTML 5⁵⁰) tag standards and Cascading

⁴⁹ <http://getbootstrap.com/>

⁵⁰ <http://www.w3schools.com/html/>

Style Sheets (CSS 3⁵¹) were used to maintain a consistent and user-friendly interface in terms of overall theme, background, fonts, styles, images, text, etc. In addition, JavaScript⁵²; some JavaScript Libraries, such as JQuery⁵³ 1.11.3; and a number of JavaScript Plugins, such as TinyMCE⁵⁴ 4.3.2, were also utilised. Ajax⁵⁵ technology was employed to increase interactivity with the user interface and allow some areas of the system to be updated without the whole page having to be reloaded; for example, to allow forms to be reloaded according to the information users provide in input fields on the same page without having to reload the entire page.

- The back-end of the DAELMS was developed through the use of the MVC (Model-View-Controller) model using the Application Development Framework CodeIgniter⁵⁶ 2.2.6. The PHP⁵⁷ 5.4.43 server-side scripting language was employed. PHP is a very common server-side script language that is well supported. One of the biggest benefits of server-side languages, such as PHP, is that they are highly customised and can generate dynamic webpages in accordance with continually changing user needs. As such, it was ideal for the objectives of the adaptive e-learning system described in this thesis. Furthermore, more recent versions of PHP, specifically PHP 4.3 onwards, support object-oriented system development. The prototype system was designed such that it was modelled as an object-based solution. This entailed that additional web-based components could be seamlessly integrated at any point through adhering to an object implementation strategy.
- Web Server: Apache.⁵⁸
- Database Management System: MySQL.⁵⁹

10.3. Implementation Issues of User Modelling

The implementation of the user model was achieved through the user ontology described in Chapter 8. The *User* class represents the top class of this ontology, as described in Section (8.5.2). This class includes the user's information and incorporates data properties that can be employed to annotate the learner in terms of key parameters, such as user name and email address, that the system can use to identify the individual who is using the system via the log management that sits in the presentation layer and via the authentication DB. The *User* class has the *hasRole* object property. This is responsible for identifying what privileges the user has in the DAELMS; i.e., it will verify whether the user is a student or a teacher. This is also performed through the "Administration Application" in the application server layer, which determines the rights and level of access for each user.

⁵¹ <http://www.w3schools.com/css/>

⁵² <http://www.w3schools.com/js/>

⁵³ <https://jquery.com/>

⁵⁴ <https://www.tinymce.com/>

⁵⁵ <http://www.w3schools.com/ajax/>

⁵⁶ <http://www.codeigniter.com/>

⁵⁷ <http://www.w3schools.com/php/>

⁵⁸ <http://www.apache.org/>

⁵⁹ <https://www.mysql.com/>

The *Preferences* class is a central concept that includes all the learner properties. It is linked to the *Student* class to represent key details about the student users. The *Preferences* class consists of data relating to the learner's knowledge level, learning style preference, learning style and dyslexia type, each of which is defined by individual classes that are linked to the *Student* class through the object properties. These aspects are critical to the system because they describe the fundamental learning characteristics of the student user.

10.3.1 Initialising user model

Before the DAELMS is able to produce a personalised learning path that is adapted to an individual user's learning style and dyslexia type, the system needs to have certain information about that user. As such, the first objective of the user modelling process is to detect and store data relating to the learning style and dyslexia type of the individual who is interacting with the system. As described previously, the Index of Learning Styles (ILS) questionnaire (Appendix A) was deemed to represent the most appropriate method by which the learning styles of the users could be detected, and the Dyslexia Type Test (Appendix C) was employed to detect the dyslexia type. The dyslexia type test that was utilised in this study was based on the free online evaluation that was published by Davis Dyslexia Association International.⁶⁰ The prototype was designed such that once the student user completes the DAELMS registration process, he or she completes the ILS and the Dyslexia Type Test. The DAELMS then utilises the test outputs to calculate the user's learning style and dyslexia type and stores this information in the form of user preferences in the student model. It is important to note that the approach taken to classify learner preferences in this study did vary somewhat from that proposed by the ILS questionnaire. As opposed to calculating values between +11 and -11 for each dimension (see Section 10.4.3 for further information), the DAELMS calculated preferences according to a strong, moderate, and balanced preference (e.g., strong active, moderate active, balanced, moderate reflective, and strong reflective). In addition, in terms of the dyslexia type test, the system only stored dyslexia type if the outputs of the test indicated that the student user's results of that dyslexia type was moderate or severe (severe reading or moderate writing) as opposed to storing the user's score for each individual question (see Section 10.4.3).

The results of the tests are managed through the profile in the presentation layer and stored in the user DB. This data allows teachers and course developers to generate and deliver learning experiences that are aligned with the user's preferred learning style and dyslexia type. When the learner enrolls on one of the available DAELMS courses, the learning management system layer also invokes the knowledge questionnaire data and uses this to determine the student user's existing knowledge. This is also stored in the user DB.

The Adaptation Engine was developed (adaption layer) as a means of generating and delivering adaptive learning experiences. This process is completed via four steps. First, the data relating to the student user's knowledge level, learning styles and dyslexia type is accessed from the student profile (presentation layer). Second, using this information, the system calculates the values of each adaptation feature by following the approach described in (Section 10.4.3,

⁶⁰<http://www.testdyslexia.com/>

Section 10.4.5, and Section 10.4.2). These values determine how each of the individual courses should be composed and presented. Third, the relevant learning concepts are accessed through the study management system (learning management system layer) and presented as individual courses that are aligned with the values of the adaptation features. Forth, the personalised course is presented to the student user via the DAELMS interface (presentation layer).

10.3.2 Updating and maintaining the user model

The user model is dynamic and, once it has been developed, it is continually updated in accordance with any user/learner changes that occur during the process of the course. For example, the user's knowledge level will continually update as he or she completes the e-learning activities. The Adaption Engine accesses and updates the learner model at regular intervals throughout the learning session in order to create personalised learning content. In addition, all personalisation decisions are made by referencing the information contained within the learner model.

As a copy of the learner model exists in the accessible memory, there is a requirement for the user repository to be updated on some occasions; for example, when the user logs out of the system or an algorithm needs to be instigated. This allows the system to quickly access the updated information and significantly increases the system performance.

10.4. Adaptation and Personalisation Features of DAELMS

The personalisation aspect of the system brings together a completely new set of requirements and contexts. As a means of distinguishing between the personalisation features of the DAELMS and single-user based personalisation, the personalisation process described in this study is referred to as "Adaptation". This adaptation is primarily defined in according to the content of the learning experience and the characteristics of the users. Each user has his or her own profile, and this profile contains key data relating to important characteristics, such as learning style and dyslexia type, that are represented by a set of attributes. Likewise, there is a set of attributes available that relate specifically to content; for example, knowledge level, learning style, etc. As such, Adaptation inherits from previous single user personalisation approaches matching the user to content attributes. A further key feature of Adaptation is that it can be applied to a group of users who share similar profiles in such a manner that it adjusts content according to a group of users as opposed to an individual user.

The biggest issue that is regularly discussed with reference to systems that incorporate personalisation is that of user privacy (Kobsa, 2007). While this is a complex and multi-faceted issue that is out of the scope of the current chapter, the author does acknowledge that there is a need to achieve the delicate balance between personalisation and privacy protection (see Section 10.4.4).

The following sections describe the adaptation and personalisation techniques that are utilised within the DAELMS.

10.4.1 DAELMS user interface personalisation

Dickenson et al. (2000) identified some of the limitations that are associated with e-learning systems that are developed specifically for dyslexic users (Dickinson et al., 2000). One of the biggest disadvantages of systems for dyslexic learners is that the efforts that are invested in developing customised visual displays that meet the needs of an individual dyslexic user are not typically transferable between applications. This entails that system users either have to engage in the time-consuming task of manually adapting each application according to their preferred settings or to reject global customisation. The *Personalisation* attribute was specifically proposed and designed for the DAEL framework as a means of overcoming this problem (Section 6.2.1)

- “Dyslexic subjects need to have the ability to adjust basic visual aspects of the system to meet their unique preferences”.

The system was also designed in accordance with the basic requirement that it facilitated the portability of user-approved visual display settings between similar media and/or systems. In addition, adherence to DAEL framework attributes is also fundamental to the original project aims and objectives (See Section 1.4.3 and 1.4.4).

10.4.1.1 User preference setting portability

Without a doubt, one of the biggest challenges associated with delivering the objectives of the DAELMS is achieving display preference portability. The majority of e-learning applications intertwine display formats with system functionality at the code level; as such, cross-application modifications are highly impractical. Bearing this in mind, research into screen modification approaches that can be utilised without software intervention at the source code level was conducted, and a number of potential strategies were identified. These are as follows:

- **Gateway Web-Mediators:** Brown and Robinson (2002) described the use of a gateway web-mediator for the purpose of pre-display HTML processing. Their web-mediator functions were specifically designed for web-users who have impaired vision and operate by parsing downloaded HTML and reformatting its content through a series of adjustments to the relevant selected parameters within the mark-up text.
- **Cascade Style Sheets (CSS):** Cascade Style Sheets (CSS) are one of the most commonly employed hypermedia customisation mechanisms. They allow developers and designers to specify the appearance of a page (e.g., the font style, type, colour and size; line, spacing, borders, etc.) completely separately from the main structure and content of the page (e.g., headings, body text, links, etc.). When used together with a compatible web-browser, CSS allows the presentation characteristics of most HTML-based documents to be modified in accordance with the majority of users' individual display preference needs.

Of the two potential approaches described above, CSS was deemed to be the most appropriate for the purpose of the DAELMS because it offers the following benefits over alternative display preference portability mechanisms:

- 1) **Established Infrastructure:** CSS is recognised as an industry standard, and it is compatible with the majority of operating browsers. In addition, the existing accessibility

features allow developers to adopt a user-specified set of display preferences via the CSS file selection. This established infrastructure facilitates the quick and easy application of previously derived display settings and seems ideally suited to the portability aspirations of the DAELMS.

- 2) **Standards and Expertise:** As CSS is in common use, is widely accepted as an industry standard and has comprehensive technical resources available, there is a significant chance that any use of the CSS model within the DAELMS will be sufficiently supported.
- 3) **Reduced System Build Time:** One of the disadvantages of portability solutions, such as the web-mediator described above, is that they require the bespoke development of software, which is very time consuming. On the contrary, the CSS model can be employed within the DAELMS without the requirement for extensive development because a large amount of the preference portability framework has already been generated and can be integrated relatively easily. There would be some development activity associated with the use of CSS; however, this would be largely related to the development of software that has the capability to generate CSS preference files that are appropriately constructed. One of the biggest advantages of the use of CSS is that there would be no requirement for software development to implement these CSS files once they are generated because they would be fully compatible with existing browser technology.
- 4) **Existing User Knowledge:** While it is not essential that users of the DAELMS have existing experience of and expertise in the browser accessibility features, where they do, the use of existing accessibility browser components within the DAELMS would ensure that the process is more intuitive.

In light of the advantages and benefits outlined above, it was determined that the strengths that the CSS approach offers in terms of settings portability entail that it represents the most appropriate screen modification approach for the DAELMS.

The front-end development techniques that were described in Section (10.2) were employed as a means of developing the required interface personalisation and portability of user preference systems within the final system interface designs of the DAELMS. In addition, all of the generated interface designs were evaluated against the dyslexic specific design principles presented in The British Dyslexia Association (2015) style guide to ensure that they were fully compliant with existing recommendations. Figure 10.1 presents some examples of the prototype user interface and the supporting interface personalisation process.

Every step involved in the personalisation process has its own unique page. This entails that every action is quick and simple to complete and, therefore, is well suited to the short-term memory capabilities that many dyslexic people exhibit. Once the student user has completed the first three steps in the personalisation process, represented as Step 1, 2 and 3 in Figure 10.1, the student can immediately apply the results to the whole system to view the appearance by selecting the “Save & Apply” button (Step 4, Figure 10.1). If the personalisation options do not suit the student, he or she can reset the system style to the default settings (Step 3, Figure 10.1) and go through the personalisation process again. If the student likes the personalisation

options, he or she can then download them in the form of a style preference file that can be applied to additional websites (Figure 10.2).

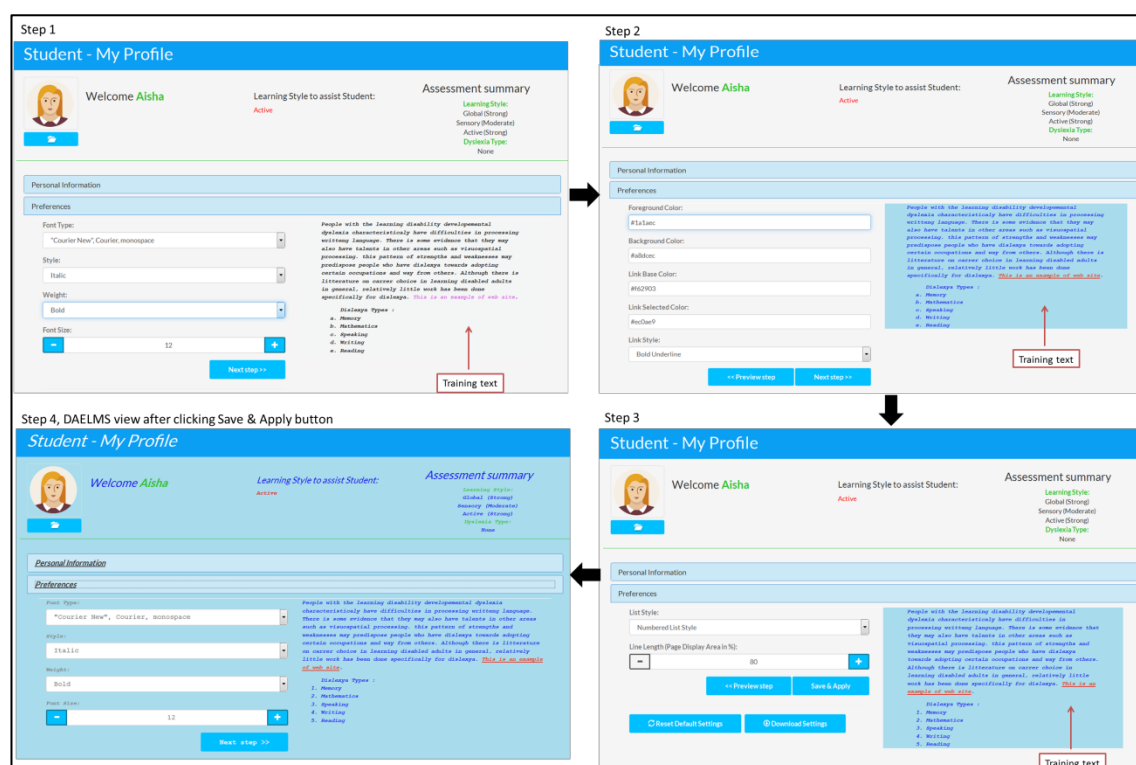


Figure 10.1 The student preferences page, personalisation process in DAELMS

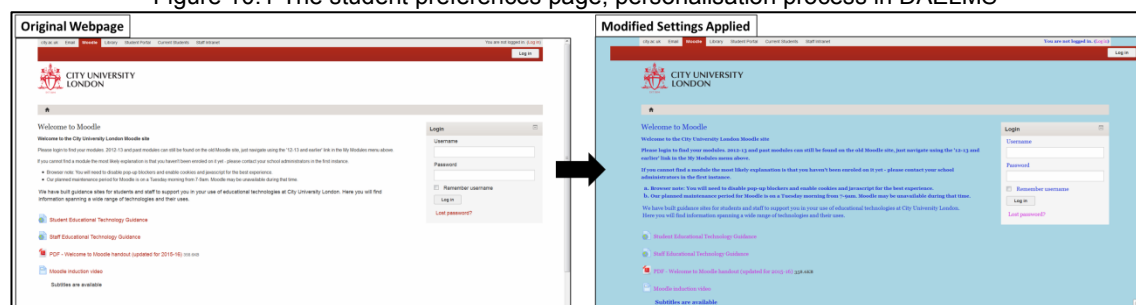


Figure 10.2 DAELMS CSS portability example for user preference settings

10.4.2 Adaptive guidance

Adaptive guidance can prevent learners from experiencing information overload by supporting them throughout their interaction with the system and offering personalised advice according to the choices they make. The purpose of adaptive guidance is to help learners to follow a learning path that is aligned with their profile such that their entire learning process is effective and efficient. When students have completed a given learning activity, their knowledge should have increased. As such, the learner model and current learner situation should be updated, and a new matching process will be required. The adaptive guidance that is integrated into the DAELMS employs a set of pedagogical rules that takes into consideration both the way in which the learner responds to the interactive *concept* (which can range from a simple exercise to a complex test) and their current progression in the overall learning process to generate personalised advice as to which action to perform next or what content they should study in the following step. Adaptive guidance can also provide the student with additional learning material that can help them to address any learning difficulties they may be exhibiting; for example, the

system may provide the learner with additional exercises or further examples to support the content already provided.

Within the DAELMS, instructional designers can employ diverse pedagogical rules to define adaptive guidance. The system incorporates different rules that infer adaptive guidance for the learner; for example, recommending a new topic that they should learn, repeating key ideas from the current topic, providing further examples, presenting more activities that are more complex or more straightforward, or repeating prerequisite learning activities. The recommendations will be specifically adapted in accordance with the progress that the learner demonstrates as he or she interacts with the system and their status in terms of the current content. For example, if the user incorrectly completes an interactive *concept* (e.g., an exercise) that is of a moderate difficulty level (Figure 10.4), the system may recommend that he or she reads more examples of the *concepts* being addressed in order to potentially correct the errors in understanding. Having read these examples, if the learner again responds incorrectly to the *concept*, the system will recommend that he or she reads information about the *concept* that is at a lower difficulty level. This will result in the knowledge level that is recorded for the user in the system being decreased, and the student will not be permitted to complete the interactive *concept* again. Because the student's knowledge level has been decreased, the system will present a new peer recommendation in accordance with the updated knowledge level. This will allow the students to discuss the topic with new recommended peers and will, therefore, support collaborative learning and allow the student to explore the topic from a new perspective. Figure 10.3 presents an overview of the rules that govern the situation outlined above, while Figure 10.4 provides an example of how they implemented in the DAELMS.

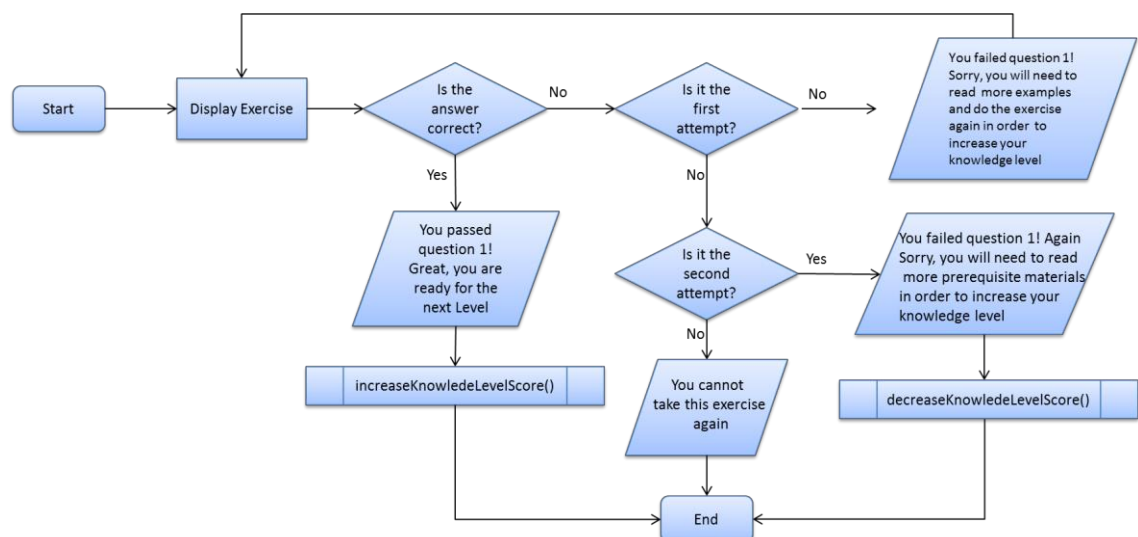


Figure 10.3 DAELMS adaptive guidance (Flowchart)

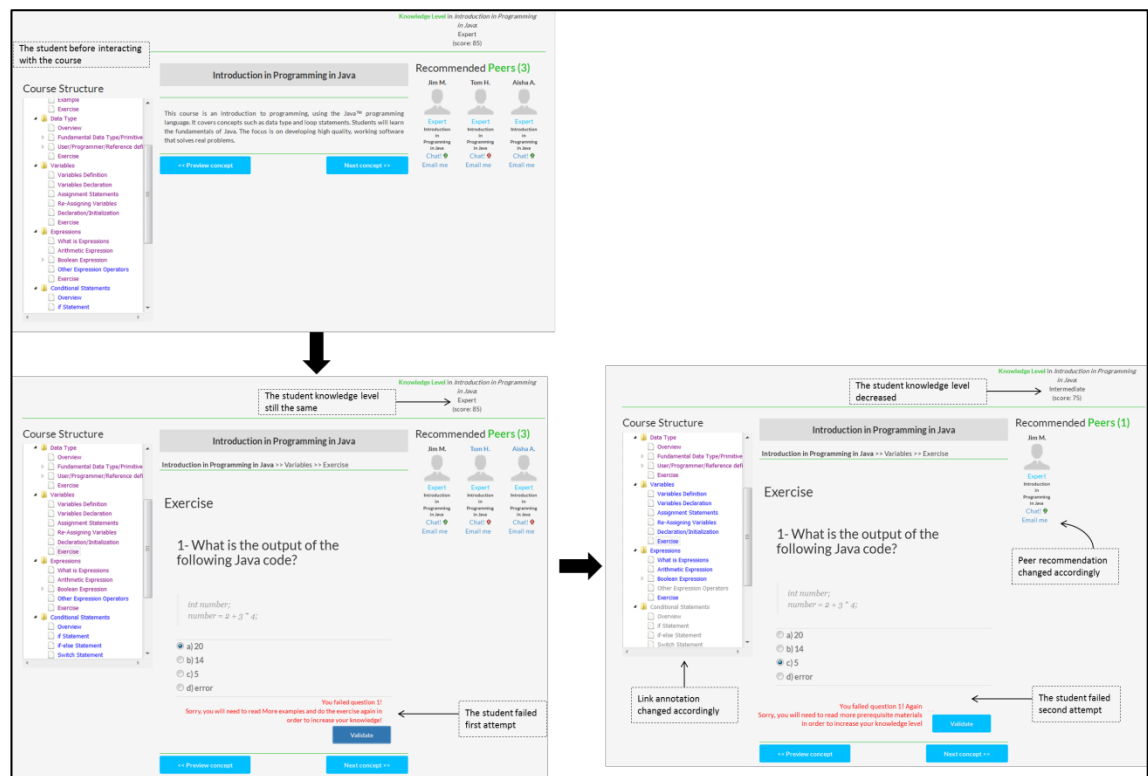


Figure 10.4 DAELMS adaptive guidance Example 1

Figure 10.4 presents the example of a learner who unsuccessfully responds to an interactive *concept* that has a moderate level of difficulty. According to the rules, variations in the paths of guidance are possible that change in response to the learner's situation and the learning content presented. Furthermore, the rules can also activate the peer recommendation (Section 10.4.4) and the link annotation algorithms (Section 10.4.5); as such, they change in direct response to the user's knowledge level.

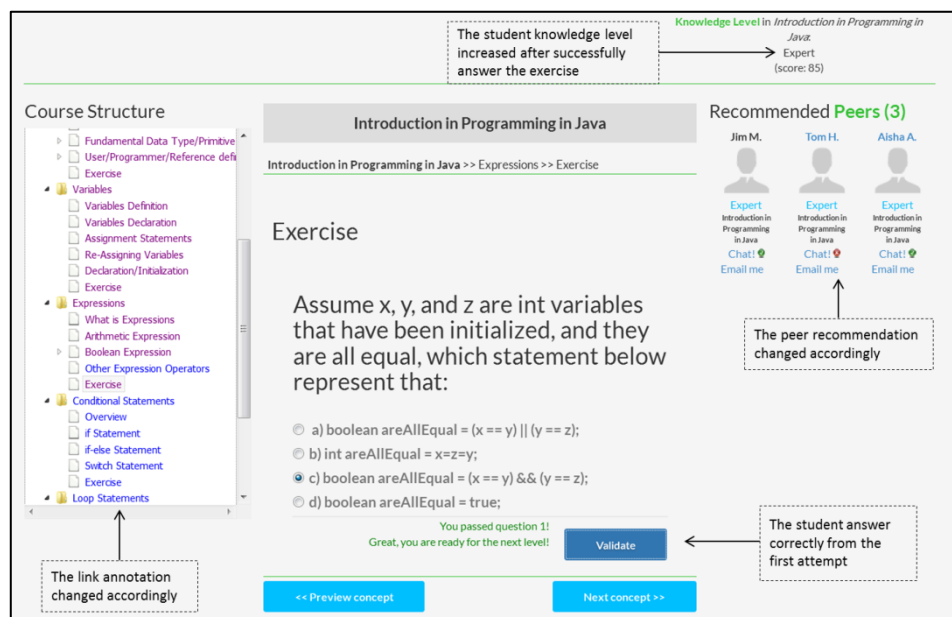


Figure 10.5 DAELMS adaptive guidance Example 2

Figure 10.4 presents an overview of a situation in which the learner responds incorrectly to an interactive *concept*. Figure 10.5 presents an overview of a situation in which the learner

responds correctly. In this case, the system will advise the learner to perform a further interactive *concept* that is at the next level of difficulty and the user's knowledge level will be increased accordingly.

10.4.3 Learning materials recommendation based on dyslexia type and learning style

A further recommendation algorithm generates recommendations according to the user's dyslexia type and learning style. The generic adaption algorithm can be applied at any of the selected learning styles models and the chosen learning styles model should be applied to the recommendation algorithm (shown in Table 10.1) and implemented in the Adaption Layer (Section 9.6.2).

When developing course materials, it may not be possible to incorporate all categories of teaching material while maintaining a coherent learning experience; as such, some learning styles may not be addressed. In such situations, the system will adapt to a student's strongest learning style as per the strategy described by Sanders and Bergasa-Suso (2010) and Bajraktarevic et al. (2003). This has the potential to ensure that students are presented with the course material that is best aligned with their needs while also maximising the overall learning experience.

For the purposes of developing the adaptation algorithm, the FSLSM model was utilised as a sample learning styles model and four learning style dimensions were taken into consideration. The main objective of the application of the FSLSM is to assign a learning style preference to each user for each dimension. However, in situations in which the student does not exhibit a strong preference for any of the four learning styles (i.e., has a low preference on a FSLSM dimension), he or she will be presented with balanced learning material that is deemed to be appropriate for a combination of learning styles in the form of the *Balanced* learning style category. The recommended materials adaption algorithm is as follows:

Algorithm 1 is in the case of the dyslexic learners (Table 10.1):

1. **C** is the current course.
2. **S** is a list of the enrolled students in course **C**, where $\mathbf{S} = \{s_1, s_2, \dots, s_n\}$
3. Dyslexia type is represented by **DT**, which is described by tuple $\langle \mathbf{y}, \mathbf{t} \rangle$, where **y** is the dyslexia type $\mathbf{y} \in \{\text{reading, writing, memory, speaking, mathematics}\}$ and **t** represents the dyslexia type strength $\mathbf{t} \in \{\text{severe, moderate, slight}\}$. The values of **y** and **t** are assigned by an assessment (Appendix C).
4. **LS** is the learning style for each student, **S**, where **LS** has eight learning styles {active, reflective, visual, verbal, sensory, intuitive, sequential, global}.
5. Max is a function that returns the learning style, **LS**, associated with the maximum numbers.
6. If the student has more than one learning style, **LS**, within the MAX function, learning style adaptation is selected randomly.
7. Recalling the DLSSM model (Section 5.3.4 and Appendix D), every $\mathbf{y} \in \mathbf{DT}$ is linked with at least one learning style in **LS**. After the student completes the dyslexia assessment

test, if the $t \in DT$ is moderate or severe, the learning style LS associated to each y will increase by 1 (see Table 10.1).

Table 10.1 presents a logical representation of the recommendation Algorithm 1, taking into consideration the assumptions outlined above.

Table 10.1 Recommendation algorithm 1 for selecting personalised learning materials based on learning style and dyslexia type

Entry point to determine which algorithm to use algorithm 1 or algorithm 2: Input: the dyslexia type $DT(s_w)$ for Student $s_w \in S$ enrolled in course C FOR ALL $y \in DT(s_w)$ { IF t NOT slight GO TO algorithm 1 } GO TO algorithm 2 // i.e. for all y, if t is slight
Algorithm 1: Input: the dyslexia type $DT(s_w)$ for student $s_w \in S$ enrolled in course C Output: personalised learning materials of course C for $s_w \in S$ based on dyslexia type DT //Initialise counter values VISUAL = 0, VERBAL = 0, SENSORY = 0, SEQUENTIAL = 0, REFLECTIVE = 0; FOR EACH $y \in DT(s_w)$ { IF ($y == \text{Reading}$) AND (t NOT slight) (INCREMENT SENSORY) AND (INCREMENT VISUAL) IF ($y == \text{Writing}$) AND (t NOT slight) (INCREMENT VISUAL) AND (INCREMENT VERBAL) IF ($y == \text{Memory}$) AND (t NOT slight) (INCREMENT VISUAL) AND (INCREMENT SEQUENTIAL) IF ($y == \text{Speaking}$) AND (t NOT slight) (INCREMENT VISUAL) AND (INCREMENT REFLECTIVE) IF ($y == \text{Mathematics}$) AND (t NOT slight) (INCREMENT VISUAL) AND (INCREMENT SEQUENTIAL) AND (INCREMENT SENSORY) } Dominant = [VISUAL, VERBAL , SENSORY, SEQUENTIAL , REFLECTIVE] IF MAX(Dominant) IS Distinct Adapt to learning style LS with MAX representation

Each student's dyslexia type and strength $\langle y, t \rangle$ are first listed in Table 9.2, followed by the set of maximum learning style (**Dominant**) and the resulting adaptation.

Table 10.2 Examples demonstrating the learning materials recommendation Algorithm 1 based on learning style and dyslexia type

Student 1: Dyslexia type assessment results: DT = {<reading, severe>, <writing, moderate>, <memory, slight>, <speaking, severe>, <mathematics, slight>}. Dominant = [sensory+1, visual+3, verbal+1, reflective+1], adaptation = visual.
Student 2: Dyslexia type assessment results: DT = {<reading, severe>, <writing, slight>, <memory, slight>, <speaking, slight>, <mathematics, moderate>}. Dominant = [sensory+2, visual+2, sequential+1], adaptation selected randomly e.g. visual.
Student 3: Dyslexia type assessment results: DT = {<reading, slight>, <writing, slight>, <memory, slight>, <speaking, slight>, <mathematics, slight>}. adaptation = go to algorithm 2.

It is now worth examining each example in Table 9.2 in more depth.

- Student 1 is classified in the “slight” category for two dyslexia types (memory and mathematics) and the “moderate” category for one dyslexia type (writing). The student is classified as being “severe” in the reading dyslexia type. According to Algorithm 1, the visual adaptation approach should be adopted because this is the area in which the student achieved the highest learning style score (Figure 10.6).
- Student 2 exhibits two learning styles that are classified in the **Dominant** set. Because the student learning style degrees are equal in this case, visual adaptation was randomly selected (Figure 10.6).
- Student 3 scored “slight” for all dyslexia types and, as such, has no severe or moderate form of any type of dyslexia. This indicates that the student is not dyslexic. Therefore, the recommendation Algorithm 2 will be applied.

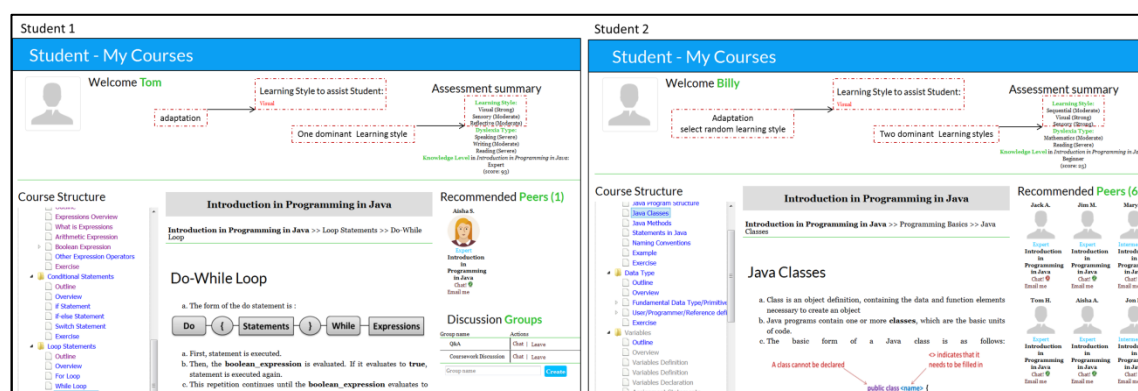


Figure 10.6 Learning materials recommendation Algorithm 1 implemented in DAELMS

Students who are unsatisfied with the leaning style that is associated with his or her dyslexia type can complete the learning style questionnaire and select the learning style that they prefer. In the event that this occurs, Algorithm 2 will be deployed.

Algorithm 2 is employed in the case of non-dyslexic learners (Table 10.3):

1. **C** is the current course.
2. **S** is a list of the students who are enrolled in **C**, where $\mathbf{S} = \{s_1, s_2, \dots, s_n\}$
3. For each learning style dimension, **LS**, in the chosen model, each student's preference is described by tuple $\langle \mathbf{a}, \mathbf{d} \rangle$, where **a** is the learning style $\mathbf{a} \in \{\text{active, reflective, visual, verbal, sensory, intuitive, sequential, global}\}$ and **d** is the degree representing its strength where **d** is a value from 0 to 6. The values of **a** and **d** are assigned by an assessment (e.g. a questionnaire defined by the learning styles model). For the FLSM model, the student preference is evaluated using the Index of Learning Styles (ILS) (Appendix B).
4. A student is categorised as "balanced" when they exhibit a low preference for all learning styles; i.e., all $\mathbf{d} = 3$. In this case, the system will select a random learning style from **LS**.
5. MAX is a function that, given a list of numbers, returns the learning style associated with the maximum numbers. Note: this is different from that calculated by Algorithm 1.
6. If the student has more than one learning style with the maximum degree, **d**, MAX will return a randomly selected learning style from the learning style, **LS**. For example, given a list of the following numbers: 2, 4, 6, 0, 4, 2, 5, 1, which are associated with the active, reflective, visual, verbal, sensory, intuitive, sequential, and global learning styles respectively, MAX returns "visual" because it is associated with the maximum number, which is 6. As a further example, given a list of the following numbers: 0, 6, 0, 6, 3, 3, 4, 2, which are associated with active, reflective, visual, verbal, sensory, intuitive, sequential and global learning styles, MAX returns a random learning style, e.g., "verbal", because both reflective and verbal have the maximum number of 6 (see Table 10.4).

Table 10.3 contains a logical representation of the recommendation Algorithm 2, which takes into consideration the assumptions stated above.

Table 10.3 Recommendation Algorithm 2 for Selecting personalised learning materials based on learning style

```

Input: the learning style LS(sw) for student sw  $\in$  S enrolled in course C
Output: personalised learning materials of course C for sw  $\in$  S based on learning style LS
Boolean isBalance = TRUE
FOR ALL a  $\in$  LS(sw)
{
    IF (d NOT 3) // i.e. balanced learner
        isBalance = FALSE
}
IF (isBalance == TRUE)
    Adapt to random learning style LS
ELSE
    RETURN MAX(LS(sw))

```

Table 10.4 presents each student's learning style dimension and degree $\langle a, d \rangle$, followed by the set of maximum learning style degree and the resulting adaptation. The strength of learning style preference is scored from 0 to 6 as follows:

- Strong: 6 or 5
- Moderate: 4
- Balance: 3 in each dimension

Table 10.4 Examples demonstrating the learning materials recommendation Algorithm 2 based on learning style

Student 4: Learning Style Scores: $LS = \{\langle \text{active}, 3 \rangle, \langle \text{reflective}, 3 \rangle, \langle \text{sensory}, 4 \rangle, \langle \text{intuitive}, 2 \rangle, \langle \text{visual}, 0 \rangle, \langle \text{verbal}, 6 \rangle, \langle \text{sequential}, 2 \rangle, \langle \text{global}, 4 \rangle\}$. MAX= {verbal}, Adaptation = verbal.
Student 5: Learning Style Scores: $LS = \{\langle \text{active}, 3 \rangle, \langle \text{reflective}, 3 \rangle, \langle \text{sensory}, 3 \rangle, \langle \text{intuitive}, 3 \rangle, \langle \text{visual}, 3 \rangle, \langle \text{verbal}, 3 \rangle, \langle \text{sequential}, 3 \rangle, \langle \text{global}, 3 \rangle\}$. Adaptation = Balanced, adopt random learning style from LS.
Student 6: Learning Style Scores: $LS = \{\langle \text{active}, 6 \rangle, \langle \text{reflective}, 0 \rangle, \langle \text{sensory}, 4 \rangle, \langle \text{intuitive}, 2 \rangle, \langle \text{visual}, 3 \rangle, \langle \text{verbal}, 3 \rangle, \langle \text{sequential}, 0 \rangle, \langle \text{global}, 6 \rangle\}$. MAX= {global, active}, Adaptation random e.g. active.

It is worth examining each example in Table 10.4 in more depth. Figure 10.7 provides screenshots of the interface that will be presented to each of the student examples provided in Table 10.4:

- Student 4 exhibits a “low” preference for two FSLSM dimensions, visual and intuitive, a “moderate” preference for the sensory and global learning styles, and a “balanced” preference for the active/reflective dimension. Accordingly, the verbal preference adaptation is selected because this exhibits the highest student learning style degree.
- Having scored 3 for each learning style dimension, Student 5 does not exhibit a strong preference for any of the FSLSM dimensions. As such, he is classified as being “balanced” for all dimensions. According to the recommendation algorithm, the system will apply a random learning style for all learning materials.
- Student 6 exhibits a preference for two learning styles (scoring 6 for both) and, because the student learning style degree was equal, the active adaptation algorithm was randomly selected.

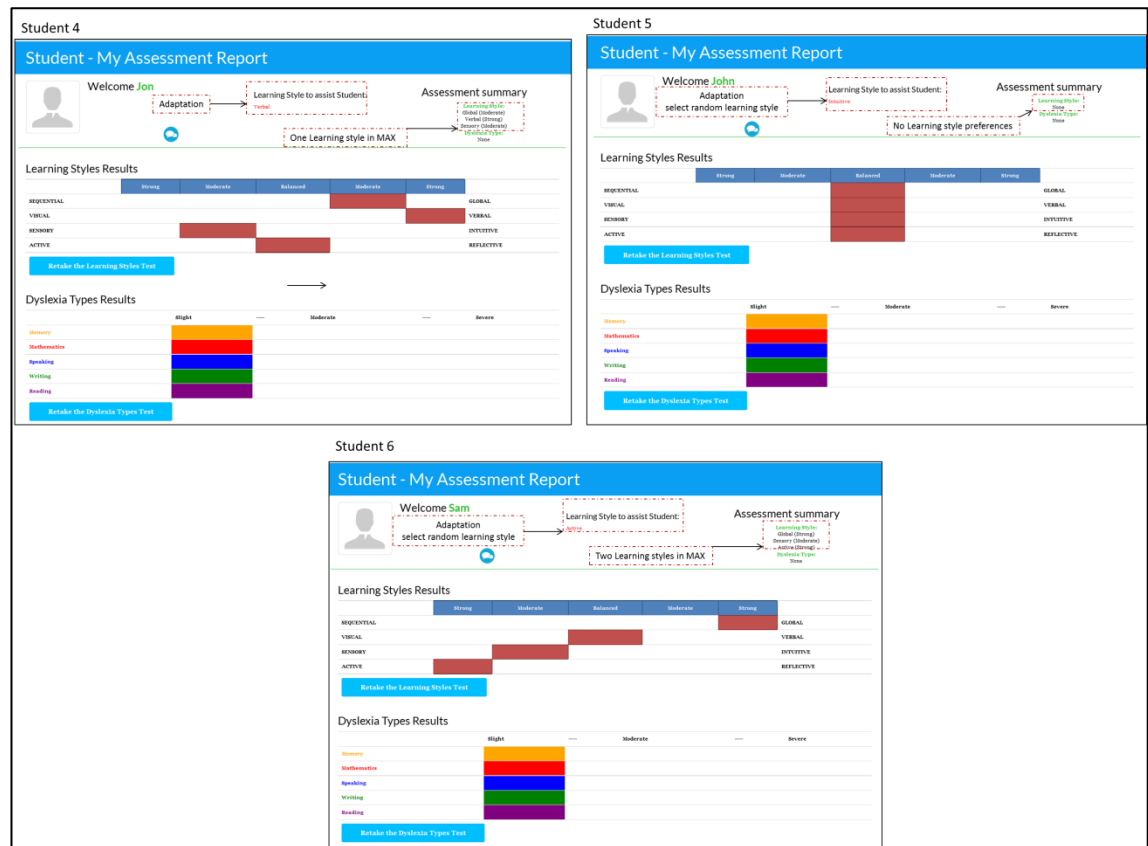


Figure 10.7 Learning materials recommendation Algorithm 2 implemented in DAELMS

In this section, we described how the learning styles and dyslexia type recommendation algorithm is generated that determines the most appropriate learning style to be applied during each student's individual learning path. The next section will present an overview of how the peer recommendation algorithm is generated.

10.4.4 Peer recommendation based on dyslexia type and learning style

One particular advantage associated with adaptive e-learning is the potential to exploit the *collective knowledge* of other learners. The learner no longer operates independently but can be assisted through interacting with other learners. The system had the capability to facilitate communication between individual learners who share learning preferences for collaborative working. This may be in the form of a simple chat interface or a more complicated VoIP application that integrates videos and images. All communication data, including the individuals who are in the process of communicating, can be annotated for its potential use (e.g., learners can set their current status to "HappyTohelp" if they are willing to do so (Fetter & Gross, 2009)). This feature can also be employed to safeguard the privacy of learners who do not want to openly share their dyslexia type or learning styles with other students.

While a variety of different algorithms could have been employed to achieve the functionality outlined above, for the purpose of this study, a simple algorithm was selected that has the capability to recommend learners of higher knowledge but share the same learning style or dyslexia type. The various elements of the algorithm are outlined below:

1. C is the current course.
2. S is a list of the enrolled students in course, C , where $S = \{s_1, s_2, \dots, s_n\}$

3. **KL** is the knowledge level of the student, s_i , in the enrolled course, C . The value **KL** is assigned by an assessment (e.g., knowledge level pre-test (Appendix F)). **KL** has three values {expert, intermediate, beginner}.
4. **LS** is the learning style for each student, s_i , where **LS** has six values {active, reflective, visual, verbal, sensory, intuitive, sequential, global}.
5. **DT** is the dyslexia type for each student, s_i , where **DT** has five values {reading, writing, memory, speaking, mathematics}.
6. **KLS** is the knowledge level score for the student, s_i , in the enrolled course, C .
7. **RS** is the set of the recommended students for non-expert student, s_w , in the current course, C .
8. **ERS** is the set of the recommended students for expert student, s_w , in the current course, C .
9. **HappyTohelp**: is a Boolean value that is set to *True* if the student is willing to help his peers and *False* if he is not.

Table 10.5 shows a logical representation of the peer recommendation algorithm, which takes into consideration the assumptions stated above.

Table 10.5 Peer recommendation algorithm

<pre>// Peer recommendation algorithm for non-expert students Input: student s_w (non-expert student) enrolled in course C Output: recommended student list for student s_w in course C $RS = \emptyset$ FOR EACH $s_i \in S$ enrolled in C { IF ($s_i.HappyTohelp == TRUE$) AND ($KL(s_i, C) > KL(s_w, C)$) AND (($LS(s_w) == LS(s_i)$) OR ($DT(s_w) == DT(s_i)$) $RS = RS \cup \{s_i\}$ } RETURN RS</pre>
<pre>// Peer recommendation algorithm for expert students Input: student s_w (expert student) enrolled in course C Output: recommended student list for student s_w in course C $ERS = \emptyset$ FOR EACH $s_i \in S$ enrolled in C { IF ($s_i.HappyTohelp == TRUE$) AND ($KL(s_i, C) == Expert$) AND ($KLS(s_i, C) > KLS(s_w, C)$) $ERS = ERS \cup \{s_i\}$ } RETURN ERS</pre>

As can be observed in Table 10.5, a list of all the students enrolled in a given course is first generated, followed by the set of logical rules and the resulting peer recommendation (see Figure 10.8). The score of the knowledge level pre- and post-test is as follows:

- The maximum score is 98.
- If the student's score ≥ 80 , the knowledge level is set to "Expert".
- If the student's score is $80 \leq \text{score} \leq 35$, the knowledge level is set to "Intermediate".
- If the student's score ≤ 35 , the knowledge level is set to "Beginner".

Table 10.6 Examples demonstrating the peer recommendation algorithm

Student 7:

Learning style = sensory and visual, Dyslexia type = reading and mathematics, Knowledge level = expert, Knowledge level score = 90

Peer recommendation: student 10.

Student 8:

Learning style = sensory, Dyslexia type = none, Knowledge level = intermediate.

Peer recommendation: student 7.

Student 9:

Learning style = visual and sensory, Dyslexia type = reading, Knowledge level = beginner.

Peer recommendation: student 7.

Student 10:

Learning style = active and global, Dyslexia type = none , Knowledge level = expert, Knowledge level score = 95

The algorithms applied to students depicted in Table 10.6 are discussed in more depth below and demonstrated in Figure 10.8.

- The system will recommend Students 8 and 9 as potential collaboration partners with Student 7 because Student 8 shares the same learning style as Student 7 and Student 9 shares the same dyslexia type.
- The system will recommend Student 10 as a potential collaboration partner with Student 7 because they are both at an "expert" level; however, Student 10 has a higher knowledge level score than Student 7.

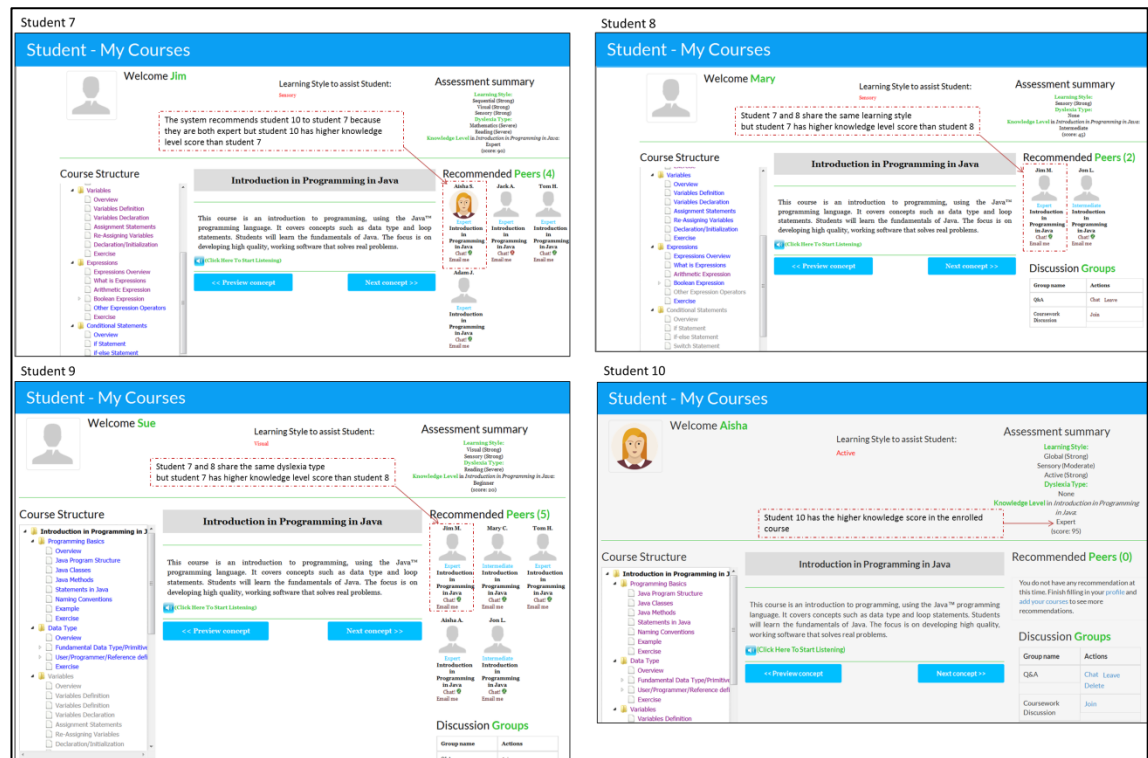


Figure 10.8 Screenshot of the peer recommendation in DAELMS

10.4.5 Adaptive link annotation based on knowledge level

This algorithm demonstrates how a very basic “Beginner”, “Intermediate” and “Expert” strategy can be applied within an adaptive e-learning system. When this approach is implemented effectively, students who are calculated as being beginners are only presented with learning material that is aligned with their current capabilities; i.e., students who are calculated as being beginners are only presented with material that is suitable for beginners. This adaptation algorithm is based on the following underlying process: if a concept is labelled in the same way as the current knowledge level of the student, it should be made visible because it is within the student’s ability level. To make this possible, each of the learning resources is allocated a knowledge level within the learning ontology (Section 8.5.3).

The adaptive link annotation is the part of the adaptive course structure (see Section 10.4.6) that informs learners of the topics that are most suitable for them in terms of their current knowledge and attainment; i.e., it helps learners to follow an optimal path through the different learning materials that are available in accordance with their current knowledge levels. The approach that is employed in the DAELMS involves adaptively annotating and dimming the links so that the user can instantly see what path to follow (see Section 3.3.2.2 for more details). To make this possible, an adaptive link annotation is constructed that modifies the structure of a course in accordance with the learner’s knowledge. The content of each concept in the link annotation, as we defined it, can be categorised as one of three educational states:

- Learned (purple)
- Ready to be learned (blue)
- Not ready to be learned (grey)

Each of the three categories is allocated a colour (as outlined above), which instantly informs the user of their progress against the dimension and their current knowledge level. The primary information that is used to determine the annotated link structure is the learner's knowledge.

The link annotation defines a stable order for the links and prevents the users from forming incorrect mental maps. As such, it can help to prevent cognitive overload, which is important for dyslexic users. The use of link dimming by presenting certain links at a lower opacity than others has the effect of hiding them and, therefore, ruling them out of use. The following algorithm represents this process:

1. **C** is the current course.
2. The course, **C**, is a collection of concepts in the system, where **Concept** $\in$ **C** (see Chapter 8)
3. **S** is a list of the enrolled students in course **C**, where **S** = { $s_1, s_2, \dots, s_n$ }
4. **AK** is the acquired knowledge for the student, s_i , in the enrolled course, **C**. The knowledge level, **KL**, increases during the completion of the course if the student, s_i , successfully learned the **Concept**.
5. **ConceptLabel** is a value to be added for each concept, where **ConceptLabel** has three values {beginner, intermediate, expert}. This allows it to be used in conjunction with the beginner, intermediate and expert knowledge level.
6. **active** is a Boolean value of True or False, which determines if the student, s_i , has the correct acquired knowledge, **AK**, for the **Concept** or not.
7. **annotation** is a parameter that is responsible for changing the colour of the **Concept** link according to the acquired knowledge, **AK**, of the student, s_i .

Table 10.7 presents a logical representation of the adaptive link annotation algorithm taking into consideration the assumptions outlined above. Figure 10.4 represents how the link annotation changes in accordance with the student's acquired knowledge

Table 10.7 The adaptive link annotation algorithm

```

Input: student  $s_w \in S$  enrolled in course C
Output: adaptive link annotation based on Acquired Knowledge AK for student  $s_w$ 
FOR EACH Conceptj  $\in$  C
{
  IF (ConceptLabel (Conceptj, C) == AK( $s_w$ , C))
    Conceptj.annotation = "blue"
    Conceptj.active = TRUE
  ELSE IF ((ConceptLabel (Conceptj, C) < AK( $s_w$ , C))
    Conceptj.annotation = "purple"
    Conceptj.active = TRUE
  ELSE IF ((ConceptLabel (Conceptj, C) > AK( $s_w$ , C))
    Conceptj.annotation = "grey"
    Conceptj.active = FALSE
}

```

10.4.6 Adaptive content and course structure

The two algorithms described in Section (10.4.3) are responsible for selecting the student's strongest learning style, and the DAELMS subsequently adapts to that learning style. The adaption occurs at the levels of course structure, course content, navigation, and communication tools. Table 9.2 in Chapter 9 presents the preferred learners' characteristics for each dimension of the FSLSM model.

As previously described in Section (9.5.2), the information presented in Table 8.2 indicates that all the FSLSM dimensions prefer all types of navigation with the exception of the global/sequential dimension. Sequential learners learn in small incremental steps and, therefore, prefer a linear learning approach. Learners of this nature tend to prefer taking logical stepwise paths to find solutions. This was taken into consideration in the course navigation designed for sequential learners by ensuring that all the possible navigation options, with the exception of the "previous" and "next" buttons, are hidden, to promote a linear advancement through the material. In contrast, global learners typically employ a holistic thinking process and tend to learn in large leaps. They have the propensity to absorb learning material in a seemingly random pattern without forming any major connections. However, once they have been exposed to sufficient material, they are able to develop a view of the whole picture. DAELMS can facilitate such an approach to learning by displaying the entire content through a general view that exposes the learner to information in a manner that provides a holistic view of the key material. In terms of the adaptive content, DAELMS provides the global learner with a summary *concept* after each of the individual *chapters*. This provides a summary of the overall picture of the topic. Figure 10.9 presents an overview of the adaptive navigation, course structure and content for the global/sequential dimension.

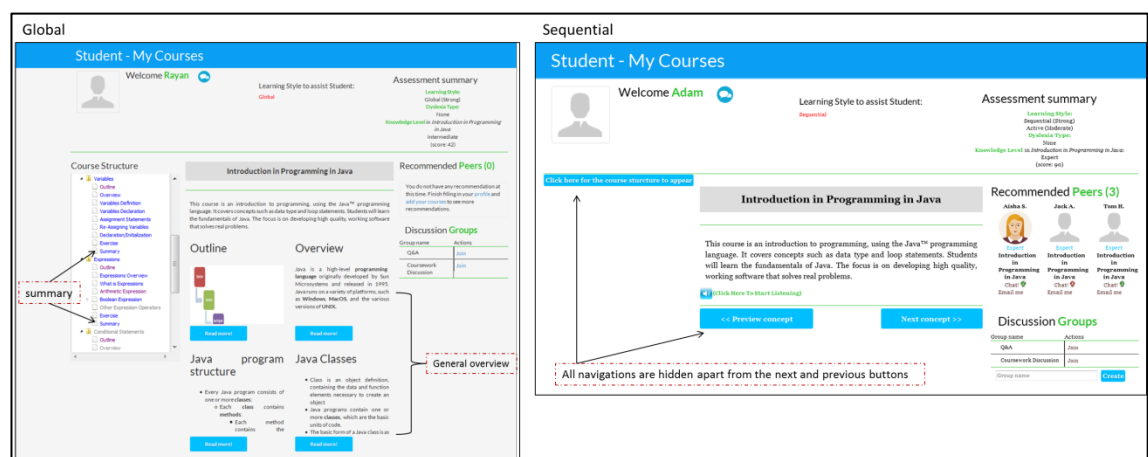


Figure 10.9 DAELMS adaptive navigation, course structure and content for global/sequential dimension

Verbal learners typically prefer to learn through words; as such, they tend to prefer communicating with others and discussing key concepts during the learning process. These types of users are expected to use the system's discussion forum on a regular basis. For this reason, all the available communication tools are available to the verbal learners in the DAELMS. While verbal learners like to learn from words and communication, visual learners learn most effectively through sight. To meet the preferences of these learners, the DAELMS

presents visual learners with a combination of diagrams and text, while limiting the display to verbal learners to just text alone. Figure 10.10 provides an example of how the topic of *WHILE LOOP* will be presented to a learner who demonstrates a preference for textual material (verbal and active learners). It also provides an overview of how material will be presented to a learner who has a visual preference (visual and intuitive learners).

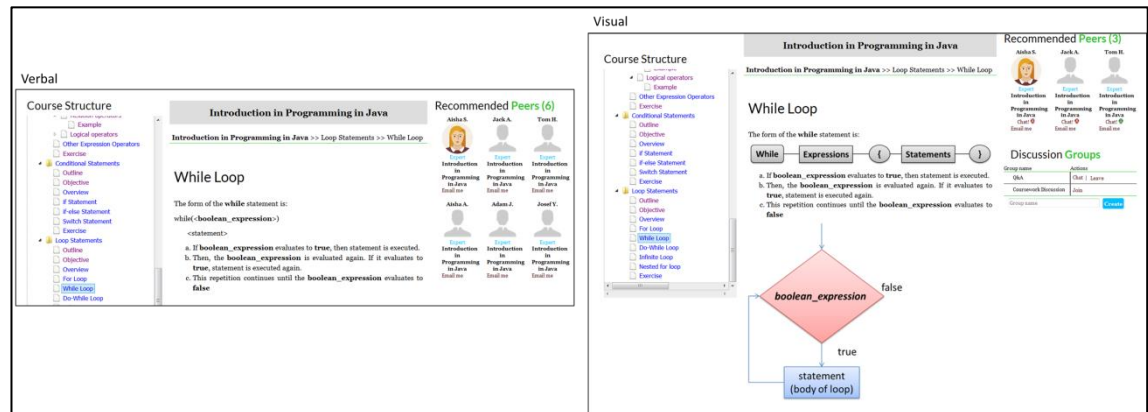


Figure 10.10 DAELMS adaptive content for visual/verbal dimension

The inclusion of discussion groups in the DAELMS was designed to provide students with a mechanism by which they can ask teachers and tutors questions and communicate with the system-recommended peers. As can be observed in Table 9.2, students who have an active learning style typically prefer social orientation (e.g., discussing and explaining learning material to each other or working in groups). On the other hand, those who have a reflective learning style exhibit social behaviour as opposed to demonstrating a propensity to think/reflect on learning material. As such, in order to support students who demonstrate a reflective learning style, it is important that the system provides them with an opportunity to work individually. As such, the DAELMS presents reflective learners with just one communication tool which is email in order to give them the opportunity to reflect on the learning materials independently. Figure 10.11 presents the adaptive communication mechanism that delivers the active/reflective dimension.

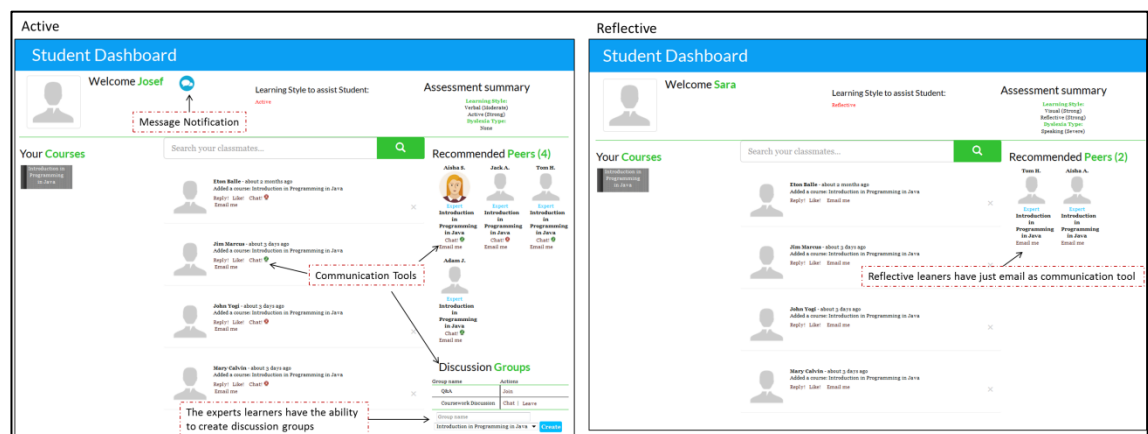


Figure 10.11 DAELMS adaptive communication for active/reflective dimension.

A less intensive approach that teachers may employ to support their learners is to incorporate different learning styles into the material that they present to students throughout the duration of the course as opposed to limiting the resources to one learning style alone. This approach can be employed to support different types of learners. For example, learners who have a sensing learning style tend to prefer to spend time reviewing examples. As such, the course structure within the same set of concepts will be presented differently to sensing learners than it is to intuitive learners. In the case of sensing learners, the examples will be presented before the explanation, while, for intuitive learners, the explanation will be presented before the example. The course structure and content for the sensory/intuitive dimension are presented in Figure 10.12.

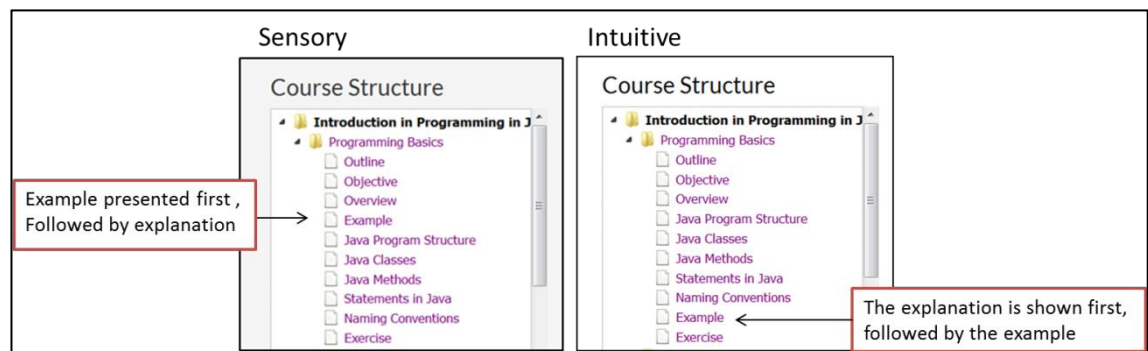


Figure 10.12 DAELMS adaptive course structure and content for the sensory/intuitive dimension

This course structure discussed in this section is based on the general course structure that was proposed in Section (9.5.2) and the *concept* class in the *learning* ontology (Section 8.5.3.2). The course structure was designed such that it could accommodate differences in terms of the learning preferences of the student. For example, global learners are presented with summaries of the key concepts, while sensory learners are provided with examples before explanations. Figure 10.13 provides an overview of the general structure of each learning unit that will be presented in the DAELMS.

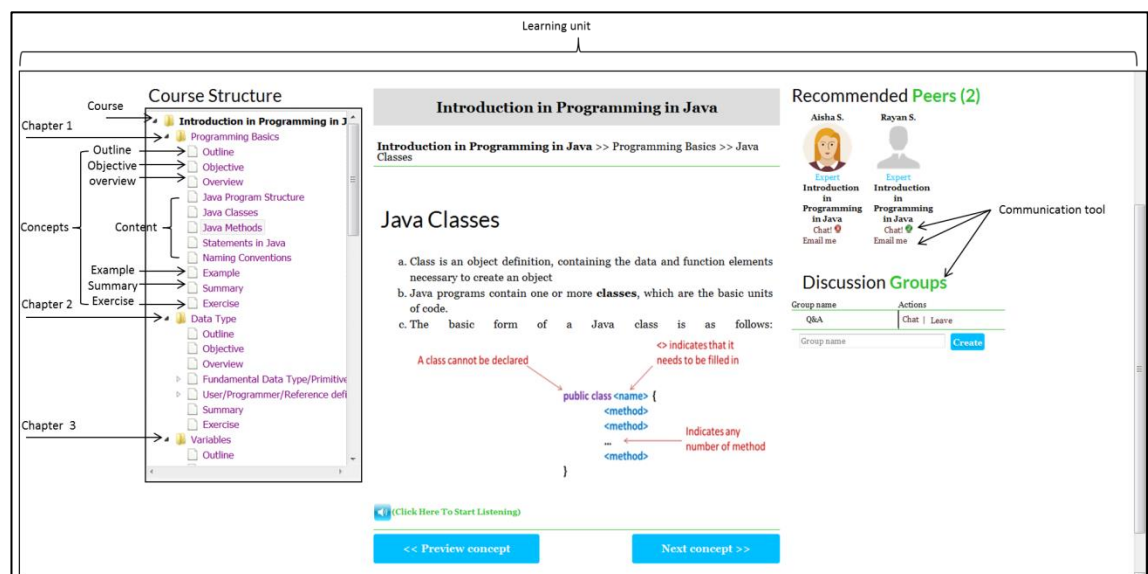


Figure 10.13 General structure of each learning unit in DAELMS

10.4.7 DAELMS as authoring tool

The underlying tool that was employed to author the adaptive courses was based on the learning ontology described in Section (8.5.3) and the general course structure presented in Figure 9.1. In order to minimise the additional effort teachers are required to use the system and the time taken to develop the system, specific course elements were selected from the learning ontology.

The authoring tool was developed to fulfil the required adaptivity of the DAELMS by providing teachers and course developers with the opportunity to generate meta-data that distinguishes between the concepts. This can be created through a simple checkbox mechanism that specifies whether the new concept is for reading dyslexia type or for a visual learning style (Figure 10.14b). In terms of the assistive technologies, the authoring tool was also extended to provide teachers and course developers with an opportunity to define the required assistive technologies for each concept in accordance with the dyslexia type specified for that concept (Figure 10.14b). In addition, the teachers and developers also have the capability to specify the type of resource in more detail. For example, they may specify whether the resource is based on graphics as opposed to text, and may detail the level of interactivity between the concepts and the students. Course structure varies from one learning style to another. The authoring tool provides the teachers and course developers with an opportunity to take every aspect of each learner's characteristics into consideration in the DAELMS, as per Table 9.2, by simply dragging and dropping the course concepts to create different course structures (Figure 10.14a). This simple, web-based approach entails that DAELMS authoring tools require less technical knowledge to teachers and course developers do not require any coding background at all to create and manage adaptive courses.

a

Course title: **Fundamentals of Computation Structure**

[Edit Course Definition](#)

[Organize Concepts by Learning Style](#)

Sensory	Reflective
Central Processing Unit (CPU)	Central Processing Unit (CPU)
Objective	CPU Overview
CPU Overview	Objective
Example	CPU Definition
CPU Definition	CPU Component
CPU Component	The purpose of CPU
The purpose of CPU	Example
Exercise	Exercise

b

Add a resource to the selected Concept

Keywords (use semi color ";" as separator): Interactive Level:

Difficulty Level:

Description:

Require Assistive Technology:

Learning Style Concerned: ☐ Visual ☐ Sensory ☒ Verbal ☐ Reflective ☐ Sequential ☐ Global ☐ Active ☐ Intuitive

Dyslexia Type Concerned: ☒ Reading ☐ Writing ☐ Speaking ☐ Mathematics ☐ Memory

Resource type:

[Save Resources](#)

Figure 10.14 DAELMS authoring tool features

Even though the DAELMS has the potential to provide both teachers and course developers with the opportunity to create adaptive courses with minimal effort, the students' perspectives alone were considered in the case study presented in Chapter 11 because adaptive authoring is out of the scope of this thesis.

10.4.8 Assistive technology in DAELMS

The DAELMS incorporates two assistive technologies. These were selected because they relate to the most common dyslexia types: spellchecker, for writing dyslexia type, and text to speech, for reading dyslexia type. For the purposes of implementing the two assistive technologies, a readily available library was employed. This is described in more detail below.

- ResponsiveVoice⁶¹ is an HTML 5 based Text-To-Speech library that was designed to add voice features to websites and apps across all smartphone, tablet and desktop devices. It supports 51 languages, offers 168 voices and is completely free for non-commercial use. This library was implemented into the DAELMS (Figure 10.15) such that it is available for all students regardless of learning style or dyslexia type. It is not uncommon for dyslexic subjects to process text very slowly. Text readers, therefore, are highly beneficial because they read the given text at a standard pace and, thereby, significantly reduce the time it takes the student to process the written information (see Section 3.7.1). Existing research indicates that an approach that incorporates a Text-to-Speech library can significantly enhance a dyslexic user's level of comprehension of a given text while also reducing the effort required to read (Leong, 1992; Elkind et al., 1996).



Figure 10.15 The text to speech as assistive technology implemented in DAELMS

- TinyMCE was used to create a discussion group and chat between the peer-recommended users. TinyMCE is an HTML editor that is commonly used in LMS systems, websites and popular web content platforms such as Wordpress. It appears in the form of a word-processor that is embedded on a webpage. As previously discussed, one of the major difficulties that dyslexic users face is spelling, and dyslexic students will commonly misspell words. Multiple spelling mistakes or bizarre spelling conventions may prevent students from understanding one another as they communicate through forums and online chats. Furthermore, one of the biggest disadvantages that dyslexic students encounter when interacting with existing e-learning systems is text-based

⁶¹ <http://responsivevoice.org/api/>

synchronised communication because dyslexics often fail to effectively communicate with tutors and other learners due to the aforementioned spelling issues. To this end, there was a distinct requirement for the DAELMS to incorporate a spellchecker. A spellchecker plugin for TinyMCE called "JavaScript Spellcheck"⁶² was selected for this purpose. This plugin can run without problems on almost any hosting platform, including Apache and TomCat. This spellchecker incorporates over 30 international dictionaries as standard, and includes terms that are related to the scientific, medical, engineering and legal professions. Figure 10.16 shows how the spellchecker appears within the DAELMS.

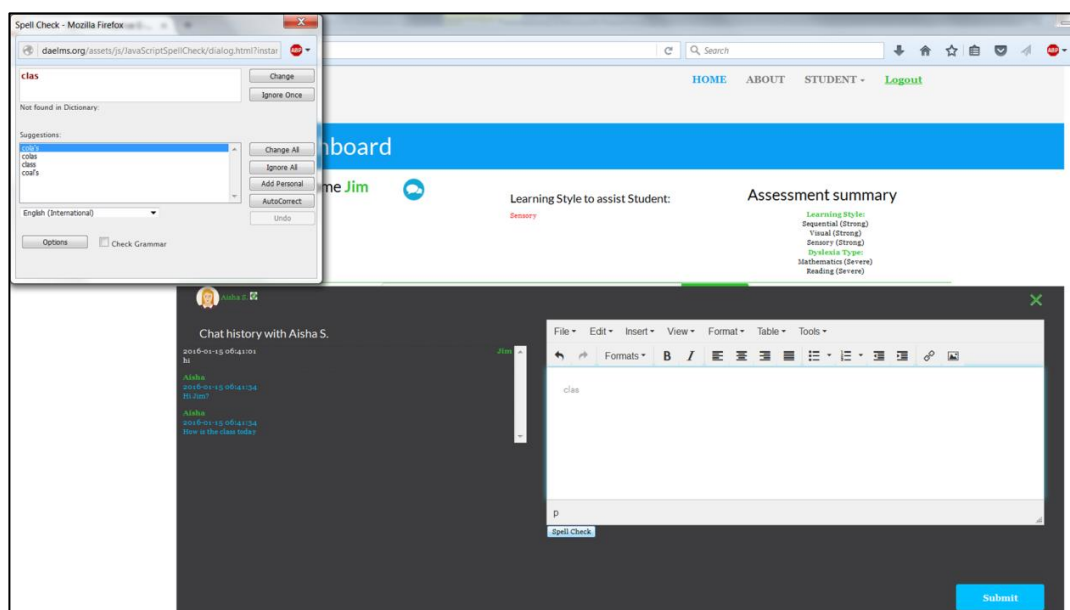


Figure 10.16 The spellchecker as assistive technology implemented in DAELMS

10.5 Chapter Ten Summary

This chapter presented an overview of the practical implementation of an adaptive e-learning system called the Dyslexia Adaptive E-Learning Management System (DAELMS). This implementation was based on Phase 3 of the methodology and architecture proposed in Chapter 9. The purpose of creating the prototype was to validate the approach outlined in this thesis by creating a working system, the functionality within which could be subsequently evaluated.

First, the required technology for implementing the DAELMS was presented. Following that, the primary component models of the DAELMS, which are learner, content, and adaptation, were described in depth before the adaptation process based on the adaptation algorithm stored in the adaption DB was also examined. The cycle of creating personalised learning in the DAELMS was then presented to demonstrate how the system operates. Finally, a personalised learning system that was created to cover the topic of a respective domain was described. The next chapter will describe the experiment design and the procedure by which the DAELMS was tested and evaluated.

⁶² <http://www.javascriptspellcheck.com/tinymce-spellchecker/>

Chapter 11 Formulation of an Experimental Evaluation Strategy for DAELMS

11.1. Introduction

This chapter will describe the methodology that was used to evaluate the DAELMS system. Section (11.2) will describe the hypothesis upon which the methodology of evaluation was designed and implemented, Section (11.2.2) will provide an overview of the parameters that were deemed to be essential in the evaluation of the DAELMS in terms of the user satisfaction and the user performance of the system. Section (11.2.3) will describe the specific procedure that was used to evaluate the system and the steps involved in the experiment. The evaluation methodology itself was designed and implemented in accordance to a distinct ethical policy; this will be described in Section (11.2.4). The key purpose of this chapter is to present the key findings of the evaluation of the DAELMS adaptive learning system in terms of the extent to which it was pedagogically effective and offered a satisfactory teaching and learning method for the learners who interacted with it. A particular focus will be placed on assessing how effectively the DAELMS facilitated learning experiences for students with dyslexia, which was one of the key objectives of this research.

11.2. Experimental Evaluation

This section will describe the experimental process that was employed to evaluate the extent to which the Dyslexia Adaptive E-Learning Management System (DAELMS) met the objectives of this research.

11.2.1 Experimental hypothesis

Before developing and implementing an experimental strategy, it is important to first generate a clear set of experimental objectives that underpin the project hypothesis. According to the aims of this research, the **H1** that was developed was as follows:

“The adaptive learning paths generated by the DAELMS system are pedagogically effective and satisfactory for the students with dyslexia”

It was determined that an appropriate experimental evaluation of the formulated hypothesis would ultimately result in the assessment of several other essential project objectives, including:

- (i) The validity of the dyslexia models employed to develop DAELMS (see Chapter 4).
- (ii) The legitimacy of the Dyslexia Adaptive E-Learning (DAEL) framework that was developed and utilised (see Chapter 6).
- (iii) The validity of the Ontology of Dyslexia Adaptive E-Learning (ODAEL) that was deployed (see Chapter 8).

11.2.2 Experimental parameters

The central hypothesis of this project highlighted the requirement to measure the knowledge that the dyslexic subjects gained as a result of interacting with the DAELMS system. As such, it

was necessary to develop an appropriate set of techniques by which this knowledge gain could be assessed, and the user application performance could be determined. The following parameters were generated to achieve this.

- 2. Laboratory Conditions:** The DAELMS system was specifically developed to operate as a distributed system that could be accessed from a large variety of different locations via the Internet. However, for the purposes of the evaluation exercise, the evaluation experiment of the system were implementing under laboratory conditions. The laboratory approach was determined to be the most suitable because it allowed the use of the specialist equipment required to adequately evaluate user interaction with the DAELMS. The limitations of this approach in terms of the lack of context for the subject and the presence of an observer during the session were accepted as unavoidable experimental constraints.
- 3. Sample-Size:** The evaluation of the existing systems that were reviewed in the literature review was performed with a relatively small sample size. For example, the evaluation of the Seeword system involved six dyslexic subjects and five control, and the Dyslexic Nursing Support system was evaluated with 31 dyslexic subjects and no control (Dickinson et al., 2000; Wright, 2001; Dickinson et al., 2002). While the findings of both of these studies were deemed to be valid, it was determined that the evaluation of the DAELMS should be performed with a larger sample population in order to increase the validity of any findings and the conclusions that were subsequently drawn. As such, the total sample size involved in the evaluation aspect of this study was 48 experimental participants. These consisted of 11 dyslexic subjects, 23 participants with symptoms of dyslexia (possible dyslexics) and 14 non-dyslexic participants.
- 4. Subject Characteristics:** The dyslexic subjects selected for the system evaluation process were individuals who displayed the symptoms and difficulties that are typically associated with dyslexia; however, they had not necessarily been explicitly stated as dyslexic through a formal assessment conducted by an educational psychologist. A further requirement was that the subjects were over the age of eighteen. The gender, age, IT competency, social grouping, educational background and other key demographics of the subjects were noted but did not constitute inclusion or exclusion factors because the DAELMS environment was specifically designed to meet the needs of a wide range of dyslexic computer users (and students with learning difficulties in general) regardless of any social or economic factors.
- 5. Measurable Performance Indicators:** Previous studies in this domain have utilised a variety of different performance indicators to manage user performance and the extent to which a system is effective in its objectives. Existing studies tend to employ a combination of subjective and objective quantifiable indicators to develop a multi-faceted view of user performance. These typically include, but are not limited to, the following:

- Learners' performance (evaluated through a comparison of pre- and post-knowledge level test results).
- The relationship between learning styles and dyslexia type (assessed by comparing the system results with the results of previous studies outlined in the literature).
- Learners' satisfaction levels (assessed through the use of post-event questionnaires).

In order to determine the extent to which the central project hypothesis of the current research was true, it was important that the students' knowledge gain as a result of interacting with the system was evaluated and treated as an indication of system performance. In addition to this measurement, user satisfaction levels were assessed through the use of post-event questionnaires. It was anticipated that this combination of subjective and objective indicators would provide a rich source of data by which the effectiveness of the DAELMS and the extent to which it met the research objectives could be assessed.

11.2.3 Experiment design

As previously explained in Section (0), this research employed both quantitative and qualitative methods during the process of system validation. The underlying assumption of the qualitative approach was that a predetermined sample data size would not be enforced. This assumption was based on the fact that this form of research is designed to elicit the opinions, feedback and ideas of the subjects as opposed to being required to fulfil a strict protocol in terms of volume. In other words, "size does not matter" but the feelings and viewpoints of the subjects does. In addition, the data analysis phase of this research involved the use of t-tests to determine the pair-wise comparisons between the learner' pre-test and post-test scores. These tests were used to determine the statistical significance of the findings. If the p-values resulting from the tests were less than 0.05, this was perceived to be indicative that the observed result is unlikely to be random with 95% probability and the result is true for the population of the students.

11.2.3.1 Student cohort

All participants were university students who were in the process of completing Computer Science related majors and were studying at either the graduate or undergraduate level. The participants consisted of students with varied learning abilities who expressed an interest in undergoing testing in the DAELMS. In total, 48 students participated in the research. Of these, 11 were dyslexic students, 23 exhibited symptoms of dyslexia and 14 were non-dyslexic. All students were over the age of 18 (as per the inclusion criteria), and the sample consisted of 16 female students and 32 males. While all the participants were technically adept, they did not have any previous experience of interacting with an adaptive e-learning system.

11.2.3.2 Experimental procedure

As a means of evaluating the true effectiveness of the adaptive learning system, two different systems were developed during the evaluation process. Version 1 was the DAELMS system, which was specifically designed to support the user throughout the learning process. Version 2 was a variation of a non-adaptive system that was developed on Moodle. Version 2 of the

system allowed the participants to navigate to different topics at leisure and provided them with an opportunity to complete the exercises that they were interested in. Version 1 presented adaptive learning experiences and techniques that were aligned with the profile of the learner (see Section 9.4). The steps involved in the experiment were as follows:

- 1) The student cohort was randomly separated into two groups of 24 subjects: Group A and Group B.
- 2) Two courses were created in the DAELMS. The first of these was entitled “Fundamentals of Computation” (Course 1) and the second “Introduction to Programming in Java” (Course 2). The students had been taught all the concepts that were included in these lessons in previous classes.
- 3) Group A completed the “Fundamentals of Computation” course on Version 1 of the system, while Group B completed the same course on Version 2 of the system.
- 4) The first session involved in the experiment was the same for all learners in both groups. First, the participants were provided with a brief overview of the study and its related objectives. They were then familiarised with the system and the concepts underlying the two systems.
- 5) Next, the students completed a five-minute pre-test, which consisted of ten questions that were designed to determine their existing knowledge of the concepts related to the course. The full text of this test can be found in Appendix F.
- 6) After completing the test, the students completed the “Fundamentals of Computation” course over a 30-minute session. The information they were presented with at this point was determined by which version of the system they were using. The students who were using Version 1 of the course were presented with the course interface shown in Figure 11.1, while those using Version 2 of the course were shown the interface presented in Figure 11.2. The differences in the design features of these two systems have been discussed in depth in previous chapters.
- 7) After completing the course, the students completed a five-minute post-test, which again consisted of ten questions. The full text of the post-test material can be found in Appendix F.
- 8) The knowledge that the students had gained as a result of interacting with the system was evaluated by calculating the differences between the pre- and post-test scores. The results of this analysis were employed to determine the effectiveness of the adaptive learning techniques.
- 9) At the end of the experiment, each learner completed a questionnaire (see Appendix E) that was designed to elicit information about his or her perceptions about different aspects of the two systems.
- 10) Once the first course was completed and closed, it became inactive and a second course “Introduction to Programming in Java” was made available. In the “Introduction to Programming in Java” course, Group A accessed the learning material using Version 2, while Group B accessed it using Version 1.

- 11) The students progressed through the lesson following the same process as that described for the first course, and the same evaluation procedure involving pre- and post-test assessments was applied.

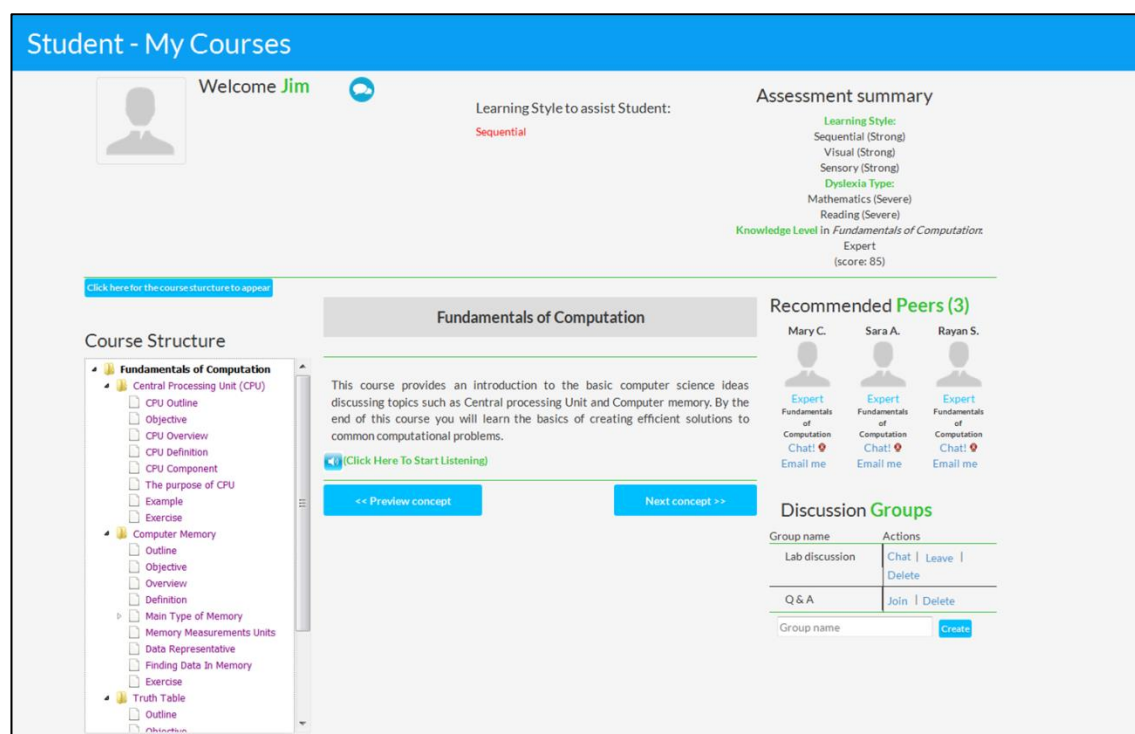


Figure 11.1 System version 1 in the experiment (DAELMS)

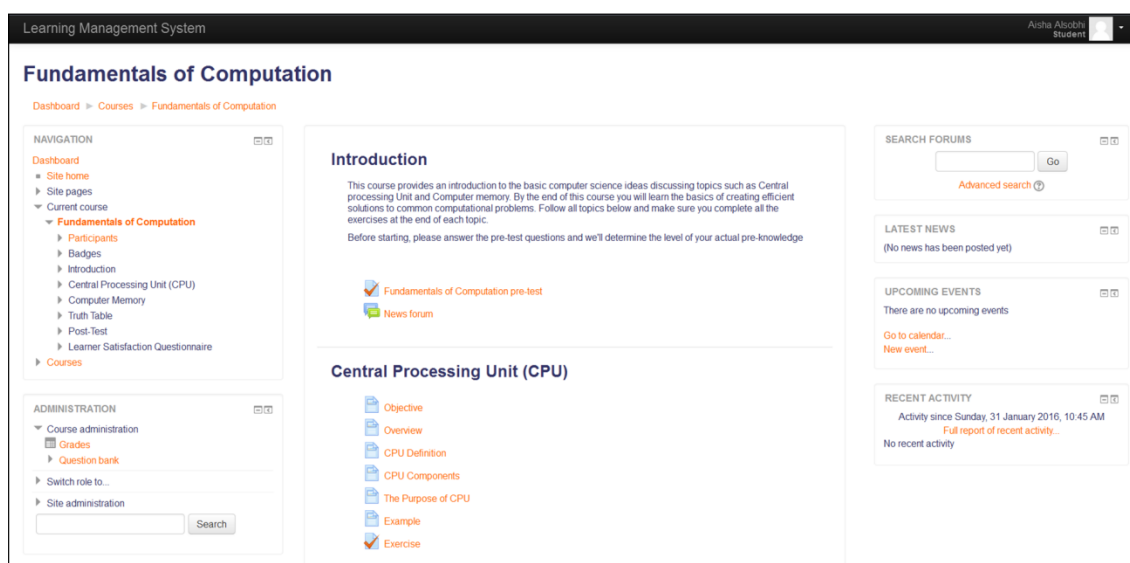


Figure 11.2 System version 2 in the experiment (Moodle)

The approach employed to assess the two systems consisted of a crossover experiment through which both groups of participants were subjected to both systems. The purpose of this was to ensure that any perceived differences in the results were not due to the composition of the students in the group.

11.2.4 Ethical considerations

It is natural for participants who are involved in any study to express concerns about how their personal information will be used and whether the data obtained during the research will be

shared with third parties in a way in which the participants can be individually identified. In order to deal with any concerns that the people who participated in this study had, an ethical policy was developed to cover the research, and this was adhered to throughout the study (see Appendix H). The main details of the ethical policy were as follows:

- To be included in the study, the subjects needed to be aged 18 or over.
- Prior to being asked to agree to participate in the research, all participants were fully informed of the project aims and purpose, the research method, likely duration, potential consequences, and the findings that were likely to be published.
- The candidates were also fully briefed on any experimental tasks they would be required to perform and the environment in which these experiments would be conducted, as follows:
 - a) All experiments were conducted in private in the presence of the participants and the researcher or the person who conducted the experiment only.
 - b) To conform to health and safety regulations, an additional team member was positioned outside the laboratory and was available in the event that the participant or researcher required assistance.
 - c) All the data collected during the experiments was recorded such that personal information about the participants was only available to the researcher who conducted the experiment. Any information that could potentially be used to identify the participants, such as name, was removed to prevent the experimental results being traced back to individual participants.
 - d) All paper-based records from the experiments, which included personal data, were stored in a secure location.
- Care was taken to ensure that the individual needs of the participants were taken into consideration and that the researcher was sensitive to the potential embarrassment that a dyslexic participant may experience while using the system.
- The participants were clearly informed that they had a right to withdraw from the study at any time, even once the experiment was in progress, should they feel unhappy, confused, embarrassed or frustrated with the tasks they were being asked to complete.
- Before commencing the experiment aspect of the research project, each participant was asked to sign a consent form that formally recorded their agreement to participate in the study (See Appendix I).
- Each participant was provided with an opportunity to see his or her individual experimental results.
- All project results and conclusions were made available to the project participants upon request.

The purpose of sharing this information with the participants was to alleviate any of the concerns the candidate may have had relating to their participation in the research.

11.3. Learner's Evaluation

The most important stakeholders in any e-learning initiatives are the learners themselves. As such, to be effective, adaptive e-learning approaches should generate personalised learning material that the learners are satisfied with. The goal of the experiment was to demonstrate:

1. The effectiveness of the personalisation provided by DAELMS as measured by an assessment of the learners' performance;
2. The extent to which the learners who interacted with the system were satisfied with it, as measured by a questionnaire that elicited their opinions on the various aspects of the system;
3. The extent to which the relationships that were calculated between the learning styles and dyslexia type were successful. As measured by comparing the results of learning style test and dyslexia test from the system with the relationship identified from the literature.

The learners completed a survey in which they were asked to share their opinions and feedback on the proposed system. The results of this survey are described in Section (11.3.1). The section commences with an analysis of the outputs of the learners' evaluation based on the information provided in the post-experiment questionnaires. Following that in Section (11.3.2), the results of the analysis in terms of the effects that the learning process had on the learners will be summarised. After that in Section (11.4), the interaction between the Felder-Silverman learning style model (FSLSM) will be investigated as a means of identifying the relationship between learning styles and dyslexia type in the proposed system. Finally, a summary of the results of the evaluation will be presented in Section (11.5).

11.3.1 Learner satisfaction

Once the experiment was finished, each learner was presented with a questionnaire to complete that was designed to elicit key information about their opinion of the adaptive learning process they had just completed. The questionnaire consisted of 24 questions in total and included both general questions about the learners' experiences and open-ended questions that were designed to obtain their opinions. In one section of the questionnaire, the learners were asked to rate their experience of using the system according to a Likert-type scale (Likert, 1932) that consisted of five ratings that ranged from "strongly agree" to "strongly disagree." The questions were grouped into six general categories. The main aim of the questionnaire was to provide information that could be used to gain insights into the extent to which the subjects were satisfied with the system. The categories of questions and the information they were designed to obtain were as follows:

- 1) The learner's opinions on the adaptive and non-adaptive system respectively: this category compared the extent to which the learner was satisfied with the adaptive and non-adaptive system.
- 2) Each learner's opinions on the extent to which the system was successful in detecting his/her dyslexia type and matching it to an appropriate learning style.

- 3) The learner's satisfaction with the adaptive presentation. A key factor that was examined in this category was the usability of the CSS and the extent to which it successfully personalised the system presentation settings.
- 4) The appropriateness of the personalised materials. This category examined the extent to which the learners were satisfied with the personalised materials they were presented with.
- 5) The learner's satisfaction with the recommendations produced by the system. This category examined the extent to which the learners felt that they benefited from the recommendations produced by the system.
- 6) Learner's interests. This section examined the effect of the adaptive system on the learner's learning motivations or interests.

The questions associated to each category are listed in Table 11.1. The complete questionnaire can be found in Appendix E. The itemised results of the analysis of learners' responses to the questions are going to be discussed in the following sections.

11.3.1.1 A comparison of adaptive and non-adaptive e-learning system

The questions in this section were designed to develop insights into the participants' overall perceptions of the adaptive and the non-adaptive learning experience. As the learners had been exposed to both courses on both systems, they were asked specific questions about the different approaches that each system employed. Figure 11.3 provides a visual representation of the learners' opinions on the adaptive and non-adaptive systems.

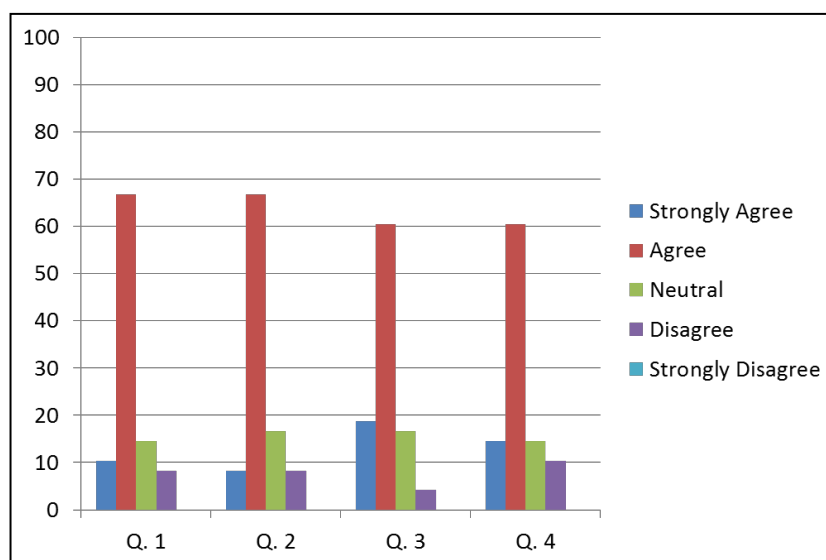


Figure 11.3 Learners response to a comparison between adaptive and non-adaptive systems Questions 1, 2, 3 and 4 compared the user's perceptions of the adaptive and non-adaptive systems.

Question 1 asked the learners to specify the extent to which they agreed with the following statement: *"I found it easier to learn a new topic using the adaptive system than I did using the non-adaptive system"*. As can be seen in Figure 11.3, a total of 77% of the learners surveyed believed that the adaptive system successfully helped them to learn new topics (10% strongly

Table 11.1 The category of learner's satisfaction questionnaire

Category	Question Number	Question
A Comparison of adaptive and non-adaptive e-learning system	1	I found it easier to learn a new topic using the adaptive system than I did using the non-adaptive system.
	2	I found it easier to solve any difficulties I encountered with the help of the recommendations of the adaptive system than I did using a non-adaptive system.
	3	Of the two systems, I prefer the adaptive system because of its interactive features.
	4	I appreciated the recommendations provided by the adaptive system because they directed me to materials that were aligned with my needs and did not require me to search the course material.
Dyslexia Type Detection in DAELMS	5	I found it useful to learn about the type of dyslexia I have and how this influences my learning style.
	6	Learning about the type of dyslexia I had helped me to better understand my strengths and weakness
	7	The adaptive system facilitated my ability to work around my weaknesses
	8	The adaptive system presented information and experiences that were aligned with the learning needs associated with my dyslexia type.
Adaptive Presentation	9	I found the site easier to read after my personalised settings had been applied.
	10	There were improvements to the aesthetics of the site once my personal settings had been applied.
	11	It was easier to navigate around the site once my personal settings had been applied.
	12	It would be useful if I could apply my personalised setting to other online resources.
The Effectiveness of the Adaptive Materials	13	The way in which the course was structured facilitated my ability to understand the materials.
	14	The way in which the exercise was structured enhanced my comprehension of the topic.
	15	The learning experiences that were presented were aligned with my current level of knowledge.
	16	The fact that the learning content presented was aligned with my learning style enhanced my learning experience.
Recommendations Presented by the System	17	The students recommended by the system allowed me to effectively learn alongside other students.
	18	The students recommended by the system enhanced my understanding of the topics and allowed me to access a variety of different perspectives.
	19	The recommended assistive technologies by the system makes my learning more effective
	20	The recommended assistive technologies by the system match my dyslexia type
Learner's Interest	21	The system is easy to use.
	22	The adaptive nature of the system increased my interest in the topic.
	23	Time passes quickly when I am interacting with the adaptive system.
	24	I would be happy to recommend it to my friends.

agreed and 67% agreed), while only 8% of the learners disagreed that the system facilitated their learning and the remainder had no strong opinion.

Question 2 asked the learners to state the extent to which they agreed that the recommendations provided by the adaptive system successfully helped them to overcome their learning difficulties. A total of 75% of the students surveyed either strongly agreed or agreed that it did.

Question 3 presented the participants with one possible reason as to why they preferred the adaptive system over the alternative system by asking them to specify whether they agreed with the following statement: *"Of the two systems, I prefer the adaptive system because of its interactive features."* 79% of the learners either strongly agreed or agreed with the statement only 4% disagreed.

Question 4 attempted to determine the reason as to why the system adaptivity was useful by asking the participants to specify whether they agreed with the following statement: *"I appreciated the recommendations provided by the adaptive system because they directed me to materials that were aligned with my needs and did not require me to search the course material."* A total of 75% of the participants either strongly agreed or agreed with this statement. Approximately 14% of the learners did not have any opinions on the system, and 10% of them disagreed with the statement.

The result of the questions that were included in this category indicated that the learners who participated in this research preferred using the adaptive system to the non-adaptive system because it presented personalised content that was aligned with their needs and eradicated the need for them to search the system for materials that were suitable to their learning requirements.

11.3.1.2 Dyslexia type detection in DAELMS

According to the results of the experiment, 23 of the study participants had not previously been diagnosed with dyslexia; however, having completed the assessment that was integrated into the system, there was strong evidence to suggest that they did exhibit some dyslexia symptoms. This finding did not come as a surprise because the majority of people do exhibit some form of reading or writing difficulty (Tibi, 2010). Furthermore, in some countries, there is no specific procedure by which dyslexics are assessed and referred for learning support. In such cases, it is left entirely to the teacher to detect the symptoms of dyslexia and the chance that a dyslexic learner is identified and provided with the assistance he or she needs is very much dependent on the teacher's ability to differentiate between dyslexia and poor academic achievement and to make an appropriate referral. As such, the likelihood that people progress beyond their school education with some undetected form of dyslexia is relatively high. The results of Question 5 revealed that more than 77% of the learners who completed the questionnaire were very happy to know their learning style and dyslexia type for the future. The 8% who disagreed with the statement were those who were already aware of their dyslexia type because they had been previously diagnosed.

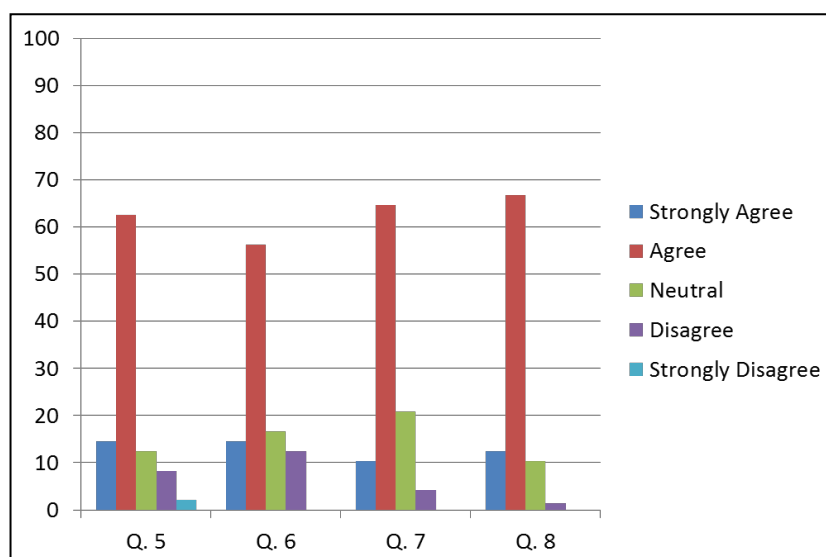


Figure 11.4 Learners' satisfaction level about dyslexia type detection in DAELMS

Question 6 assessed the extent to which the learners were satisfied with the detection of their dyslexia type and how it raised their awareness of their strengths and weaknesses from different perspectives. As Figure 11.4 highlights, more than 70% of the users surveyed either strongly agree or agreed with the statement that *“Learning about the type of dyslexia I had helped me to better understand my strengths and weakness”*. Again, as was the case with Question 5, those who did not agree with the statement had previously received a dyslexia diagnosis.

In Question 7, the participants were asked how much they agreed with the statement that the system provided them with all the information they need to work around their learning difficulty. The results of the questionnaire revealed that 75% of the learners either strongly agreed or agreed with the statement, while only 4% responded negatively (the remaining learners did not have any strong opinion).

Question 8 attempted to ascertain the extent to which the participants felt that the personalised materials recommended by the DAELMS were suitable for their dyslexia type. As Figure 11.4 indicates, more than 79% of the learners surveyed felt that they benefited from the personalised materials and were satisfied with the quality of them, while 10% of the learners had no strong opinion and the remaining 1% of learners were not happy with the personalised materials.

11.3.1.3 Satisfaction with adaptive personalisation

The questions in this category were included in the questionnaire as a means of determining the learners' usage of the personalised presentation settings features that are available in the adaptive system. Figure 11.5 presents a visual representation of the extent to which the learners were satisfied with the adaptive presentation.

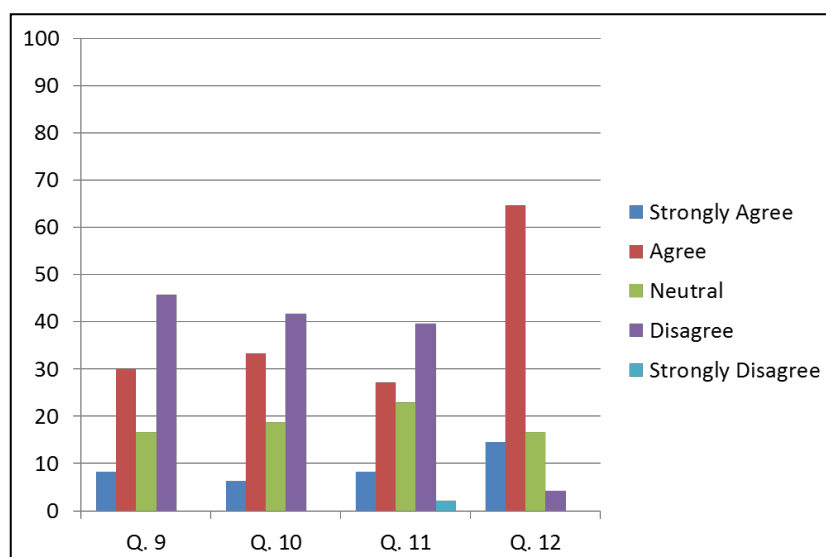


Figure 11.5 Learners' satisfaction level with adaptive presentation

Question 9 asked the participant to disclose the extent to which they agreed with the statement “*I found the site easier to read after my personalised settings had been applied.*” Only 38% of the learners questioned either strongly agreed or agreed with this statement. More than 45% of the learners disagreed, and the remainder had no opinion on the personalised settings. Questions 10 and 11 verified the participants' perceptions of the extent to which the system presentation improved in terms of aesthetic feel and navigation following the application of the personalised settings. More than 41% of the learners disagreed that the aesthetic feeling of the system was enhanced as a result of the application of the personalised settings, while 39% of the respondents either strongly agreed or agreed. In terms of the extent to which the application of the personalised settings improved navigation, 39% of the respondents disagreed, while more than 22% did not have any opinion. The responses provided to Questions 9, 10 and 11 indicate that the DAELMS has good presentation features that do not require enhancement through the application of personalised settings. Moreover, even when the students did change the personalised settings in accordance with the system recommendations, the system remained easy to read and navigate.

The responses that the participants gave to Question 12 revealed that 79% of those questioned liked the idea of having the option to apply their preferred personal presentation settings to other websites. Overall, the learners were satisfied with the adaptive presentation of the DAELMS system, with only a minority of learners specifying that they were dissatisfied.

11.3.1.4 The effectiveness of the adaptive materials

It was necessary to assess the effectiveness of the adaptive materials as a means of evaluating the quality of the personalisation and determining the personalised learning materials that were generated were in agreement with the learners' expectations and requirements. Questions 13 to 16 of the questionnaire were designed to provide information about the learners' feelings about the personalised materials. A summary of the responses that were provided for each answer is provided in Figure 11.6.

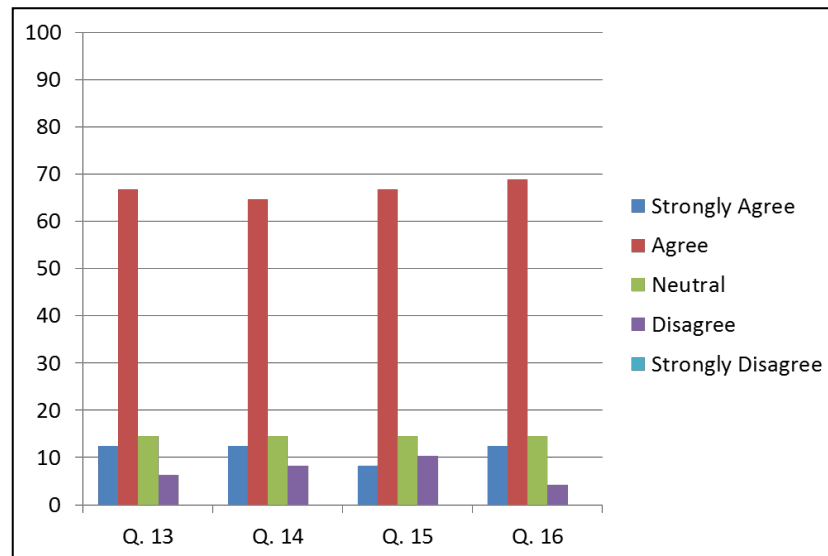


Figure 11.6 Learners' response to the effectiveness of the adaptive materials

Question 13 was focused on the statement *"The way in which the course was structured facilitated my ability to understand the materials."* The course structure was based on the students' learning style and the structure proposed in Section (9.5.2). More than 79% of the respondents strongly agreed or agreed that the structure was useful in helping them to grasp the overall learning materials, while just 6% of the participants stated otherwise. Since learning materials that are either too easy or too difficult to master generally frustrate students, Question 14 was designed to assess the extent to which the participants agreed that the exercises they were presented with at the end of each topic were effective. More than 77% of the learners strongly agreed or agreed that the exercises facilitated their understanding of the course material. Only 8% of the learners responded negatively to the statement that the exercises facilitated their understanding.

The purpose of Question 15 was to examine the extent to which the personalised materials that were presented to the students were appropriate to their knowledge level. As the results presented in Figure 11.6 indicate, 75% of the learners strongly agreed or agreed that the personalised learning materials that were generated by the DAELMS were appropriate to their knowledge level, while more than 14% did not have an opinion either way. Only 10% of the students disclosed that they disagreed that the materials reflected their knowledge level. A possible explanation is a large proportion of these learners were those with prior knowledge of programming.

Questions 16 attempted to examine the suitability of the personalised materials recommended by the DAELMS in terms of the participant's learning style. As can be observed in Figure 11.6, more than 80% of learners strongly agreed or agreed that, overall, they benefited from the personalised materials that were presented by the DAELMS and that they were satisfied with the quality of them. A total of 14% of those questioned indicated that they had no strong opinion of the suitability of the learning materials, while 4% of learners were not happy with the suitability of the personalised materials. In general, the majority of students perceived the learning content that was presented by the DAELMS to be suitable, while a minority of learners did not.

11.3.1.5 Recommendations Presented by DAELMS

Questions 17 and 18 were related to the peer recommendations generated by the system. Some learning styles, such as active learners, prefer to discuss their thoughts with other people. The results of the questionnaire, as presented in Figure 11.7, reveal that more than 85% of the students strongly agreed or agreed that the peer recommendations generated by the system were useful. Furthermore, the peer recommendation and the collaborative tools aspects of the system received positive feedback in the open comments section.

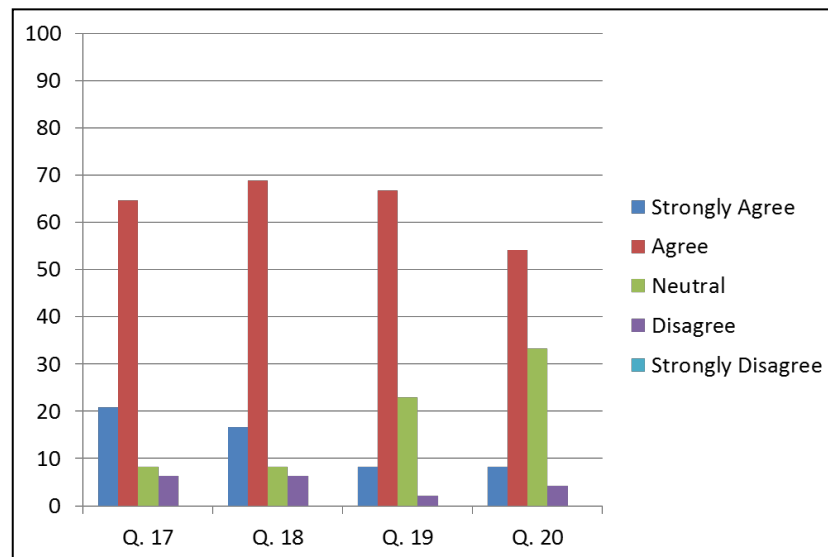


Figure 11.7 Learners' opinion regarding peer and ATs recommendations

Question 19 was related to the assistive technologies recommendation and was designed to investigate whether these helped the learners to overcome their difficulties. As can be seen in Figure 11.7, 75% of learners strongly agreed or agreed that the assistive technologies incorporated in the DAELMS system helped them to overcome their difficulties, while less than 2% of learners did not agree and other learners did not have a strong opinion either way. According to the answers provided to Question 20, learners liked the overall idea of assistive technology being recommended to them in order to remediate their dyslexia type (62% positive, 33% neutral and 4% negative). The results for this question were interesting in so far as there were more "neutral" responses to this question than there were to any other question. This was due to the fact that the question asked the student if the ATs match their dyslexia type or not; however, the version of the DAELMS system tested incorporated only two ATs: one for reading difficulties and one for writing difficulties.

11.3.1.6 Learner's interest

The questions that featured on the questionnaire in this category were designed to assess the extent to which the learners were keen to work with the adaptive system. They were also set as a means of determining the extent to which adaptive learning can effectively increase student's motivation to learn. Figure 11.8 presents a visual representation of the participants' responses to these questions.

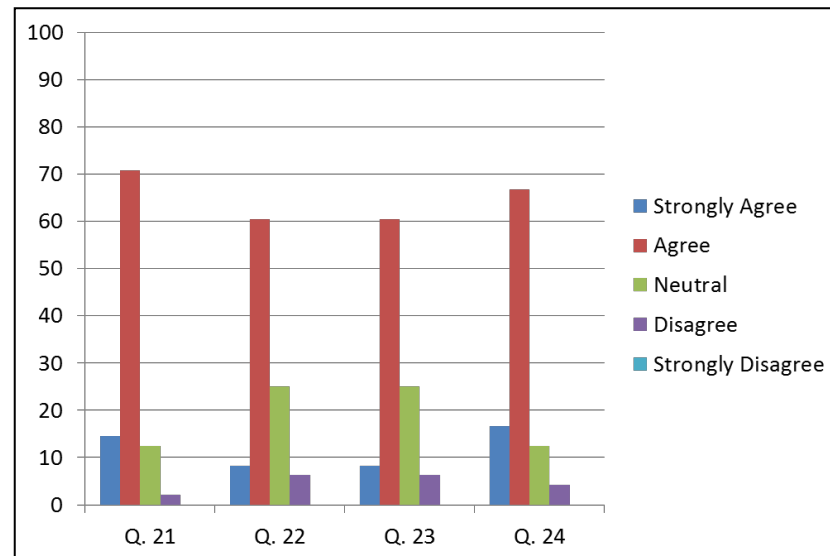


Figure 11.8 The effect of adaptive system in promoting learners interest

Firstly, the respondents were asked to specify the extent to which they believed the system was user friendly and easy to use. As the results presented in Figure 11.8 indicate, more than 85% of the students involved in the research responded positively. In Questions 22 and 23, the learners were asked to specify the extent to which they agreed with the statement that the adaptive system promoted their engagement in learning. The results revealed that more than 68% of the learners questioned strongly agreed or agreed with the statement, while only 6% of them did not. The remaining students had no opinion either way. In the open comment sections, many of the students complained that they were required to complete too many tests to determine their dyslexia type or learning style. This will be taken into consideration in the development of future versions of the system, and later iterations will incorporate functionality that will facilitate the automatic detection of a student's learning style (see Section 12.5). In Question 24, the participants were asked to specify the extent to which they agreed with a statement that they would recommend the DAELMS adaptive system to their friends. More than 83% of the learners questioned either strongly agreed or agreed with the statement, and none of the participants disagreed with it.

11.3.1.7 The main findings

The questionnaire results revealed some interesting findings relating to the learners' opinions and experiences of using the DAELMS adaptive learning system. First, the vast majority of learners who participated in the evaluation were satisfied with all aspects of personalised learning; in particular, the peer recommendation functionality and the personalised learning materials. This can be observed in Figure 11.9, which presents a visualisation of the responses the students provided to the questionnaire.

The findings also revealed that adaptive learning was more beneficial for beginner learners who had a lower ability and less experience than it was for expert learners. This could be attributed to the fact that the beginner learners benefited from the prescriptive learning experience, while the expert learners had more existing knowledge and understanding of the subject (e.g. programming) and, therefore, wished to have more control over their learning experience.

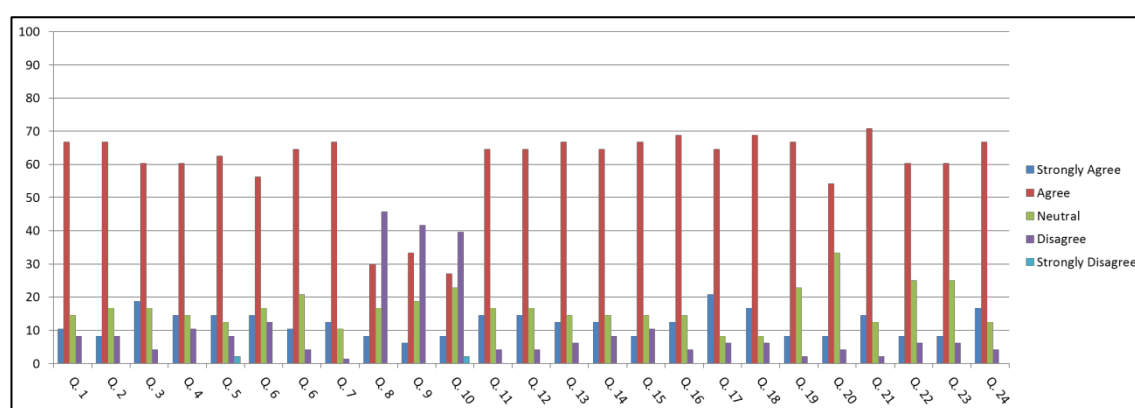


Figure 11.9 Summary of learners' evaluation

The peer recommendation functionality of the system promotes a process of collaborative learning between students. As a result of the increased popularity of Web 2.0 applications, students increasingly like to share and discuss their ideas with their peers, and many learners use social technologies on a regular basis to facilitate their personal communications and to access the information they need. Teachers and instructional designers need to be aware of the potential that Web 2.0 technologies hold for enhancing teaching and learning experiences. Furthermore, the use of functionalities that provide students with an opportunity to discuss their ideas and findings with students who have the same learning style can enhance their knowledge and understanding and improve their perceptions of a learning experience.

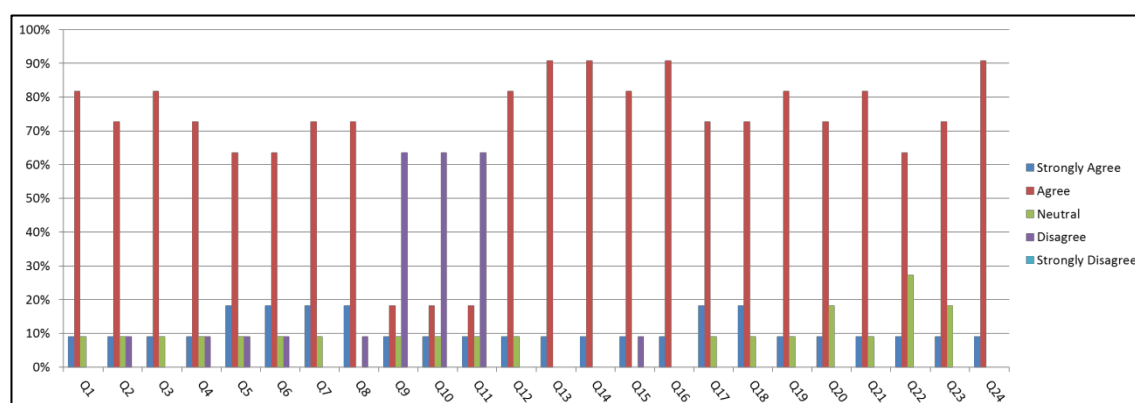


Figure 11.10 Summary of dyslexic learners' evaluation

Figure 11.9 presents the responses provided to each of the questions in the questionnaire by all the experiment participants, while Figure 11.10 shows the responses provided by the 11 participants who have previously been diagnosed with dyslexia. As Figure 11.10 shows, Question 13, 14 and 16, all of which relate specifically to the effectiveness of the learning materials, had the highest response from the dyslexic learners in terms of agreement that those aspects were beneficial. More than 90% of the dyslexic learners agreed with the statement that the learning content presented in the DAELMS was aligned with their learning style and subsequently enhanced their learning experience. Question 19 addressed the assistive technologies in particular, and more of than 80% of the learners with dyslexia agreed with the statement *"The recommended assistive technologies by the system makes my learning more effective"*. Furthermore, more than 80% of the dyslexic learners involved in the experiment

specified that they preferred the adaptive system to the non-adaptive system. This finding supports the main claim of this thesis, which is that if an e-learning system presents material that is adapted to the learning style of the students with dyslexia, it will enhance their learning experience.

11.3.2 Learner performance

One of the most important tasks associated with the evaluation of any educational system involves assessing how much the learners have learned from the topics they have been introduced to in the system. To prove the effectiveness of the proposed system, it is necessary to prove that the learners who interacted with it gained new knowledge as a result of doing so. Therefore, in this subsection, we consider the results of the pre- and post-tests over the period of this experiment as a means of assessing the effectiveness of the system. To generate accurate and reliable data, the Knowledge Gain (KG) scores were calculated using a method proposed by Hovland et al., 1949. The KG scores were determined by calculating the difference between a learner's pre- and post-test score (Equation 11.1) was used to calculate the adjusted knowledge gain. This equation omits any negative values because these were considered to represent invalid data.

Equation 11.1 Knowledge Gain

$$KG = \text{Max}(0, \text{Score}_{\text{post-test}} - \text{Score}_{\text{pre-test}})$$

The following subsections present an overview of the effectiveness of the DAELMS in terms of different aspects of the students' learning.

11.3.2.1 General learning effect

Hypothesis H2: *The post-tests scores are significantly greater than the pre-test scores for the adaptive system (DAELMS) across all groups.*

Table 11.2 and Table 11.3 present the mean and standard deviation of the pre-test, post-test, and the associated knowledge gain for the students who completed the revision exercise on the adaptive system (DAELMS) and the non-adaptive system (Moodle).

Table 11.2 Test and Knowledge gain results (Course 1)

Group	Pre-test Score		Post-test Score		KG	
	Mean	Std. Deviation	Mean	Std. Deviation	Mean	Std. Deviation
A (DAELMS)	60.83	14.11	64.58	12.41	3.75	2.21
B (Moodle)	60.54	18.32	62.62	19.29	3.12	2.47

Table 11.3 Test and Knowledge gain results (Course 2)

Group	Pre-test Score		Post-test Score		KG	
	Mean	Std. Deviation	Mean	Std. Deviation	Mean	Std. Deviation
A (Moodle)	47.83	14.09	49.66	13.67	3.00	1.86
B (DAELMS)	47.00	15.44	53.75	12.00	7.50	3.29

Having studied Course 1 "Fundamentals of Computation" (the easy learning material) on the DAELMS, Group A obtained a slightly higher KG than the students in Group B, who studied the materials on the non-adaptive system, Moodle (see Table 11.2). While, once the learning material became more complex in Course 2, "Introduction to programming in Java," the students in Group B, who studied the material on the DAELMS, obtained a significantly higher knowledge

gain than the students in Group A, who studied the material on the non-adaptive system, Moodle (see Table 11.3).

As a means of verifying that the adaptive system actually increased the students' ability to learn the materials, a pair-wise comparison of the pre- and post-test scores was performed (per group, per course). Table 11.4 presents a summary of the results of the four paired samples t-tests for Groups A and B for the two courses. According to the pre- and post-test scores for Course 1, the scores of both groups of participants increased significantly (the result of the post-tests were significantly higher than the result of pre-tests). However, the students in Group A, who worked with the adaptive system, showed more progress than those in Group B, who worked with the non-adaptive system. According to the pre- and post-tests for Course 2, the scores of the students who interacted with the DAELMS (grey cells in the table) indicated significant improvement as a result of their work with the system, while those who had interacted with the non-adaptive system (white cells in the table) showed no improvement (P-value = 0.10 is greater than 0.05).

Table 11.4 The result of the Matched-Pairs T-Tests between Score_{pre-test} and Score_{post-test}

Group	Course 1				Course 2			
	Paired Differences		T	P-value	Paired Differences		T	P-value
	Mean	Std. Deviation			Mean	Std. Deviation		
A	3.75	2.21	8.30	<0.001	1.83	5.27	1.70	0.10
B	2.08	4.40	2.31	<0.05	6.75	6.00	5.50	<0.001

The main difference between Course 1 and 2 related to the complexity of the material. Course 2 employed the knowledge introduced in Course 1 and extended it by introducing more advanced topics, such as the use of Boolean operators in loop and condition statements. The analysis of the students' learning demonstrates that personalised learning systems have a higher impact on a student's ability to learn complex material. This is an important finding because, when learners deal with materials that are more basic, they require less support in the form of adaptive recommendation. They typically enhance their understanding of the topic by practising the exercises and, in most cases, they infrequently require access to supplementary content or personalised learning. On the other hand, when learners are presented with more complex materials, they stand to benefit more from personalisation and adaptation. Similarly, when learners respond incorrectly to exercises, they can benefit from adaptive recommendations that present ideas and avenues through which they can discuss their logic and understanding.

11.3.2.2 Effect on dyslexic students

The analysis of the effect of learning that will be presented in this section was performed in exactly the same way as the analysis described above; however, in this case, it was specifically limited to the dyslexic learners. The correlation between knowledge gain and the pre-test scores of dyslexic learners who used the adaptive and the non-adaptive systems was calculated, and Figure 11.11 presents two scatter plots that depict this correlation. The left-hand plot presents the data collected following the completion of Course 1, while the right-hand plot presents the data collected following completion of Course 2. Both plots show that there was a clear negative correlation between knowledge gain and the pre-test scores. The dyslexic learners who had

lower pre-test scores gained more knowledge as a result of using the adaptive system than those with higher pre-test scores. However, no such correlation was observed in the test scores obtained by those students who used the non-adaptive system. These plots indicate that the dyslexic students benefited more from completing e-learning experiences on the DAELMS than they did from interacting with the non-adaptive system. Table 11.5 presents the statistical data relating to the students who had low pre-test scores in terms of their post-test scores after completing both courses.

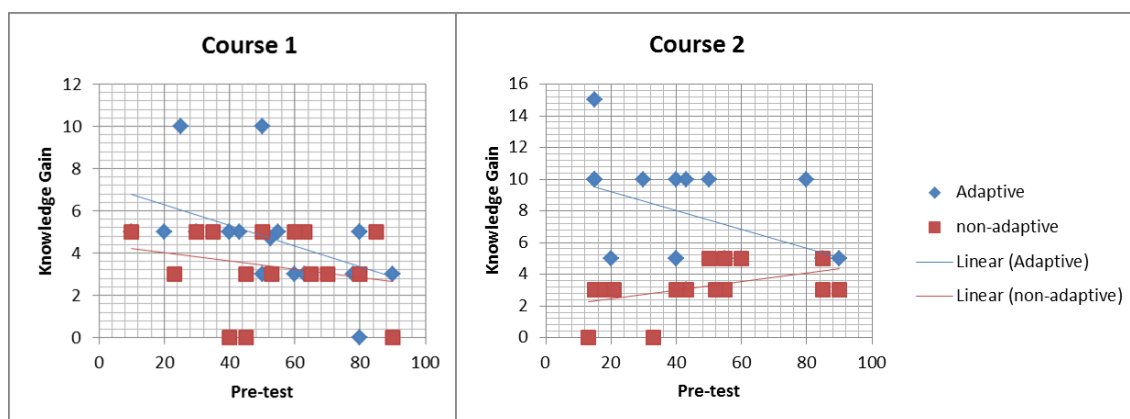


Figure 11.11 Knowledge gain vs. pre-test scores: Left Course 1; Right Course 2

Table 11.5 Statistics about dyslexic students' interaction with two systems

	Course 1		Course 2	
	Adaptive System (DAELMS)	Non-adaptive System (Moodle)	Adaptive System (DAELMS)	Non-adaptive System (Moodle)
Score_{pre-test}	52.58	51.41	43.26	45.29
Score_{post-test}	57.29	53.64	51.11	47.82
KG	4.70	3.41	7.82	3.11

As the results of the analysis outlined in Table 11.5 demonstrate, dyslexic students benefit from interacting with e-learning systems that offer more personalised content and recommendations. They typically experience problems understanding different materials with various difficulty levels. Therefore, personalised content and adaptive recommendations are of particular use to them, especially when they respond incorrectly to an exercise or question. On the other hand, more advanced dyslexic learners benefit less from adaptivity because they already have a good understanding of the materials they read/attempt and, therefore, have less to gain from external input.

11.3.2.3 Overall key findings

Overall, the results of the analysis reveal that the performance of all learners improved more as a result of interacting with the adaptive e-learning system than it did from interacting with the non-adaptive system. This was confirmed by comparing the KG scores of the learners who studied with the adaptive system with those who studied with the non-adaptive system. Learners consistently performed better when using the adaptive system. Such an improvement in learning outcomes can be attributed to a good match between the difficulty level of the content presented, the learners' abilities, and their preferences. It may also be due to the fact

that the learners engaged more with the adaptive system because it helped them to overcome any problems they encountered through presenting appropriate adaptive recommendations. The findings of the analysis revealed that the DAELMS and a semantic ontological approach to e-learning are capable of generating personalised e-learning systems that are effective and appropriate to the needs of the students who interact with them. Furthermore, the results reveal the adaptive system was more beneficial to the non-adaptive system in two situations in particular:

- When employed to teach complex topics: The results of the KG analysis revealed that the students who engaged with the more advanced materials benefited more from the support provided by the adaptive system. When the students were presented with complex material and exercises, they needed more advice and supplementary content to overcome their problems.
- When used by dyslexic learners: The results of the KG analysis indicate that the availability of personalised content and adaptive recommendations was more helpful for weaker dyslexic students than it was for all other learners. This can be attributed to the fact that the DAELMS presented the learners with appropriate materials and recommendations based on their dyslexia type and learning style.

11.4. The analysis of the Relationship between FSLSM and Dyslexia Type

The outputs of the literature review presented in Section (5.3.1) revealed that there is a relationship between learning styles and dyslexia type. The study described in this section was designed to assess the extent to which there is a direct relationship between the four dimensions of the FSLSM and dyslexia type as a means of verifying the relationship identified in the literature review, which was subsequently used to develop the DLSM (see Section 5.3.4). To this end, an experimental study involving 34 students with dyslexia (11 dyslexic and 23 possible dyslexics) was conducted. In order to identify the students' learning styles and dyslexia type, a collaborative student modelling approach was employed via which the students were required to complete the ILS questionnaire (see Appendix B) and a dyslexia assessment test to detect dyslexia type (see Appendix C). This study and the subsequent results are presented in the following two subsections.

11.4.1 Study

For the purposes of the in-depth analysis, the learning style values were divided into three groups: active, balanced, and reflective preference. These groups were based on the recommendations presented by Felder and colleagues (Felder & Silverman, 1988; Felder & Spurlin, 2005) and in line with the need to reduce questions as a means of increasing reliability (see Section 8.5.5). Therefore, values greater or equal to +4 indicate a preference for one pole, those smaller or equal to -4 indicate a preference for the other pole, and values between +3 and -3 indicate a balanced learning style. In order to analyse the relationship between learning style and dyslexia type, only those cases in which the learning style was strong or moderate were

taken into account. The same approach was employed within the dyslexia assessment test; i.e., only the cases in which the student demonstrated severe or moderate dyslexia type were taken into consideration.

11.4.2 Discussion

The purpose of this study was to identify if there were any further indications to support the literature review findings; i.e., that there is a relationship between the four dimensions of FSLSM and dyslexia type. The results obtained within this aspect of the research were promising and further supported the claims made in the literature that there is a relationship between the visual/verbal dimension in particular. The distribution of learning style across the dyslexic learners involved in this research is presented in Figure 11.12.

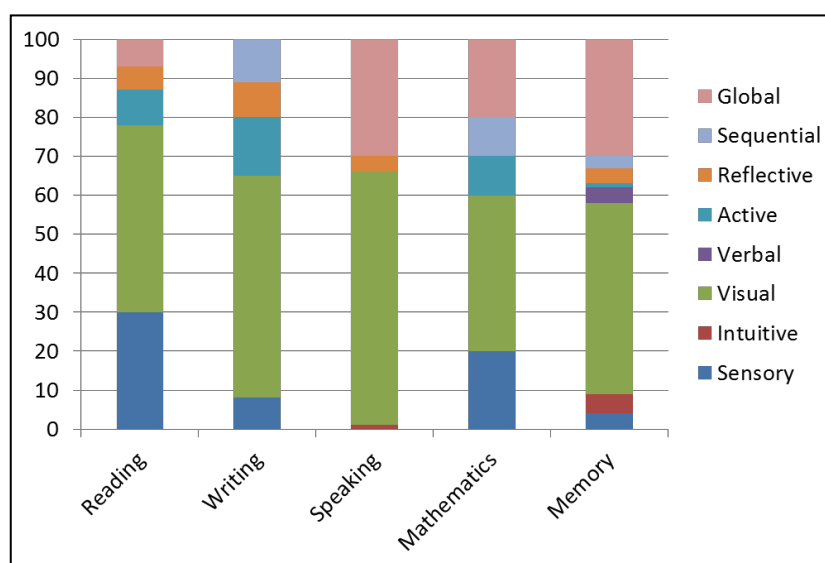


Figure 11.12 Dyslexic learners' learning style data distribution

In terms of the reading dyslexia type, the findings of the literature review presented in Section (5.3.2) revealed that people who have reading dyslexia tend to primarily mentally process information in terms of images and feelings, not sounds or words. The results of the study conducted within this research support the view that there is a strong correlation between visual preference and learners with reading difficulties. This was expected, since a large number of studies, as summarised by Beacham, Szumko and Alty (2003), have found that 97% of dyslexic learners are visual learners and the remaining 3% are located in the mild-verbal range. The results of the current study also found that there is a correlation between dyslexia reading difficulties and sensory learning style.

The results of the current study also revealed that learners who have a writing dyslexia type tend to be visual learners. This in line with the findings of the previous research reviewed in the literature review described in Section (5.3.2). However, according to the relationships between the four dimensions of the FSLSM and dyslexia type described in the literature, learners with writing dyslexia type also prefer a verbal learning style, and this statement was not supported by the results of the current study, which found that none of the learners that had a writing dyslexia type were verbal learners.

According to the DLMS (Section 5.3.4), learners who have a speaking dyslexia type tend to exhibit a visual and reflective learning style. This assumption was supported by the findings of the current study. Moreover, this study demonstrated that 30% of learners who have speaking dyslexia tend to be global learners. This finding is new and, as far as the author is aware, has not been discussed in previous research in this domain.

In terms of memory dyslexia type, this study found that there was a correlation between memory dyslexia type and visual learning style. However, there was no evidence to support the view that learners with memory dyslexia type prefer sequential learning style. In fact, on the contrary, the results of this study revealed that such students tended to prefer a global learning style.

The results obtained during this study indicated that students with mathematics dyslexia prefer a visual learning style. This is in agreement with the findings of existing research in this area. However, there was insufficient evidence to support the claims made in the literature that learners with mathematics dyslexia prefer a sequential and sensory learning style.

11.5. Chapter Eleven Summary

This chapter presented the overall results of the experiment through which a variety of students interacted with the DAELMS system. Following the introduction presented in Section (11.1), the methodology and the process of evaluation were described. Section (11.3) then described the outputs of the questionnaire, which evaluated the learners' level of satisfaction with the adaptive system and the impact that interacting with the system had on their learning process. The results of this evaluation revealed that the learners were satisfied with their experiences using the DAELMS. Furthermore, their learning outcomes significantly improved as a result of working with the adaptive system. The findings also revealed that the learners' knowledge gain significantly improved when using the DAELMS to learn more complex material and that the dyslexic students who interacted with the adaptive e-learning system benefited the most from using this system.

The outcomes of the last two sections reveal that the majority of dyslexic learners are visual learners. These findings are in agreement with the findings of the literature review presented in Section (5.3.1). The following chapter will discuss the conclusion and the limitations of the research approach, and will present recommendations for future work in this area.

Chapter 12 Conclusions and Future Work

12.1. Introduction

The majority of existing research in this domain has involved children, and very limited data was available that focussed on adults, especially those studying at a degree level in higher education. Prior to this project, I had very limited experience of working with people with dyslexia; however, I could see the potential that lay in this field. I was particularly interested in how dyslexia does not typically manifest itself in the obvious signs that one would typically associate with a disability; for example, those exhibited by people with down syndrome or other severe learning difficulties. To all intents and purposes, dyslexia is a hidden disability that can cause learners significant frustration and disappointment if not properly assessed and understood.

This study was designed to gain insights into the experiences of a group of dyslexic students who are studying in higher education, to understand their perspectives and to identify the difficulties they encounter, if any, as a result of their dyslexia. By taking into account student's perspectives, this study developed a view of the typical challenges university students with dyslexia encounter.

This study highlights the key areas that should be investigated in relation to the ongoing debate over the definition of dyslexia. As highlighted, numerous definitions and theories of dyslexia and its associated symptoms exist, and there is a requirement for clearer guidelines as to how an institutional approach to dyslexia can be developed.

This thesis presented a novel approach by which a personalised learning experience can be developed for students with dyslexia in accordance with their dyslexia type and learning style. This chapter summarises the work conducted within this thesis. It revisits the objectives of the thesis and examines the extent to which these objectives were achieved. Following that, it outlines the contributions that this research can make to the field of technology-inspired learning. The chapter progresses to discuss the limitations of this study, before concluding with a discussion on how the key learnings can be applied within future research work.

12.2. Answering the Research Questions

This section revisits the main research questions (Section 1.4.2) that underpinned this study and examines the extent to which they were answered.

Research question one (RQ1): In comparison to traditional e-learning systems, do dyslexic students exhibit any significant differences in their learning outcomes when engaging with an adaptive e-learning system?

This research question was at the heart of the study methodology. The researcher highlighted the main challenges that students with dyslexia typically encounter when engaging with traditional e-learning systems. This research discussed how the use of synchronised activities, such as online chat, could represent a significant disadvantage for students with dyslexia due to their reading, spelling and writing difficulties. This research also described how one of the main

reasons as to why e-learning applications may not be as effective for dyslexic students as they are for standard learners can be attributed to the fact that technology developers have not incorporated a consideration of the different types of dyslexia in system design. The majority of the technologies that are available are very generic, and they do not incorporate functionality that adapts learning experiences according to the true needs of the user. The first three chapters of this thesis examined how existing literature in this domain highlights the main challenges that dyslexic students encounter when using non-adaptive e-learning systems. Chapter 9 and Chapter 10 subsequently presented the Dyslexia Adaptive E-Learning Management System (DAELMS), and Chapter 11 described how there is a significant difference between the proposed adaptive e-learning system (DAELMS) that was used by the experimental group and the traditional e-learning system (Moodle) that was used by the control group. Section (11.3.2) in Chapter 11 provided a detailed overview of how the performance of the dyslexic learners increased as a result of interacting with the adaptive system (DAELMS).

Research question two (RQ2): From the point of view of students with dyslexia, what key elements will an e-learning system need to offer in order to be sufficiently adaptive?

Chapter 6 presented a comprehensive overview of the adaptive e-learning domain and proposed a series of generic design principles that should be taken into consideration during the development of computer systems for dyslexic users. The results of this investigation were developed into a framework entitled the Dyslexia Adaptive E-Learning (DAEL) framework, which provided a clear and focused set of design requirements that should steer the development of e-learning technologies that are designed to assist dyslexic learners. A key element of the research involved taking dyslexic learners' point of view into consideration and, to achieve this, the DAEL framework was evaluated by 111 dyslexic participants. The results of the evaluation indicated the features of an adaptive system that were most important from the perspective of students with dyslexia were a personalised system interface, the ability to support different assistive technologies, and a consideration of the disability type of the user. The methodology by which the evaluation was conducted and the outputs of the review were described in Chapter 7.

Research question three (RQ3): What is dyslexia? How is it manifest? What learning difficulties do students with dyslexia typically encounter?

This question was addressed in the early stages of the research. To create an adaptive learning system that can cater to the needs of a specific group of people, it is first imperative that you have a solid understanding of the needs and preferences of that group. Chapter 2 presented an overview of the definition, theory, classification, signs and learning styles associated with dyslexia. The results of this investigation led to the development of three research models. These formed the basis for the development of the theoretical requirements for providing adaptive, personalised learning experiences (see Chapter 4).

Research question four (RQ4): How can systems that offer more personalised and flexible learning experiences based on dyslexia types and learning styles be utilised to enhance the learning outcomes of dyslexic students?

Chapter 8 described the design of the Ontology for Dyslexia Adaptive E-Learning (ODAEL) approach, which was developed to specifically address the limitations of the traditional e-learning systems by achieving the user requirements that were identified during the process of the research. The proposed ontological modelling incorporated a clear separation of adaptivity components. The fundamental aim of this novel approach was to improve the flexibility, extensibility and reusability of existing learning systems, while offering pedagogically effective and satisfactory learning experiences for dyslexic learners. The proposed ontological approach facilitates the development of adaptive e-learning systems (DAELMS) (Chapter 9 and Chapter 10) that support different adaptation techniques, concept sequencing and domain of knowledge without having an impact on the existing adaptive engine implementation. Chapter 11 presented an evaluation of the system, and found that it could effectively present the user with learning materials that were aligned with their learning style or dyslexia type and, when it did so, it enhanced learning outcomes.

The next section presents a detailed overview of the contribution of this research.

12.3. Contribution to Knowledge

It is anticipated that this research will be of significant value to researchers who have an interest in dyslexia, learning styles and adaptive e-learning systems that are based on an ontological approach. When developing the DAELMS, it is imperative that the developer recognises that each dyslexic user represents a unique individual who has very specific and distinctive learning needs. However, before commencing development activity, it is first important to develop in-depth insights into the nature and manifestations of dyslexia. Such an understanding will allow the developer to ensure that the functionality and adaptability of the system maximises its benefit to dyslexic students. In Section (5.2.1) we proposed a **Dyslexia Symptoms and Classification Model (DSCM)** that was developed through a comprehensive analysis of the conditions and symptom characteristics of different types of dyslexia. The DSCM forms the basis of the understanding of dyslexia that was employed in this thesis and represents the foundation upon which the Dyslexia Type ontology was created (Section 8.5.4). In addition, in Section (5.2.2) the researcher forms the **Dyslexia Assistive Technologies Model (DATs)** which identifies the types of assistive technologies that can be employed to facilitate the learning experiences of dyslexic students in accordance to their dyslexia type and classification as defined by the DSCM (Section 5.2.2). A combination of the information gained through the development of DSCM subsequently facilitated the acquisition of information that could be employed to associate each dyslexia type identified in the DSCM described in Section (5.2.1) with the learning style dimensions of the FSLSM model presented in Section (2.7.4.3). This resulted in the development of the **Dyslexia and Learning Style Model (DLSM)** (Section 5.3), in which each dyslexic type was mapped with the associated preferred learning styles to deliver a personalised learning experience for dyslexic learners based on his/her learning style.

Chapter 6 describes the technical requirements that were collected for the DAELMS. These requirements contributed to the development of the **Dyslexia Adaptive E-Learning (DAEL)** framework. The DAEL is a generic framework that can be readily applied to develop adaptive e-

learning systems that cater to any type of disabilities. In Chapter 7, the framework was validated from the perspective of students with dyslexia. The DAEL framework was subsequently employed as a reference by which the DAELMS was developed. As such, using a specific ontology to represent each component of adaptivity makes it possible to separate the adaptivity components, thus facilitating the development of e-learning systems that are flexible and extensible and that incorporate adaptation components that can be reused. Integrating these discrete adaptation components at runtime delivers flexible, personalised learning experiences. Furthermore, through the use of logic rules and adaption algorithms to facilitate the flexibility and extensibility of the system in implementing different adaptive effects, it becomes possible to enhance the extent to which the adaptation rules are reusable and modifiable. As such, developers and designers can readily enhance or alter the adaptation techniques employed within given courses of study without having any major impact on the overall system. Logic rules also represent a transparent map of the underlying functionalities behind the system and provide sufficient flexibility such that instructional designers can quickly and easily modify the adaptation rules. Chapter 8 described the process by which the **Ontology for Dyslexia Adaptive E-Learning (ODAEL)** was designed to overcome the limitations of the existing e-learning systems that were surveyed as part of this research to achieve both the properties and technical requirements described above.

This extensive research will culminate in the design of a fully adaptive e-learning application **Dyslexia Adaptive E-Learning Management System (DAELMS)** that delivers personalised learning materials that are aligned with an individual's preferred learning style and the type of dyslexia they have. DAELMS offers **Adaptation** features (Section 10.4), which are primarily defined in according to the content of the learning experience and the characteristics of the users. Each user has his or her own profile, and this profile contains key data relating to important characteristics, such as learning style and the matching dyslexia type, that are represented by a set of attributes. Likewise, there is a set of attributes available that relate specifically to content; for example, knowledge level, learning style, etc. As such, Adaptation approaches match the user to content attributes. A further key feature of Adaptation is that it can be applied to a group of users who share similar profiles in such a manner that it adjusts content according to a group of users as opposed to an individual user. The adaption occurs at the levels of course structure, course content, navigation, and communication tools.

The additional areas in which the research can make a meaningful contribution are outlined below:

- **Authoring Tools:** While there are tools in existence that allow the creation of learning objects, very few facilitate the creation of personalised courses. The ontology-based adaptive e-learning system that was proposed in this research enables authors to reuse the existing components of adaptivity to create new adaptive learning experiences without the need to learn or use any code. The authoring tool of DAELMS facilitates the ability to distinguish between two different learning styles by incorporating the possibility for teachers and course developers

to use metadata to provide key information about the learning material created. When developing content that is specifically targeted at visual or verbal learning styles, teachers and course developers will be provided with a simple checkbox that allows them to quickly and easily specify whether the learning objects should be visual or verbal (Section 10.4.7)

- **Collaborated learning:** involves fostering collaborative communication between students to enable the achievement of common objectives. Adaptive collaborated learning represents a meaningful and productive means of supporting individual learning. The DAELMS supports collaborative learning through facilitating peer recommendation and group discussion. These basic facilities guide students through the learning process, be it individual or collaborative. Furthermore, in the case of collaborative learning, they encourage learners to interact with one another by encouraging them to share opinions, explain the approach they used and the reasoning they applied during the process, and to share details of what they have learned. This, in turn, helps students to remediate their difficulties and work around their weaknesses. Particularly “active” learners learn better, when performing group works and engaging in discussions (Section 10.4.6).

The next section will critically analyse the system that was developed.

12.4. Reflection and Critical Analysis

One of the main objectives of this thesis was to develop an adaptive and personalised e-learning system that overcame the existing interoperability issues and lack of social interaction and collaboration that are associated with e-learning systems. This section describes some of the ways in which the research was limited.

One of the biggest challenges that was encountered during the process of the research concerned the identification of people with dyslexia who could participate in the evaluation of the system. Although many dyslexia centres and universities both in and outside the UK were contacted, there was a distinct lack of satisfactory responses. One of the dyslexic students who was interviewed during the study revealed that he had not known he was dyslexic until he had commenced his postgraduate study, at which point one of his tutors noticed there was an issue. He was later diagnosed as having severe reading dyslexia. He was very lucky that his tutor was able to spot the symptoms of dyslexia. To ensure an adequate understanding of the participants of the research, they were requested to complete a dyslexia assessment test following registration. As dyslexia is a disability that may not be readily observable, this was important, because it provided an opportunity for the participants’ specific strengths and weaknesses to be identified. It is important to note that, as was the case with the student described above, a dyslexic participant is an individual who displays the symptoms and difficulties that are typically associated with dyslexia; however, this does not necessarily mean that the participant has been explicitly assessed by an educational psychologist as dyslexic. This could be considered to represent a limitation of the study.

A further limitation of this thesis concerned the fact that the number of people who participated in the study was very low and the demographic was restricted. All of the participants were students and mostly consisted of individuals who were studying Information Systems or Computer Science at the university level. Although university students represent one of the target groups of users for the adaptive e-learning system and were, therefore, highly relevant as test subjects, it would have been useful to compare the results with those resulting from further research with non-university students as test persons, or with university students who were completing different majors.

In addition to the limitations described above, the system evaluation aspect of the research was also limited. In an ideal world, the DAELMS system would be tested over a longer duration, perhaps a full term, and with more material. Even though the system usability questionnaires provided useful information on the use of DAELMS, the results focussed on short-term use of the system and it would have been interesting to evaluate the long-term effects of working with it.

Another aspect that could be considered to represent a limitation of this research was the fact that it randomly selected a learning style (Section 10.4.3). This did not cater for the fact that students typically demonstrate more than one learning style and was problematic for three reasons. First, incorporating consideration of more than one learning style would have further enhanced and personalised the learning experience. Second, considering just one learning style prevented the identification of similarities and differences between the characteristics the learners exhibited when interacting with more than one model. Third, by selecting the strongest learning style or a random learning style and dismissing the others, the system did not mix learning styles, which may have further enhanced the learning experience.

One of the key attributes of the DAELM framework is the ability to support multiple languages. However, the DAELMS developed in this study was available in only one language: English. Supporting additional languages, such as Arabic or Spanish, will increase the adaptivity of the system and, therefore, improve the students' learning experiences.

Finally, the DAELMS did not fully implement the *Assistive Technologies* ontology. Instead, just two types of the assistive technologies for dyslexic students were employed (See Table 3.1) and both of these were aimed at the writing and reading dyslexia type (Section 10.4.8), which is the most common dyslexia types (see Figure 5.1).

Despite the limitations outlined above, the student evaluation revealed that the users were really satisfied with the inclusion of assistive technologies in the system. In future, the research could include more assistive technologies that aid students with dyslexia with their learning process.

The next section will discuss the future direction of this thesis.

12.5. Future Research

The findings and prototypes developed in this thesis can form the basis for further research studies that focus on the development of advanced adaptivity systems for students with dyslexia. Future research can take a number of directions. For example, it can concentrate on extending the different parts of research conducted within this thesis or, alternatively, can

combine the key elements of this research with additional components. The possible future directions for the research will be discussed in more detail in the following paragraphs.

Future work in this area could focus on developing mechanisms by which the learning styles of dyslexic learners can be automatically detected and the functionality adapted accordingly. A dynamic student modelling approach could be employed to evaluate students' behaviour and performance on an ongoing basis and offer appropriate support when required. By seeking student feedback as to whether the system and learning material should be adapted and/or by offering them choices as to how the course content can be adapted in accordance with their learning styles, the system can access further information and feedback that will can be incrementally employed to enhance later adaptation and improve the reliability of the student model. This will create courses that continually improve to better meet student needs.

An additional avenue that is worth exploring in future work is methods of incorporating key information about the relationships between learning styles and dyslexia type into the method by which a user's learning style is detected and the effectiveness of the additional information is evaluated. Furthermore, additional dyslexia types, such as defective visual processing, motor control problems and defective sequence recollection, should be investigated with respect to improving the adaptivity of the system.

Future work should also focus more strongly on assessing the basic concept of adaptivity. For example, investigations can be performed that assess which adaptation features are generally more effective than others, and whether there are learning styles that can be supported in a more effective manner by the proposed concept than others.

In the future, it would also be useful to consider methods by which DAELMS can be integrated with existing Web 2.0 infrastructures; for example, to allow users to interact with their friends' social networks as well as facilitating communication between users. APIs may represent one important technology that will facilitate such as solution. Another potential advantage of harnessing the power of Web 2.0 and its associated characteristics (e.g., tagging, voting, commenting, and user-generated content) would be that it would further enhance the adaptive and personalised e-learning services that are delivered to students. Incorporating additional functionality such as collaborative authoring (editing the content developed of other users, describing content using tags, rating, commenting on the content, etc.) would further allow users to have an influence on the content that is recommended.

The personalised navigation annotated course structure can also be potentially improved. In the current study, different colours were employed to annotate the course structure on the personalised navigation bar. However, future studies could investigate the use of alternative visual clues, such as different icons, font sizes and special characters, to clarify the educational status of the content behind the links.

In addition to the recommendations provided above concerning how the system can potentially be improved, the ultimate objective of future studies should be to engage in the long-term evaluation of the proposed approach by implementing it in different educational environments.

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Appendix A. Peer Reviewed Publications and Contributions

This appendix includes details of refereed publications which relate to the research presented in this thesis. The publications are listed at the beginning of the thesis and a copy of the first page of each paper is attached below.

[Images of first pages removed due to copyright issues (copyright held by publishers)]

An Attempt to Link Dyslexia Types and Symptoms to the Current Assistive Learning Technologies



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Introduction

Technologies have a tremendous impact on education today. As a result of the widespread, and accelerating, dissemination of digital technologies, there has been a profound effect on how people learn. These effects have been greatly debated over the years. While many educational developers have agreed on the effects technologies have brought on educational performance, little attention has been made to the relationship between such technologies effects and individual differences such as individuals who suffer dyslexia. There are readily available Assistive Technologies that offer potential to help students with learning difficulties such as dyslexia. This paper will attempt to tease out these technologies and dyslexia types, hence attempt at providing a solution. **The focus should not be on correlating one technology to one disability. Instead of identifying different pedagogical needs such as help with reading and writing. Then, trying to meet those needs by looking at the whole range of ways that available.** "Assistive Technology" refers only to hardware and software designed to facilitate the use of computers by people with impairments.

Dyslexia Definition

Many authors over the years have made attempts at defining dyslexia. Up till now, researchers have still not agreed on a definition for dyslexia, probably the variation of the definition due to the variation of the scientific backgrounds of the individual researchers and what they conceptualise as the fundamental cause of dyslexia [2]. Many definitions and perspectives have been expressed in turn to describe dyslexia, from the time when the concept of dyslexia was first introduced in the academic and medical world. Various perspectives in which dyslexia is defined are acknowledged. However, for the purpose of this research, dyslexia will be defined mainly from educational point of view. Therefore, the main definition of dyslexia that will be considered in this paper is the definition by the British Dyslexia Association (BDA):

"The word 'dyslexia' comes from the Greek. The prefix 'dys' means difficulty, and the root-word 'lexia' means language. The literal translation is 'difficulty with words. It is a difference in the brain area that deals with language. It affects the underlying skills that are needed for learning to read, write and spell. Brain imaging techniques show that dyslexic people process information differently. Dyslexic people, of all ages, can learn effectively but often need a different approach" [3].

Dyslexia Classification

There are various types of dyslexia. It is hard to categorise specific dyslexia as a single condition. There have been various attempts in the literature at classifying dyslexia. Classifying dyslexia helps to provide more insight into what dyslexia difficulties are. Therefore, provide a proper solution for them. We consider Ingram [1] classification as we highly acknowledge other classification and arguments. Dyslexia can be divided into three categories [1]:

Visuo-Spatial

Persons with **visuo-spatial** difficulties cannot recognize groups of letters. People with this form of dyslexia may also confuse reversible letters, transpose letters in syllables and syllables in words and words in phrases. They may also read words backwards.

Speech Sound

Persons with **speech sound** difficulties have problems in understanding spoken language. Difficulty arises in breaking words into syllables and in forming sentences.

Correlating

Person who have problems **correlating** are unable to find the appropriate speech sounds for individual letter or sounds in writing (this is seen more commonly with monosyllabic words)

Dyslexia Signs and Symptoms

Since types of difficulties and needs of student with dyslexia may vary from one student to another and it is nearly impossible to make generalisations when designing the module material prior to the start of the learning period, teachers and module developers must deal with each dyslexic student as an individual case. Therefore, there is a plenty of possible problems that characterise dyslexic people in the literature such as [3; 4; 5]. This can be divided into six areas of difficulties, which are **Reading, Writing, Speaking, Memory, Organisational, and Mathematics.**

Findings

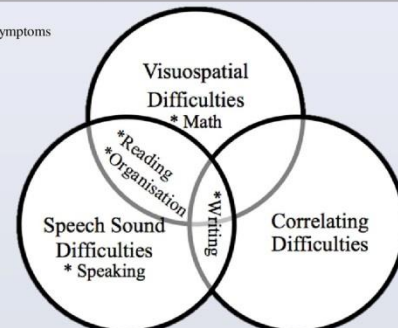
After studying the above type and symptoms we draw our conclusion.

Visuo-spatial symptoms = reading + writing + organisation + mathematics.

Speech sound symptoms = reading + writing + organisation + speaking.

Correlating symptom = Writing

* Dyslexia Symptoms



After conducting an extensive study concerning the available assistive technologies in the respective domain, Table 1. Shows 17 technologies, which have been developed for helping dyslexic students in their educational process. Each dyslexia symptoms has been match to group of technologies.

Assistive Technologies for Dyslexic Students						
Text to Speech Readers		Reading			Reading Pens	
		Optical Character Recognition				
Typing Programs	Word Prediction Software	Digital Record	Voice Recognition Software	Electronic Dictionaries	Speech-to-text	
Organisation						
Personal Organisation						
Map-reading software						
Speech recognition programs			Spelling		Voice Recording Programs	
Mathematics						
Communication Programs		Screen Magnifiers		Screen Readers for Mathematics		

In order to link dyslexia types and symptoms to the readily assistive technology in more precise yet compact way, a decision table has been developed. According to Reference [1] dyslexia has three different categories, which are here the conditions for the decision table. The alternatives for these conditions are simple Boolean values (Y/N). We have 3 conditions so $2^3=8$ different alternatives. TABLE. 1. Shows 17 different assistive technologies considered as the actions for the decision table. Whereas, the action entries are check marks, representing which of the actions in a given column are to be performed. TABLE 2. below illustrates the decision table:

Dyslexia Type	Action	Conditions							
		Visuospatial Difficulties	Speech Sound Difficulties	Correlating Difficulties	Reading	Writing	Speaking	Mathematics	Organisation
Assistive Technologies	Text to Speech Readers	Y	Y	Y	Y	Y	Y	Y	Y
	Optical Character Recognition	Y	Y	Y	Y	Y	Y	Y	Y
	Reading Pens	Y	Y	Y	Y	Y	Y	Y	Y
	Typing Programs	Y	Y	Y	Y	Y	Y	Y	Y
	Word Prediction Software	Y	Y	Y	Y	Y	Y	Y	Y
	Digital Record	Y	Y	Y	Y	Y	Y	Y	Y
	Voice Recognition Software	Y	Y	Y	Y	Y	Y	Y	Y
	Electronic Dictionaries	Y	Y	Y	Y	Y	Y	Y	Y
	Speech-to-text	Y	Y	Y	Y	Y	Y	Y	Y
	Personal Organisation	Y	Y	Y	Y	Y	Y	Y	Y
	Map-reading software	Y	Y	Y	Y	Y	Y	Y	Y
	Navigation Programs	Y	Y	Y	Y	Y	Y	Y	Y
	Speech recognition programs	Y	Y	Y	Y	Y	Y	Y	Y
	Mathematics	Y	Y	Y	Y	Y	Y	Y	Y
	Voice Recording Programs	Y	Y	Y	Y	Y	Y	Y	Y
	Map-reading software	Y	Y	Y	Y	Y	Y	Y	Y
	Navigation Programs	Y	Y	Y	Y	Y	Y	Y	Y

Conclusion

This will help e-learning developers before making any plan or design. This will establish the functional or technical requirements the design must meet, considering the needs and constraints imposed by students with dyslexia, policies and the environment.

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Appendix B. Index of Learning Style

For each of the questions below, select either "a" or "b" to indicate your answer. Please choose only one answer for each question. If both "a" and "b" seem to apply to you, choose the one that applies more frequently. When you are finished selecting answers to each question please select the submit button at the end of the form.

Active / Reflective

1. I understand something better after I
 - (a) try it out (active).
 - (b) think it through. (reflective)
2. I would rather first
 - (a) try things out. (active)
 - (b) think about how I'm going to do it. (reflective)
3. When I start a homework problem, I am more likely to
 - (a) start working on the solution immediately. (active)
 - (b) try to fully understand the problem first. (reflective)
4. When I have to work on a group project, I first want to
 - (a) have "group brainstorming" where everyone contributes ideas. (active)
 - (b) brainstorm individually and then come together as a group to compare ideas. (reflective)
5. When I am learning something new, it helps me to
 - (a) talk about it (active).
 - (b) think about it. (reflective)
6. In a study group working on difficult material, I am more likely to
 - (a) jump in and contribute ideas. (active)
 - (b) sit back and listen. (reflective)

Sensory / Intuitive

1. I would rather be considered
 - (a) realistic. (sensory)
 - (b) innovative. (intuitive)
2. If I were a teacher, I would rather teach a course
 - (a) that deals with facts and real life situations. (sensory)
 - (b) that deals with ideas and theories. (intuitive)
3. I find it easier
 - (a) to learn facts. (sensory)
 - (b) to learn concepts. (intuitive)
4. I prefer the idea of
 - (a) certainty. (sensory)
 - (b) theory. (intuitive)
5. I prefer courses that emphasize
 - (a) concrete material (facts, data). (sensory)
 - (b) abstract material (concepts, theories). (intuitive)
6. I am more likely to be considered
 - (a) careful about the details of my work. (sensory)
 - (b) creative about how to do my work. (intuitive)

Visual / Verbal

1. When I think about what I did yesterday, I am most likely to get
 - (a) a picture. (visual)
 - (b) words. (verbal)
2. I prefer to get new information in
 - (a) pictures, diagrams, graphs, or maps. (visual)

- (b) written directions or verbal information. (verbal)
- 3. In a book with lots of pictures and charts, I am likely to
 - (a) look over the pictures and charts carefully. (visual)
 - (b) focus on the written text. (verbal)
- 4. When someone is showing me data, I prefer
 - (a) charts or graphs. (visual)
 - (b) text summarizing the results. (verbal)
- 5. When I get directions to a new place, I prefer
 - (a) a map. (visual)
 - (b) written instructions. (verbal)
- 6. When I see a diagram or sketch in class, I am most likely to remember
 - (a) the picture. (visual)
 - (b) what the instructor said about it. (verbal)

Sequential / Global

- 1. I tend to
 - (a) understand details of a subject but may be fuzzy about its overall structure. (Sequential)
 - (b) understand the overall structure but may be fuzzy about details. (global)
- 2. Once I understand
 - (a) all the parts, I understand the whole thing. (Sequential)
 - (b) the whole thing, I see how the parts fit. (global)
- 3. When solving problems in a group, I would be more likely to
 - (a) think of the steps in the solution process. (Sequential)
 - (b) think of possible consequences or applications of the solution in a wide range of areas. (global)
- 4. I learn
 - (a) at a fairly regular pace. If I study hard, I'll "get it." (Sequential)
 - (b) in fits and starts. I'll be totally confused and then suddenly it all "clicks." (global)
- 5. When I am learning a new subject, I prefer to
 - (a) stay focused on that subject, learning as much about it as I can. (Sequential)
 - (b) try to make connections between that subject and related subjects. (global)
- 6. When I solve math problems
 - (a) I usually work my way to the solutions one step at a time. (Sequential)
 - (b) I often just see the solutions but then have to struggle to figure out the steps to get to them. (global)

Appendix C. Dyslexia Type Test

A checklist for dyslexic adults will not provide enough information for a diagnostic assessment, but it can be very useful in promoting a better self-understanding and a pointer towards future assessment needs. Below are the questions that were found to be more predictive of dyslexia (as measured by prior diagnosis). In order to provide the most informative checklist, scores for each answer indicate the relative importance of that question.

Reading

	Absolutely	Somewhat	Rarely or Never
1. Complains of dizziness, headaches or stomach aches while reading or studying.			
2. Confused by letters, numbers, words, sequences or verbal explanations.			
3. Reading or writing shows repetitions, additions, transpositions, omissions, substitutions, and reversals in letters, numbers and/or words.			
4. Complains of feeling or seeing non-existent movement while reading, writing, or copying.			
5. Seems to have difficulty with vision, yet eye exams don't reveal a problem.			
6. Reads and rereads with little comprehension.			

Writing

	Absolutely	Somewhat	Rarely or Never
1. High in IQ, yet may not test well academically; tests well orally, but not written.			
2. Trouble with writing or copying; pencil grip may be unusual.			
3. Handwriting varies or is illegible.			
4. Spells phonetically and/or inconsistently.			

Mathematics

	Absolutely	Somewhat	Rarely or Never
1. Has difficulty telling time, managing time, learning sequenced information or tasks, or being on time.			
2. Computing math shows dependence on finger counting and other tricks.			
3. Can count, but has difficulty counting objects and dealing with money.			
4. Can do arithmetic, but not word problems. Has problems showing math steps on paper.			

Memory

	Absolutely	Somewhat	Rarely or Never
1. Excellent long-term memory for experiences, locations, or faces.			
2. Poor memory for sequences or information that has not been experienced.			
3. Thinks primarily with images and feeling, not sounds or words (little internal dialogue).			

Speaking

	Absolutely	Somewhat	Rarely or Never
1. Hears things not said or not apparent to others; easily distracted by or overly sensitive to sounds.			
2. Difficulty putting thoughts into words; leaves sentences incomplete; speaks in halting phrases or stutters under stress; mispronounces long words, or transposes phrases, words, and syllables when speaking.			
3. Learns best through hands-on experience, demonstrations, experimentation, observation, and visual aids.			

Appendix D. Logic Rules for the (DLSM) Model

This Appendix lists the logic rules which govern the developing of personalised materials for dyslexics learners, applied to the Felder-Silverman (1988) (FS) learning styles model. A full description of the FSLSM model is given in Section (2.7.4.3).

<i>IF dyslexia type is “reading” THEN learning style is “sensory” OR “visual”;</i>
<i>IF dyslexia type is “writing” THEN learning style is “verbal” OR “visual”;</i>
<i>IF dyslexia type is “speaking” THEN learning style is “reflective” OR “visual”;</i>
<i>IF dyslexia type is “mathematics” THEN learning style is “sensory” OR “visual” OR “sequential”;</i>
<i>IF dyslexia type is “memory” THEN learning style is “sequential” OR “visual”;</i>

Appendix E. Questionnaire on Learner Satisfaction

This appendix shows the questionnaire designed to test learners' satisfaction regarding the DAELMS system.

Learners' Personal Information

Age:

☐ 19 – 22 ☐ 23 – 26 ☐ >26

Gender:

☐ male ☐ female

Stage of study:

☐ Year 1 ☐ Year 2 ☐ Year 3 ☐ > Year 3

Have you previously been diagnosed with dyslexia?

☐ Yes ☐ No

Please rate how strongly you agree or disagree with each of the following statements by circling the appropriate number. (Scale is from 5 being strongly agree to 1 being strongly disagree):

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
A Comparison of adaptive and non-adaptive e-learning system					
1. I found it easier to learn a new topic using the adaptive system than I did using the non-adaptive system.	5	4	3	2	1
2. I found it easier to solve any difficulties I encountered with the help of the recommendations of the adaptive system than I did using a non-adaptive system.	5	4	3	2	1
3. Of the two systems, I prefer the adaptive system because of its interactive features.	5	4	3	2	1
4. I appreciated the recommendations provided by the adaptive system because they directed me to materials that were aligned with my needs and did not require me to search the course material.	5	4	3	2	1
Dyslexia and Type Adaptive E-learning					
5. I found it useful to learn about the type of dyslexia I have and how this influences my learning style.	5	4	3	2	1
6. Learning about the type of dyslexia I had helped me to better understand my strengths and weakness	5	4	3	2	1
7. The adaptive system facilitated my ability to work around my weaknesses	5	4	3	2	1
8. The adaptive system presented information and experiences that were aligned with the learning needs associated with my dyslexia type.	5	4	3	2	1
Adaptive Presentation (Style Sheet)					
9. I found the site easier to read after my personalised settings had been applied.	5	4	3	2	1
10. There were improvements to the aesthetics of the site once my personal settings had been applied.	5	4	3	2	1
11. It was easier to navigate around the site once my personal settings had been applied.	5	4	3	2	1
12. It would be useful if I could apply my personalised setting to other online resources.	5	4	3	2	1

The Effectiveness of the Adaptive Materials					
13. The way in which the course was structured facilitated my ability to understand the materials.	5	4	3	2	1
14. The way in which the exercise was structured enhanced my comprehension of the topic.	5	4	3	2	1
15. The learning experiences that were presented were aligned with my current level of knowledge.	5	4	3	2	1
16. The fact that the learning content presented was aligned with my learning style enhanced my learning experience.	5	4	3	2	1
Recommendations Presented by the System					
17. The students recommended by the system allowed me to effectively learn alongside other students.	5	4	3	2	1
18. The students recommended by the system enhanced my understanding of the topics and allowed me to access a variety of different perspectives.	5	4	3	2	1
19. The recommended assistive technologies by the system makes my learning more effective	5	4	3	2	1
20. The recommended assistive technologies by the system match my dyslexia type	5	4	3	2	1
Learner's Interest					
21. The system is easy to use.	5	4	3	2	1
22. The adaptive nature of the system increased my interest in the topic.	5	4	3	2	1
23. Time passes quickly when I am interacting with the adaptive system.	5	4	3	2	1
24. I would be happy to recommend this system to my friends.	5	4	3	2	1
Describe three aspects of the adaptive system that you liked. 1. 2. 3.					
Describe three aspects of the adaptive system that you did not like. 1. 2. 3.					
Describe three ways in which you think the system can be improved. 1. 2. 3.					

Appendix F. Pre and Post Knowledge Level Test

This appendix shows the ten questions designed to test learners' knowledge of the two courses covered by the DAELMS. The knowledge level test is completed both before (known as the pre-test) and after (known as the post-test) the adaptive and non-adaptive system, and is used to assess learning gain. Below is the knowledge level test for both courses

Fundamentals of Computation

1. Approximately how many bytes make one Megabyte?
 - a) One Million
 - b) One Thousand
 - c) Ten Thousand
 - d) One Hundred
2. What is the name of the circuit board that contains the CPU?
 - a) Plug-in-card
 - b) Sound card
 - c) SIMM
 - d) Motherboard
3. A truth table is
 - a) A table that defines the output of a logic circuit.
 - b) A table of values that are input into a computer.
 - c) A hardware item that determines the outcome of a gate.
 - d) An input device needed all the time by the CPU.
4. How many possible states does a binary bit have?
 - a) 2, these are 1 and 0
 - b) 1, because a bit is only 1 box
 - c) 3, these are 0, 1 and 2
 - d) 2, these are 1 and 2
5. How many different representations can one have using 5 bits?
 - a) 10, this is obtained by working out 5×2 .
 - b) 1 representation.
 - c) 5, 1 for every bit.
 - d) 32, this is obtained by working out $2 \times 2 \times 2 \times 2 \times 2$
6. In the binary number 10011, which is the most significant bit?
 - a) The '1' at the far right (at the end of the number).
 - b) All 1's are equally significant.
 - c) The '1' at the far left (at the beginning of the number).
 - d) The first '0'
7. In a conditional statement, the first part is the antecedent and the second part is the:
 - a) Predicate
 - b) Consequent
 - c) Subject
 - d) Disjunct
8. In a three-variable truth table, there are six rows.
 - a) True
 - b) False
9. "It is not the case that the car is red and the truck is blue" can be symbolized by...
 - a) $\sim p \ \& \ q$
 - b) $\sim (p \vee q)$
 - c) $\sim (p \ \& \ q)$
 - d) $\sim p \ \& \ \sim q$
10. In a disjunction, even if one of the statements is false, the whole disjunction is still true:
 - a) True
 - b) False

Introduction to Programming in Java

1. Choose the best definition for a Class.
 - a) A group of students in a class
 - b) An object definition, containing the data and function elements necessary to create an object.
 - c) An action for a program
 - d) All of the above
2. Choose the appropriate data type for this value: true
 - a) Int
 - b) String
 - c) Double
 - d) Boolean
3. `x=10;`
`x=x++*++x`
now x=?
 - a) error
 - b) 110
 - c) 120
 - d) 122
4. Which of the following means that in order for the conditional to happen, either x must be less than 3 or y must be greater than or equal to 4?
 - a) `If ((x < 3) && (y > 4))`
 - b) `If (x < 3 y >= 4)`
 - c) `If ((x < 3) || (y >= 4))`
 - d) `If ((x > 3) || (y <= 4))`
5. What is the proper way to declare a variable?
 - a) `VariableName variableType;`
 - b) `VariableName;`
 - c) `VariableType;`
 - d) `VariableType variableName;`
6. If you want your conditional to depend on two conditions BOTH being true, what is the proper notation to put between the two Boolean statements?
 - a) `&`
 - b) `&&`
 - c) `|`
 - d) `||`
7. `If(x=10)`
`b=1; else`
`b=0;`
now b=?
 - a) Error
 - b) 1
 - c) 0
 - d) Unknown
8. A class cannot be declared:
 - a) Static
 - b) Private
 - c) Default
 - d) None of the above
9. In Java, the % refers to
 - a) percentages
 - b) modulus operator
 - c) division
 - d) data storage
10. `x=x+10;`
can be written as:
 - a) `x+=10;`
 - b) `x=+10;`
 - c) `x++10;`
 - d) cannot be done

Appendix G. Screenshots of the System

This appendix shows screenshots of the DAELMS system. It starts with the flow of registration and login process.

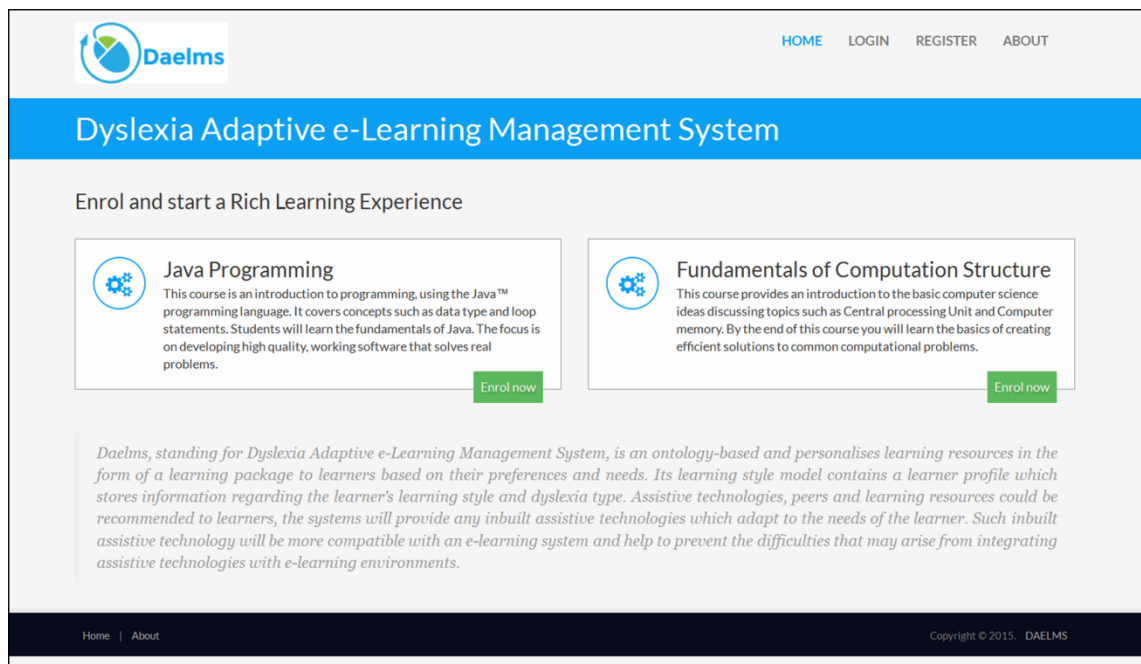


Figure G.1 Home page

The screenshot shows the DAELMS Registration page. At the top, there is a navigation bar with links for HOME, LOGIN, REGISTER, and ABOUT. Below this is a blue header with the text "Register in Daelms". The main content area contains a registration form. The form includes fields for First Name, Last Name, Email, Telephone, Password, and Confirm Password. There are also checkboxes for "The system will use your knowledge level information for peer recommendation" and "I accept the Terms and Conditions of DAELMS". A "Submit" button is located at the bottom of the form.

Figure G.2 Registration page

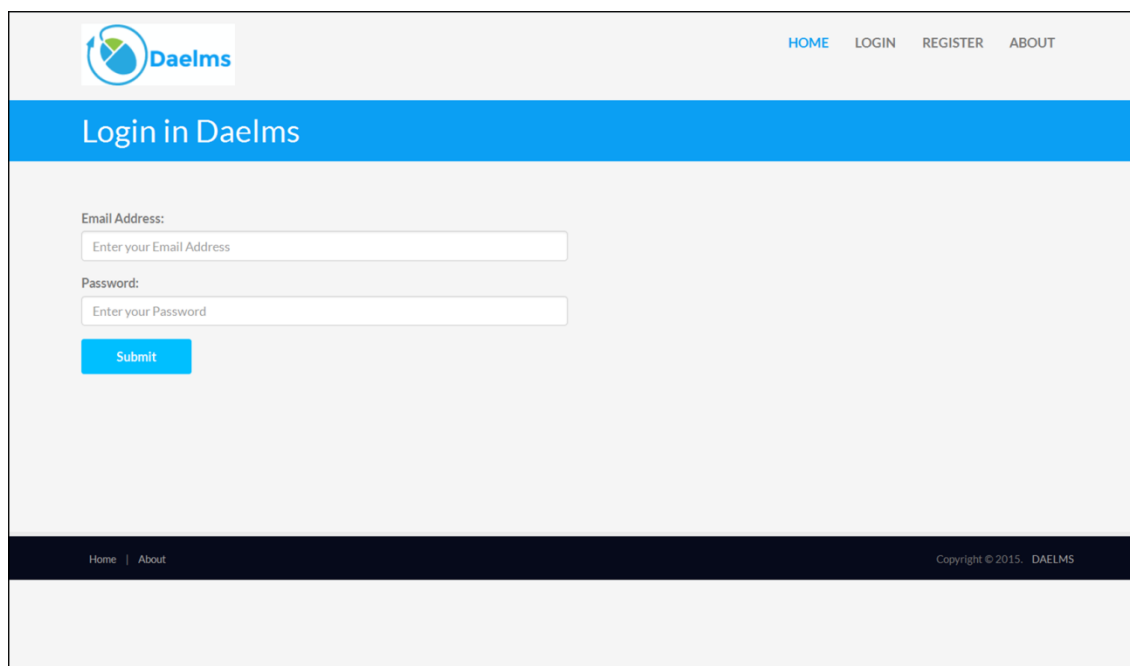
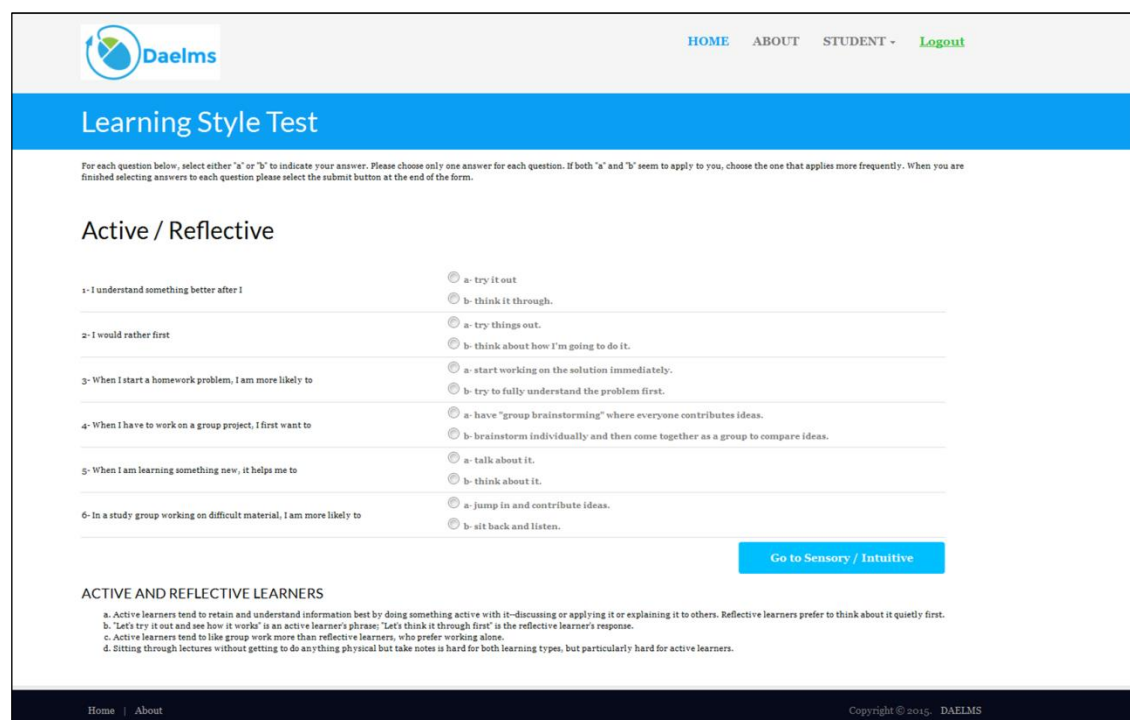


Figure G.3 Login page



For each question below, select either 'a' or 'b' to indicate your answer. Please choose only one answer for each question. If both 'a' and 'b' seem to apply to you, choose the one that applies more frequently. When you are finished selecting answers to each question please select the submit button at the end of the form.

Active / Reflective

1- I understand something better after I	☐ a- try it out. ☐ b- think it through.
2- I would rather first	☐ a- try things out. ☐ b- think about how I'm going to do it.
3- When I start a homework problem, I am more likely to	☐ a- start working on the solution immediately. ☐ b- try to fully understand the problem first.
4- When I have to work on a group project, I first want to	☐ a- have "group brainstorming" where everyone contributes ideas. ☐ b- brainstorm individually and then come together as a group to compare ideas.
5- When I am learning something new, it helps me to	☐ a- talk about it. ☐ b- think about it.
6- In a study group working on difficult material, I am more likely to	☐ a- jump in and contribute ideas. ☐ b- sit back and listen.

[Go to Sensory / Intuitive](#)

ACTIVE AND REFLECTIVE LEARNERS

- a. Active learners tend to retain and understand information best by doing something active with it—discussing or applying it or explaining it to others. Reflective learners prefer to think about it quietly first.
- b. "Let's try it out and see how it works" is an active learner's phrase; "Let's think it through first" is the reflective learner's response.
- c. Active learners tend to like group work more than reflective learners, who prefer working alone.
- d. Sitting through lectures without getting to do anything physical but take notes is hard for both learning types, but particularly hard for active learners.

Figure G.4 Learning style test

Dyslexia Type Test

A checklist for dyslexic adults will not provide enough information for a diagnostic assessment, but it can be very useful in promoting a better self-understanding and a pointer towards future assessment needs. Below are the questions that were found to be more predictive of dyslexia (as measured by prior diagnosis). In order to provide the most informative checklist, scores for each answer indicate the relative importance of that question.

Reading

- 1- Complains of dizziness, headaches or stomach aches while reading or studying. ☐ Absolutely ☐ Somewhat ☐ Rarely or Never
- 2- Confused by letters, numbers, words, sequences or verbal explanations. ☐ Absolutely ☐ Somewhat ☐ Rarely or Never
- 3- Reading or writing shows repetitions, additions, transpositions, omissions, substitutions, and reversals in letters, numbers and/ or words. ☐ Absolutely ☐ Somewhat ☐ Rarely or Never
- 4- Complains of feeling or seeing non-existent movement while reading, writing, or copying. ☐ Absolutely ☐ Somewhat ☐ Rarely or Never
- 5- Seems to have difficulty with vision, yet eye exams don't reveal a problem. ☐ Absolutely ☐ Somewhat ☐ Rarely or Never
- 6- Reads and rereads with little comprehension. ☐ Absolutely ☐ Somewhat ☐ Rarely or Never

[Go to Math](#)

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Figure G.5 Dyslexia type test

Fundamentals Of Computation Structure Enrolment Test

Please answer the following questions, in order to test your knowledge in the enrolled course

3- A truth table is

- a) A table that defines the output of a logic circuit.
- b) A table of values that are input into a computer.
- c) A hardware item that determines the outcome of a gate.
- d) An input device needed all the time by the CPU.

[<< Preview Step](#) [Next step >>](#)

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Figure G.6 Knowledge level test

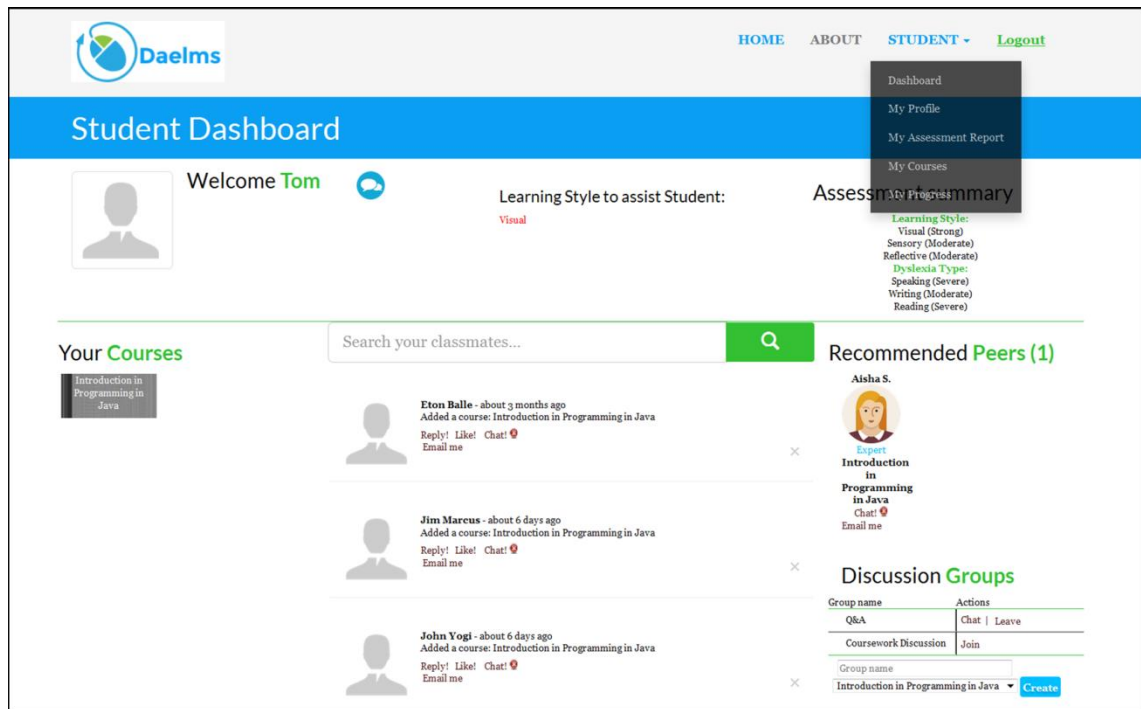


Figure G.7 Student's dashboard

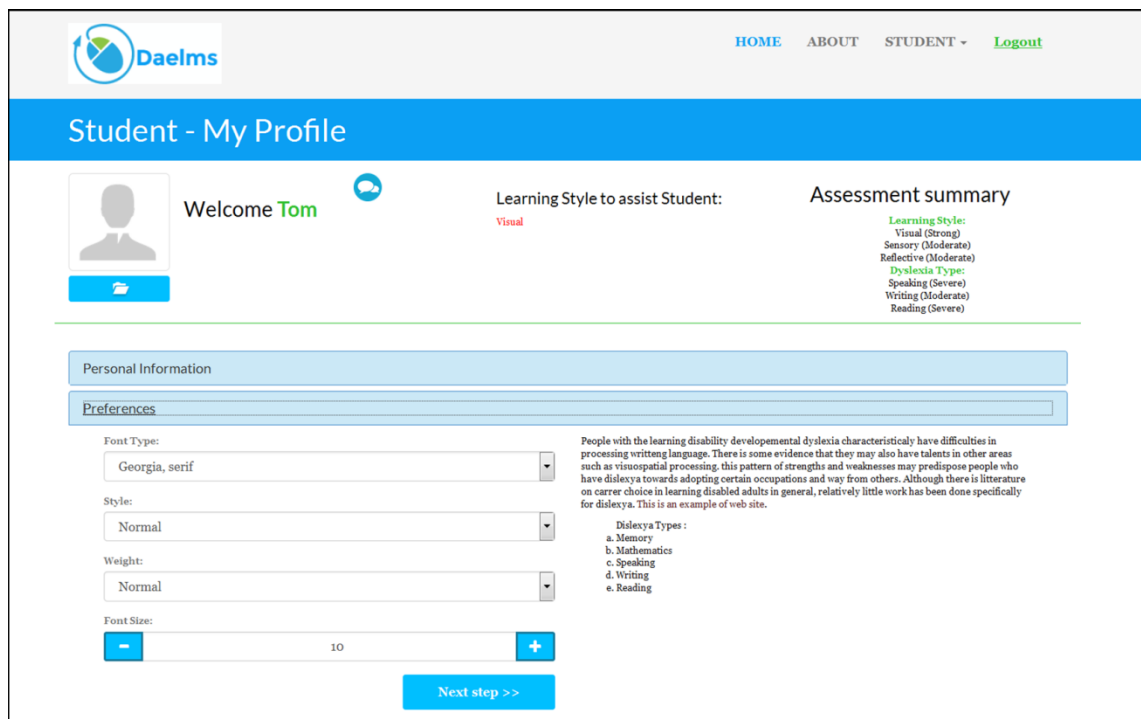


Figure G.8 My profile page

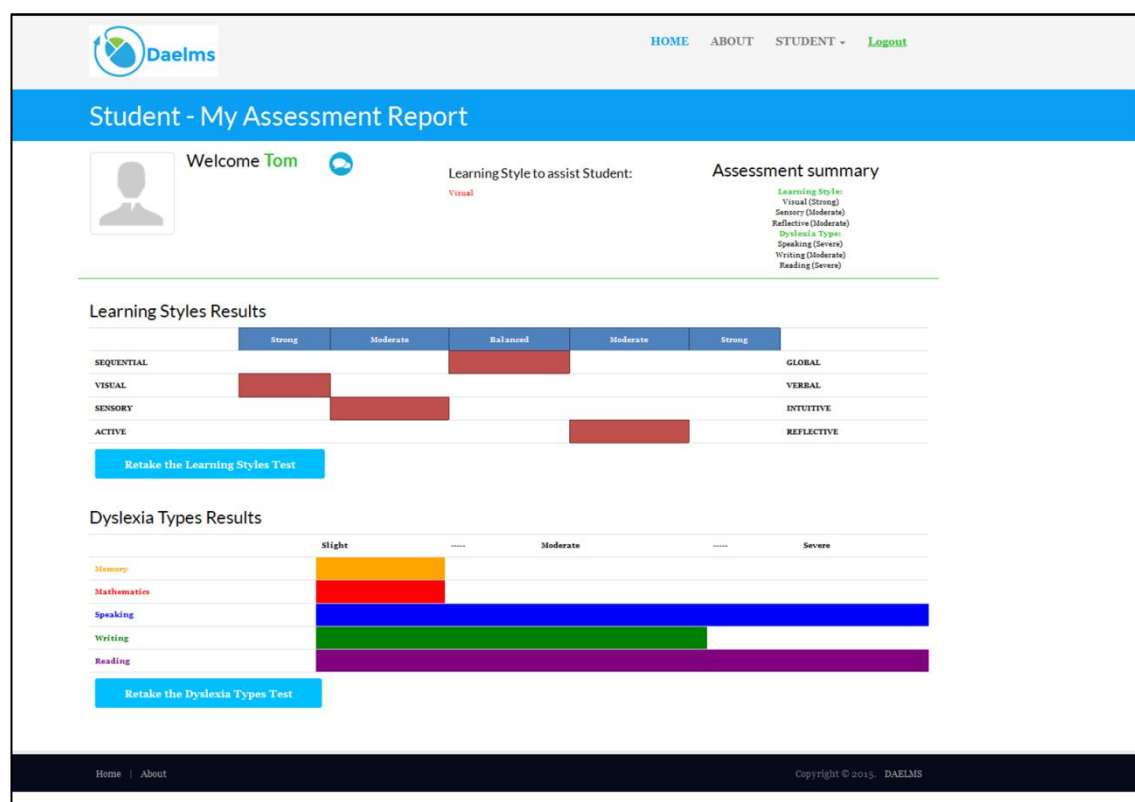


Figure G.9 My assessment report page

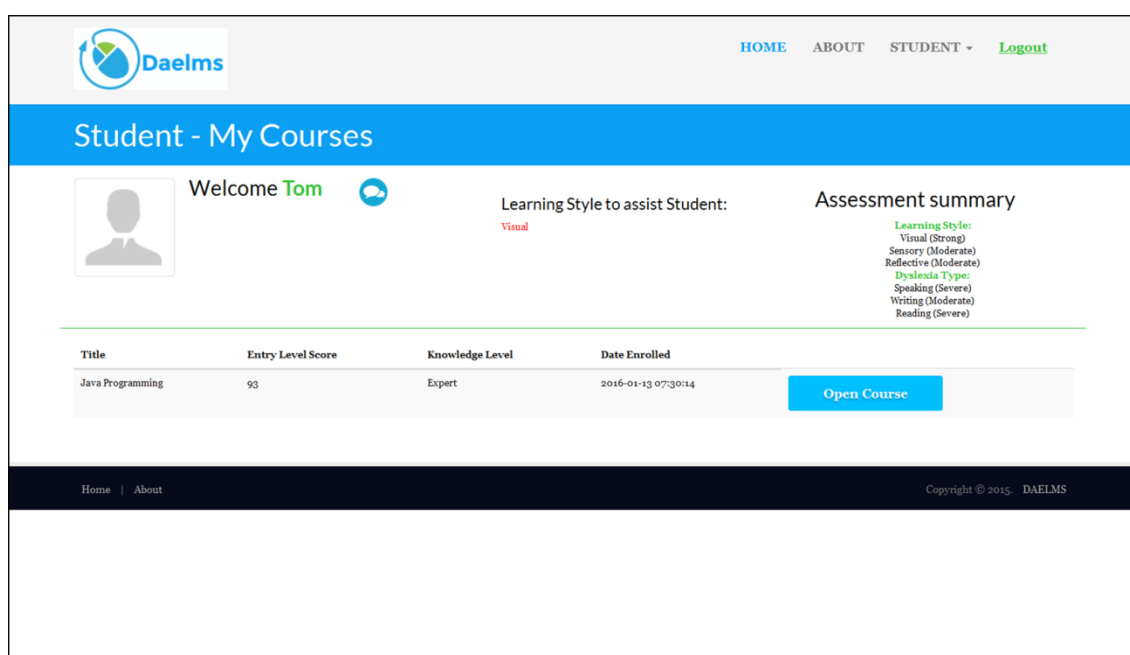


Figure G.10 My course page


[HOME](#)
[ABOUT](#)
[STUDENT](#)
[Logout](#)

Student - My Progress



Welcome **Tom**

Learning Style to assist Student:

Visual

Assessment summary

Learning Style:
Visual (strong)
Sensory (Moderate)
Reflective (Moderate)
Dyslexia Type:
Speaking (Severe)
Writing (Moderate)
Reading (Severe)

Title	Pre-test Date	Pre-test Score	Pre Knowledge Level	Acquired Level Score	Acquired Knowledge Level	Post-test Date	Post-test Score	Post Knowledge Level
Java Programming	2015-11-13 07:52:20	90	Expert	93	Expert			

Take post test

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Figure G.11 My progress page

Appendix H. Ethical Declaration Form



Form D: Declaration Form

This form should be given to your supervisor along with your project proposal. It must also be included in your Project Report.

Student Project: Ethical Approval Request			
Name:	Student ID:	Date:	
Aisha Alsobhi	M00369309	08/02/2015	
Supervisor: Dr. Nawaz Khan and Dr. Harjinder Rahanu			
Title Ontological Approach for Developing an Adaptive E-Learning System Based on Students with Dyslexia Learning Styles			
Ethical Approval Statement: Declaration A (i) I have studied the Ethical Approval section. (ii) I have established that my study does not require additional human participation. (iii) I agree to re-apply for approval if the nature or goals of my project change. ☐			
Declaration B Project Goals involving human participation: the main hypothesis of the experiment is: "The adaptive learning paths generated by the proposed system are pedagogically effective and satisfactory for the students with dyslexia" The main objective for this experiment is to test the validity and suitability of the proposed system and to meet the above research hypothesis. As a result, certain essential parameters were determined. • Learners' performance (evaluated through a comparison of pre- and post-knowledge level test results). • The relationship between learning styles and dyslexia type (assessed by comparing the system results with the results of previous studies outlined in the literature). • Learners' satisfaction levels (assessed through the use of post-event questionnaires). (i) I have studied the Ethical Approval section. (ii) My study involves human participation through - o observation - o questioning. (iii) Participants will be selected without coercion (see Chart 1). (iv) I will obtain informed consent (see Chart 2) from each participant using Form C. (v) I have arrangements in place for the protection of personal data (see Chart 3). (vi) I agree to re-apply for approval if the nature or goals of my project change. ✓			
Declaration C My project does not fulfil the conditions for fast track Ethical Approval and I am applying separately to the Ethics Committee. Note: to make an application to the Ethics Committee, you need to complete Form E - Application for Ethical Approval (download from http://tinyurl.com/sst-ethics) ☐			
Student Signature.....Aisha Alsobhi..... Date.....08/02/2015.....			
Supervisor's Signature..... <i>[Signature]</i> Date.....08/02/2015.....			

Appendix I. Ethics Consent Form



Middlesex University School of Engineering and Information Sciences Research Consent Form C

This consent form, a copy of which has been given to you, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, please ask. Please take the time to read this form carefully and to understand any accompanying information.

Research Project Title

Ontological Approach for Developing an Adaptive E-Learning System Based on Students with Dyslexia Learning Styles

Researcher

Aisha Alsobhi

Experiment Purpose

The adaptive learning paths generated by the proposed system are pedagogically effective and satisfactory for the students with dyslexia.

Participant Recruitment and Selection

The dyslexic subjects selected for the system evaluation process were individuals who displayed the symptoms and difficulties that are typically associated with dyslexia; however, they had not necessarily been explicitly stated as dyslexic through a formal assessment conducted by an educational psychologist. A further requirement was that the subjects were over the age of eighteen. The gender, age, IT competency, social grouping, educational background and other key demographics of the subjects were out of the scope of this experiment.

Procedure

- First session included a brief explanation of the study, familiarisation with the system and familiarity with the concept of the system. (15 Minutes)
- The other session contained a 5-minutes pre-test, a 30-minutes interaction with the system and a 5-minutes post-test. Each of the tests contains 10 questions to determine the students' background knowledge of the subject.

Data Collection

The system will collect the following data:

- Learners' performance (evaluated through a comparison of pre- and post-knowledge level test results).
- The relationship between learning styles and dyslexia type (assessed by comparing the system results with the results of previous studies outlined in the literature).
- Learners' satisfaction levels (assessed through the use of post-event questionnaires).

Confidentiality

- Prior to being asked to agree to participate in the research, all participants were fully informed of the project aims and purpose, the research method, likely duration, potential consequences, and the findings that were likely to be published.
- The candidates were also fully briefed on any experimental tasks they would be required to perform and the environment in which these experiments would be conducted, as follows:
 - a) All experiments were conducted in private in the presence of the participants and the researcher or the person who conducted the experiment only.
 - b) To conform to health and safety regulations, an additional team member was positioned outside the laboratory and was available in the event that the participant or researcher required assistance.
 - c) All the data collected during the experiments was recorded such that personal information about the participants was only available to the researcher who conducted the experiment. Any information that could potentially be used to identify the participants, such as name, was removed to prevent the experimental results being traced back to individual participants.
 - d) All paper-based records from the experiments, which included personal data, were stored in a secure location.

Likelihood of Discomfort

- The participants were clearly informed that they had a right to withdraw from the study at any time, even once the experiment was in progress, should they feel unhappy, confused, embarrassed or frustrated with the tasks they were being asked to complete.
- Before commencing the experiment aspect of the research project, each participant is asked to sign this consent form that formally recorded their agreement to participate in the study.
- Care was taken to ensure that the individual needs of the participants were taken into consideration and that the researcher was sensitive to the potential embarrassment that a dyslexic participant may experience while using the system.

Finding out about Results

- Each participant was provided with an opportunity to see his or her individual experimental results.
- All project results and conclusions were made available to the project participants upon request.

Agreement

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a participant. In no way does this waive your legal rights nor release the investigators, sponsors, or involved institutions from their legal and professional responsibilities. You are free to not answer specific items or questions in interviews or on questionnaires. You are free to withdraw from the study at any time without penalty. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation. If you have further questions concerning matters related to this research, please contact the researcher.

Participant

Date

Investigator/Witness

Date

A copy of this consent form has been given to you to keep for your records and reference.

Appendix J. XML Course Structure

This appendix shows part of the xml structure for Introduction to programming in Java course. The xml structure is based on the learning ontology described in (Section 8.5.3) and it follows the general course structure presented in (Figure 9.1).

```
<?xml version="1.0" encoding="UTF-8" ?>
<root>
  <course>
    <id>1</id>
    <name>Introduction in Programming in Java</name> <!-- course name -->
    <name_url>java-programming</name_url>
    <title>Java Programming</title> <!-- course title -->
    <description> <!-- course description -->
      This course is an introduction to programming, using the Java™ programming language. It covers concepts such
      as data type and loop statements. Students will learn the fundamentals of Java. The focus is on developing
      high quality, working software that solves real problems.
    </description>
    <objective> teach java programming principles</objective> <!-- course objective -->
    <entry_test_url>enrol/test/1-java-programming</entry_test_url> <!-- pre test-->

    <test_param>{"q1":{"answer":"b","mark":5},"q2":{"answer":"d","mark":3},"q3":{"answer":"c","mark":15},"q4":{"
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  <chapter>
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      <name>Programming Basics</name> <!-- concept name -->
      <title>Programming Basics</title> <!-- concept title -->
      <objective> <!-- concept objective -->
        <h2>Objective</h2>
        <ul>
          <li>Understand fundamental of programming such as classes, methods, and statements</li>
          <li>Be aware of the important topics and principles of programming in Java</li>
        </ul>
      </objective>
      <children> <!--consists of concepts -->
        <id>5</id>
        <name>Outline</name> <!--outline -->
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        <objective />
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        <course_id>1</course_id> <!-- belong To course id 1 -->
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        <difficulty_level>1</difficulty_level> <!-- easy -->
        <order>0</order> <!-- concept order depend on the student's learning style-->
        <learning_style_id>8</learning_style_id> <!--intuitive learning style-->
        <cls_id>61</cls_id> <!--described By resource-->
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      <id>7</id>
      <name>Overview</name> <!--overview -->
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      <!-- overview for each learning style will be here -->
      <!-- children 1, 2 ... n -->
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</course>
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