An Investigation into Matching Learning Material to the Different Needs of Arabic Learners with Dyslexia

by
Weam Gaoud Alghabban

A thesis submitted to
the University of Birmingham
for the degree of
DOCTOR OF PHILOSOPHY

School of Computer Science
College of Engineering and Physical Science
The University of Birmingham
January 2023

Abstract

Dyslexia is a common learning disability that affects people's ability to spell, read words and their fluency in language. Adaptive e-learning is becoming increasingly popular as a tool to help individuals with dyslexia. It provides more-customised learning experiences and interactions based on the learners' characteristics. Each learner with dyslexia has unique characteristics for which content should ideally be suitably tailored. However, adaptation to satisfy the individual needs and characteristics of learners with dyslexia is limited. In particular, the benefits of adapting e-learning based on dyslexia type or reading skill level have not yet been sufficiently explored, despite the type of dyslexia and the learner's reading skill level being critical factors. Most previous studies have focused upon the technological aspects and have been marked by inadequately designed and controlled experiments to assess the system's effectiveness. This limits the ability to understand the effectiveness of adaptation.

This thesis aims to increase understanding about the value of adaptation of learning material based on individual dyslexia types and reading skill levels and to understand how this affects the learning experience of learners with dyslexia. To do this, an empirical evaluation through three controlled experiments with a reasonable number of subjects has been undertaken and assessed using the following metrics: learning gain, word understanding, learner satisfaction and perceived level of usability. In all three experiments, careful experimental design and precise reporting of results are all considered. A dynamic, web-based e-learning system that matches learning material based on dyslexia type and/or reading skill level was implemented to support these experiments.

Across the three experiments, the findings reveal that matching learning material to dyslexia type, reading skill level and the combination of both, yields significantly better short- and long-term learning gains and improves the learners' perception of their learning.

To my parents, and my sister

Acknowledgements

I would like to express my special thanks and gratitude to everyone who has supported me through this fascinating journey.

Foremost, exceptional and warm thanks to my supervisor, Dr Robert Hendley, for allowing me to conduct research and providing me with essential help and feedback along the process. I am deeply inspired by his vision, motivation, sincerity and dynamism. There have been so many meetings when I felt anxious and depressed before the meeting started; those feelings wholly disappeared after our meeting. Working and studying under his supervision was a great privilege and honour. I am incredibly grateful for his support during my health issues and my personal life. I would also like to express my gratitude for his empathy, friendship and fantastic sense of humour that reduces the pain of being away from my daughter. I appreciate everything he has done for me.

My sincere thanks go to Dr Rowanne Fleck for her advice at the beginning of my research. I would like to express my gratitude to my research group representatives, Professor Christopher Baber, Professor Russell Beale and Dr Sandy Gould, for taking time to comment on my research and respond to hard questions. Much appreciation goes to my examiners, Professor Christopher Baber and Dr Sandra Woolley for their insightful engagement with my work.

Many thanks go to the University of Tabuk and the Saudi Arabian Cultural Bureau in the United Kingdom for financially supporting my PhD. and making this educational journey possible. My thanks extend to all the teachers and students in the Kingdom of Saudi Arabia who were involved in my studies and facilitated my research.

I am incredibly grateful to have a loving and greatest family: my mother, Wedad, and my father, Gaoud, for their love, sincere prayers, unconditional and continual support, and their extremely wise and motivational perspective all my life. No words can express my gratitude to my parents in this very intense academic stage. I have learned the value of achieving my potential from them. Also, I owe my brothers, nieces and nephews so many thanks for their valuable prayers and support. I am truly sorry for all the complaints I made during this stage. A special thanks to my lovely sister, Amany, and my brother-in-law, Abdullah. Words cannot express how grateful I am to them for supporting me in everything and especially for encouraging me throughout this experience and taking care of my little daughter. Without them, I could not have accomplished this. ‘I dedicate this success and achievement to you’. I also would like to say a big and warm thank you to my daughter, Alghaliah, for giving me unlimited pleasure and happiness, especially when she is away from me during this academic journey.

Last but not least, big thanks to my brother, Ahmed, for his sacrifice to travel with me and leave everything behind him. It was impossible to start this academic journey without him being here with me. Only a brother can do that for a sister. When he is around me, I feel stronger and safer. That is why I am always proud to have him in my life. ‘Thank you so much, my kind brother, for everything’.

My gratitude is extended to my friend, Sabreen Ahmadjee. It is great to know that I have an exceptional friend in the United Kingdom like you, whom I can trust with my joys, gripes, and my secret chocolate cake recipe. I do not have enough words to express how much I appreciate all the times you listened to me and were there when I needed someone. It is lovely to know that you care enough to stick by my side through the good and bad times. I do not know what I would do without you. You always be close to my heart. ‘Thank you so much for being the kind of person you are. Love and best friends forever’.

Big thanks to my friends for their constant support and listening, especially Wad, Abo–Fadel, Natasha, Hadeel and Hebah.

My thanks also go to all the people who have helped me to complete this work.

‘Thank you so much to all of you.’

This thesis was copy edited for conventions of language, spelling and grammar by Cambridge Proofreading.

Weam Alghabban

Contents

List of Figures

List of Tables

List of Abbreviations

CTML	Cognitive Theory of Multimedia Learning
DTRSLT	Dyslexia Type and Reading Skill Level Training
ELS	E-Learner Satisfaction
IU	Instructional Unit
LO	Learning Object
LPD	Letter Position Dyslexia
MSA	Modern Standard Arabic
S1	Reading letters with short vowels
S2	Reading words with Sakin letter(s)
S3	Reading words with short vowels and Sakin letter(s)
SA	Spoken Arabic
SUS	System Usability Scale
VLD	Vowel Letter Dyslexia

List of Definitions of Key Terms

Affix A morpheme that is attached to a word stem to form a new word or word form.

Attentional dyslexia Experiences difficulty in encoding the position of letters between words.

Hearing processing dyslexia Experiences loss of attention, noise distraction and forgetting instructions.

Letter identity dyslexia Experiences difficulty in accessing the abstract letter's identity from its visual form.

Letter position dyslexia Experiences difficulty in encoding the order of the letters within a word.

Neglect dyslexia Neglecting either the left or right side of a word or sentence.

Non-transparent orthography The relationships between letters and sounds are inconsistent and the language permits many exceptions.

Phonological dyslexia Difficulty with processing phonemes and dividing words into syllables and in matching sounds to their written forms.

Rapid naming deficit dyslexia Difficulty in naming a letter or number quickly.

Slow-speed processing dyslexia Experiences slow information processing when studying in the classroom, reading a book or when writing a story or writing homework.

Surface dyslexia Difficulty in recognising a word by sight, which makes learning and remembering words hard.

Transparent (shallow) orthography The relationships between letters and sounds are consistent.

Visual dyslexia/orthographic input buffer dyslexia Experiences difficulty in letter identification, letter position encoding and letter-to-word binding.

Visual processing dyslexia Experiences inaccurate copying and confusion between reversible letters such as b and d.

Chapter 1

Introduction

1.1 Introduction

In recent years, electronic learning (e-learning) has become increasingly popular and more accessible in many educational fields due to its flexibility in time and place (Rodrigues et al., 2019). E-learning can be generally defined as: *'an innovative web-based system based on digital technologies and other forms of educational materials whose primary goal is to provide students with a personalised, learner-centred, open, enjoyable and interactive learning environment supporting and enhancing the learning processes'* (p. 95) (Rodrigues et al., 2019). It opens an avenue for learners with learning disabilities and represents a major force towards empowering them by providing learning, training, assessment or support (Benmarrakchi et al., 2017c). One target could be learners who have difficulties with reading, which is considered to be an indicator of dyslexia.

However, most traditional e-learning systems are designed for generic learners, regardless of each individual's differences and needs (Broadhead et al., 2018; Ouherrou et al., 2018; El Kah and Lakhouaja, 2018; Sasupilli et al., 2019; EL_Rahman, 2021). Like non-disabled learners, learners with dyslexia differ in abilities, knowledge and skills, and personalities and preferences. However, traditional e-learning systems offer all learners with dyslexia the same learning material in the same sequence regardless of their different needs and characteristics. This may be problematic and lead to frustration and dissatisfaction with the learning process, which, in turn, impacts learners' engagement and learning outcomes and increases dropout rates (Sun et al., 2008).

Adaptive e-learning systems offer an alternative to the 'one-size-fits-all' approach in traditional e-learning systems by tailoring systems to the end users' requirements (Brusilovsky, 2012). Adaptive e-learning systems aim to better satisfy learners' needs by adapting the traditional learning approach to different learner attributes, such as personality, knowledge level and learning style. An adaptive e-learning system can customise the sequence of learning materials and presentation formats, change elements of the user interface or highlight important text according to learners' characteristics to enhance learning (Brusilovsky and Millán, 2007). Therefore, to achieve a more successful learning environment, teaching approaches and learning materials should be adapted to fit the specific needs of learners with dyslexia rather than treating them all in the same way.

This thesis aims to investigate the impact of adapting learning material based on the different characteristics of learners with dyslexia by conducting several experiments with an empirical evaluation.

This chapter introduces the relevant background and the motivation for this work and the research questions that are investigated. Then, it provides the research methodology, the contributions of this research to the existing literature and shows a list of publications resulting from this work. Finally, the structure of this thesis is outlined.

1.2 Background and Motivation

Language, a communication tool between individuals, is fundamental to human development by providing a way for people to express their thoughts and question the world around them. Language learning includes four basic skills: reading, writing, listening and speaking. Reading is a significant branch of language. Reading is: *'the process of extracting and constructing meaning through interaction and involvement with written language'* (p. 11) (Snow, 2002). It is a major focus of the early school years because it develops the mind and opens the door for individuals to the world of knowledge. Most readers can read grade-level appropriate written texts comfortably. In contrast, a proportion of readers faces difficulty in reading, resulting in their social and educational exclusion (Mastropavlou and Zakopoulou, 2013). Such readers are known as individuals with dyslexia.

Dyslexia is defined by the main International Classification of Diseases, ICD-10, as: *'a specific and significant impairment in the development of reading skills, which is not solely accounted for by mental age, visual acuity problems, or inadequate schooling'* (p. 245) (World Health Organization, 1992). It may affect the following skills: reading comprehension, word recognition and the performance of tasks that require reading skill (World Health Organization, 1992). The reading performance in children with dyslexia is significantly below the expected level based on age, intelligence and school placement (Lyon et al., 2003).

In today's society, dyslexia is one of the most prevalent learning disabilities in childhood (Ziegler et al., 2003), making up 80% of the population with learning disabilities (Lerner, 1989). Dyslexia affects a wide range of people, regardless of their abilities and background (Nordqvist, 2017). However, its form and intensity vary depending on the language's orthography[1] (El Kah and Lakhouaja,

[1] Languages have various levels of orthographic depth: Transparent (shallow) orthography, non-transparent (deep) orthography, and both.

2015; Aldabaybah and Jusoh, 2018). For instance, English dyslexia differs from Arabic dyslexia (Elbeheri and Everatt, 2007). Moreover, according to Spencer (1999), readers in transparent orthographic languages, such as Turkish, Italian and Spanish, face fewer difficulties in reading than readers in non-transparent orthographies, such as Dutch, English and French.

Some existing research has considered different characteristics of learners with dyslexia in adaptive e-learning systems in different languages to achieve a more appropriate learning experience and interaction. For example, studies have examined learning style, dyslexia type, knowledge level, user experience and cognitive traits (Alsobhi et al., 2015a,b; Benmarrakchi et al., 2017c; Abdul Hamid et al., 2017; Alsobhi and Alyoubi, 2019, 2020; Srivastava and Haider, 2020; El Fazazi et al., 2021; Al-Dawsari and Hendley, 2021). However, most previous studies have been marked by a lack of well-designed and careful experimental evaluations in terms of assessing learning experience. This leads to difficulty in evaluating the effectiveness of the proposed systems, and so the benefit remains unclear. It has been argued that designing controlled evaluations of adaptive e-learning systems is more important than simply proposing new and innovative ones (Gauch et al., 2007). It is rare to consider the characteristics of learners with dyslexia in adaptive e-learning systems and even more rare to include an empirical evaluation.

This thesis bridges this under-investigated gap by investigating and understanding the impact of matching learning material based on different characteristics of learners with dyslexia, particularly their dyslexia type and reading skill level. This research targets dyslexia in Arabic as few studies target dyslexia in this language (Alsswey et al., 2021), even though Arabic is widely spoken and has a considerable rate of dyslexia (El Kah and Lakhouaja, 2015; Benmarrakchi et al., 2017b; Alghabban and Hendley, 2020a; Al-Dawsari and Hendley, 2022). Several controlled experiments were conducted to achieve this understanding and evaluate the learning experience of learners with dyslexia.

1.3 Research Questions

Three questions are addressed in this work, all of which relate to the impact of matching learning material based on different characteristics of learners with dyslexia, and the findings are evaluated in terms of learning gain, satisfaction and perceived level of usability.

The key research question for this thesis is:

Does matching e-learning material based on the characteristics of learners with dyslexia improve those learners' experience of learning?

Some studies have attempted to investigate the benefits of adapting learning material based on one or more characteristic(s) of learners with dyslexia. However, the benefit of those adaptations remains unclear due to the lack of experimental evaluation. Different characteristics can be considered in adaptive e-learning, such as dyslexia type, learning style, personality and knowledge level. However, including all learners' characteristics to answer this broad question is difficult due to practical and time constraints. Therefore, this research makes the question more specific by focusing on two characteristics of dyslexia: dyslexia type and reading skill level. These characteristics are significant factors in education (Felder and Silverman, 1988; Essalmi et al., 2010; Klašnja-Milićević et al., 2011; Friedmann and Haddad-Hanna, 2014; Friedmann and Coltheart, 2016).

Adaptation based on dyslexia type and reading skill level (as a separate characteristic of learners with dyslexia) in different languages is under-investigated and has received little attention in published research (Alsobhi et al., 2015a,b; Al-Dawsari and Hendley, 2021). There is also a debate surrounding the effects of adaptation based on the combination of dyslexia type and reading skill level (Alsobhi and Alyoubi, 2019). These facts warrant a study to investigate whether matching learning material based on 1) each characteristic and 2) the combination of both characteristics is beneficial, and its evaluation in terms of learning gain, satisfaction and perceived level of usability. Therefore, the key research question can be broken down into three specific sub-questions as follows:

Research Question 1: Does matching e-learning material based on dyslexia type improve learning gain compared to non-matched material, and does it achieve a high level of learner satisfaction and perceived level of usability?

Research Question 2: Does matching e-learning material based on reading skill level improve learning gain compared to non-matched material, and does it achieve a high level of learner satisfaction and perceived level of usability?

Research Question 3: Does matching e-learning material based on a combination of dyslexia type and reading skill level improve learning gain compared to non-matched material, and does it achieve a high level of learner satisfaction and perceived level of usability?

The effectiveness of matching learning material based on dyslexia type is investigated in the first research question. The effectiveness of matching learning material based on reading skill level is investigated in the second research question. Finally, the effectiveness of matching learning material based on combining dyslexia type and reading skill level is investigated in the third research question.

1.4 Research Methodology

The scope of this research encompasses learners with dyslexia and adaptive e-learning systems, so an overview of the theoretical foundation of dyslexia and the concept of adaptive e-learning was conducted before beginning the research. The next step was to investigate the issues related to adaptation based on the different characteristics of learners with dyslexia in e-learning systems. As a result, the research highlighted current issues that need further study.

In this work, a framework for evaluating the impact of matching learning material based on the characteristics of learners with dyslexia was proposed to address current research issues. Three different experiments were conducted to investigate whether matching learning material to dyslexia type and reading skill level is beneficial. Each experiment follows the same approach with different learner characteristics. Experiment 1 targets dyslexia type; Experiment 2 targets reading skill level; and Experiment 3 combines dyslexia type and reading skill level. To support these experiments, a dynamic, web-based e-learning system was built. The system provides different reading activities for Arabic learners with dyslexia using two versions to support the experimental conditions. The matched version matches learning material to the targeted learner characteristic(s), and the non-matched version provides generic learning material. In all other aspects, the two versions of the system are the same. Between-subjects experimental design was used in all experiments.

After identifying the main research questions and designing the e-learning system, the schematic process for each experiment was developed by: 1) defining its hypotheses, 2) identifying measurements and data collection tools, 3) developing the experimental procedure, 4) selecting participants, 5) running the experiment, 6) collecting and analysing data and 7) drawing conclusions regarding the hypotheses (Alshammari, 2016).

1.5 Research Contribution

The contributions of this thesis can be summarised as follows:

It contributes to the recent literature on dyslexia and adaptation by highlighting the importance of adapting learning material to the individual's dyslexia type and reading skill level. This is a significant gap in current research targeted at dyslexia in Arabic (Alghabban et al., 2017; Benmarrakchi et al., 2017a,b,c; El Kah and Lakhouaja, 2018; Ouherrou et al., 2018; Aldabaybah and Jusoh, 2018; Al-Dawsari and Hendley, 2021), and also other languages, such as English (Broadhead et al., 2018; Sasupilli et al., 2019; Srivastava and Haider, 2020; Burac and Cruz, 2020; El Fazazi et al., 2021), Malay (Noor et al., 2017; Abdul Hamid et al., 2017; Pang and Jen, 2018) and Spanish (Rello et al., 2017; Arteaga et al., 2018). This gap has not been investigated, addressed or appropriately evaluated in an adaptive e-learning system for learners with dyslexia.

The major contribution of this work comes from carefully investigating and examining the effectiveness of adaptation based on dyslexia type (Alghabban and Hendley, 2020a,b), reading skill level (Alghabban et al., 2021; Alghabban and Hendley, 2021, 2022b) and a combination of both dyslexia type and reading skill level (Alghabban and Hendley, 2022a). This research is unique in that it is based on careful experimental design and controlled experimental evaluation that involved a reasonable number of subjects, and it analyses and reports the quantitative findings in terms of learning gain, learner satisfaction and perceived level of usability. This work is also distinctive in assessing whether the learned content can be generalised to another context, both in the short and long term, by assessing performance on new material that was not taught in the system. Also, this work assesses word understanding in the short and long term. This adds originality and novelty by providing evidence for the significance of adapting learning material to meet the different needs of learners with dyslexia in e-learning systems.

1.6 List of Publications

A number of research papers arising from this work have been published. These papers are outlined below.

Peer-reviewed journal papers

- **Alghabban, W.G.**, Hendley, R. (2023). Adaptive E-Learning and Dyslexia: an Empirical Evaluation and Recommendations for Future Work. Interacting with Computers. iwad036, pp. 1–10. https://doi.org/10.1093/iwc/iwad036.

- **Alghabban, W.G.**, Hendley, R. (2022). Perceived level of usability as an evaluation metric in adaptive e-learning: A case study with dyslexic children. SN Computer Science. Volume 3, pp. 1–11. https://doi.org/10.1007/s42979-022-01138-5

Conference papers–Full

- **Alghabban, W.G.**, Hendley, R. (2022). Exploring the effectiveness of adaptation based on dyslexia type and reading skill level to support learners with dyslexia. In Proceedings of the 35$^{\text{th}}$ International BCS Human-Computer Interaction Conference, pp. 1–10. http://dx.doi.org/10.14236/ewic/HCI2022.11

- **Alghabban, W.G.**, Al-Dawsari H.M., Hendley, R. (2021). Understanding the impact on learners' reading performance and behaviour of matching e-learning material to dyslexia type and reading skill level. In: Fang X. (eds) HCI in games: Serious and immersive games. HCII 2021. Lecture notes in computer science, Volume 12790. Springer, Cham. pp. 135–154. https://doi.org/10.1007/978-3-030-77414-1_11

- **Alghabban, W.G.**, Hendley, R. (2021). Student perception of usability: A metric for evaluating the benefit when adapting e-learning to the needs of students with dyslexia. In Proceedings of the 13th International Conference on Computer Supported Education, Volume 1: CSEDU, ISBN 978-989-758-502-9; ISSN 2184-5026, pp. 207–219. https://doi.org/10.5220/0010452802070219

Conference papers–Late breaking

- **Alghabban, W.G.**, Hendley, R. (2020). Adapting e-learning to dyslexia type: An experimental study to evaluate learning gain and perceived usability. In: Stephanidis C. et al. (eds) HCI International 2020 - Late breaking papers: Cognition, learning and games. HCII 2020. Lecture notes in computer science, Volume 12425. Springer, Cham. pp. 519–537. https://doi.org/10.1007/978-3-030-60128-7_39

- **Alghabban, W.G.**, Hendley, R. (2020). The impact of adaptation based on students' dyslexia type: An empirical evaluation of students' satisfaction. In Adjunct publication of the 28th ACM Conference on User Modeling, Adaptation and Personalization (UMAP'20 Adjunct), Association for Computing Machinery, New York, NY, USA, pp. 41–46. https://doi.org/10.1145/3386392.3397596

1.7 Thesis Structure

This thesis comprises six chapters, including this introduction. Chapter 2 presents the theoretical foundations of dyslexia in terms of definition, causes, symptoms and classifications. It also covers how dyslexia varies in different languages and cultures. The co-occurrence of dyslexia with other developmental disorders is covered. Different interventions that support people with dyslexia are presented.

Chapter 3 explores the meaning of learning and outlines different fundamental learning theories with a discussion of each theory and its limitations. Then, the chapter covers the advantages and disadvantages of e-learning, followed by the concept of adaptive e-learning and the main components of an adaptive e-learning system. The literature on e-learning and adaptive e-learning for learners with dyslexia is also covered, highlighting research issues that need further investigation.

Chapter 4 presents the motivation behind this work and describes the proposed framework for evaluating the impact of adapting learning material based on characteristics of learners with dyslexia. It also presents an overview of the experimental design used to achieve the research's aims.

Chapter 5 presents the results of the experimental evaluation of adapting learning material based on learners' characteristics: dyslexia type and reading skill level. It explains the different experiments that have been conducted to investigate whether adapting learning material to these two characteristics is beneficial. Three experiments are presented, each with its objectives, hypotheses, procedure, results and interpretation of the results in relation to previous work. Experiment 1 is concerned with the effectiveness of adaptation based on dyslexia type; Experiment 2 addresses the effectiveness of adaptation based on reading skill level; and Experiment 3 investigates the effectiveness of adaptation based on the combination of dyslexia type and reading skill level.

Finally, the thesis is summarised, and the research questions are revisited in Chapter 6, which also highlights the main contributions of this work. This chapter also examines the study's limitations and suggests a possible future research agenda.

Chapter 2

Dyslexia Background

2.1 Introduction

Dyslexia, or specific reading disability, belongs to the family of learning disabilities (Shaywitz et al., 2008). It is one of the most common learning disabilities, affecting about 80% of those people identified as learning disabled (Lerner, 1989). This chapter presents the theoretical foundations of dyslexia in terms of definition, causes, symptoms and classifications. It covers how dyslexia varies between different languages and cultures and some of the developmental disorders that occur as comorbidities. At the end of this chapter, interventions for people with dyslexia are presented.

2.2 Definition of Dyslexia

German ophthalmologist Rudolf Berlin coined the term dyslexia (Wagner, 1973) from a combination of two Greek words: *dys-* meaning *difficulty* or *impaired* and *lexis* meaning *word*. The literal translation is *difficulty with words* (Critchley, 1968; Berninger et al., 2008; Alsobhi et al., 2014). It is widely accepted to be one of the most important learning disabilities (de Quirós and Schrager, 1978; Stanovich, 1994).

Various communities, researchers and international organisations have proposed definitions of dyslexia. Three definitions are commonly cited (Wajuihian and Naidoo, 2011), including one given by the World Federation of Neurologists in 1968: *'a disorder manifested by difficulty in learning to read, despite conventional instruction, adequate intelligence and socio-cultural opportunity. It is dependent upon fundamental cognitive disabilities, which are frequently constitutional in origin'* (p. 7) (Krupska and Klein, 1995).

At the beginning of the 21st century, this definition was expanded to *'a specific learning disability that is neurobiological 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 growth of vocabulary and background knowledge'* (p. 2) (Lyon et al., 2003).

Thirdly, the British Dyslexia Association (2010) offers the following definition, adopted from Rose (2009): *'Dyslexia is a learning difficulty that primarily affects the skills involved in accurate and fluent word reading and spelling. Characteristic features of dyslexia are difficulties in phonological awareness, verbal memory and verbal processing speed. Dyslexia occurs across the range of intellectual abilities. It is best thought of as a continuum, not a distinct category, and there are no clear cut-off points. Co-occurring difficulties may be seen in aspects of language, motor co-ordination, mental calculation, concentration and personal organisation, but these are not, by themselves, markers of dyslexia. A good indication of the severity and persistence of dyslexic difficulties can be gained by examining how the individual responds or has responded to well-founded intervention'.*

The main International Classification of Diseases, ICD-10, provides the following formal definition of dyslexia:

> *'The main feature of this disorder is a specific and significant impairment in the development of reading skills, which is not solely accounted for by mental age, visual acuity problems, or inadequate schooling. Reading comprehension skill, reading word recognition, oral reading skill, and the performance of tasks requiring reading may all be affected. Spelling difficulties are frequently associated with the specific reading disorder and often remain into adolescence even after some progress in reading has been made. Children with the specific reading disorder frequently have a history of specific developmental speech and language disorders, and comprehensive assessment of current language functioning often reveals subtle contemporaneous difficulties. In addition to academic failure, poor school attendance and problems with social adjustment are frequent complications, particularly in the later elementary and secondary school years. The condition is found in all known languages, but there is uncertainty as to whether or not its frequency is affected by the nature of the language and of the written script'* (p. 245) (World Health Organization, 1992).

To sum up, many definitions of dyslexia exist; however, no consensus has been reached. People with dyslexia are often called dyslectics or dyslexics. However, following the general guidelines on writing about people with disabilities (Cavender et al., 2008), we do not use these terms and instead use this descriptive phrase: **individuals/people/learners/children with dyslexia**.

2.3 Causes of Dyslexia

Dyslexia can be linked to genes and, therefore, runs in families. Imaging scans show the brain in people with dyslexia processes language differently. The following sections describe these differences.

2.3.1 Genetic Basis of Dyslexia

Dyslexia has a genetic component. Research has linked reading difficulties to genes (Stein, 2001; Olson, 2002; Taipale et al., 2003). Initially, the phonological skill was seen as hereditary and linked to a specific genetic component. Later, the orthographic skill was also discovered to be inherited and linked to other unique genetic components (Stein, 2001; Olson, 2002).

Molecular studies have associated dyslexia with several candidate genes. The first candidate gene, dyslexia susceptibility 1 candidate 1 (DYX1C1), was discovered in 2003 (Taipale et al., 2003). In 2005, three different genes were discovered and observed as being linked to dyslexia. These genes are: KIAA0319 (Cope et al., 2005), roundabout drosophila homolog 1 (ROBO1) (Hannula-Jouppi et al., 2005) and doublecortin domain-containing protein 2 (DCDC2) (Meng et al., 2005). These genes are located on various chromosomes, such as 6 and 15 (Cope et al., 2005).

Overall, as the molecular genetics of dyslexia are discovered, many potential treatments have emerged. One is the modifications of genetic chromosomal material to prevent the expression of dyslexia in future generations (Olson, 2002). Also, there is the possibility of early assessment of dyslexia by genetic screening (McGrath et al., 2006).

2.3.2 Neuroimaging Techniques

The reading process involves widely distributed areas of the brain and various component operations (Fiez and Petersen, 1998; Brown et al., 2001). Modern neuroimaging techniques, such as functional magnetic resonance imaging (fMRI) and positron emission tomography (PET), have produced clear images of the different activities and areas of the brain that may be involved in the reading process (Brown et al., 2001).

In dyslexia, brain-imaging studies have focused on several targets. The fMRI technique, for example, has been used to examine the size and symmetry of the plana temporal in people with and without dyslexia (Larsen et al., 1990). The planum temporal is a gross anatomical structure in the brain. According to Larsen et al. (1990), 70% of people with dyslexia were more likely to exhibit planum symmetry, whereas only 30% of those without dyslexia showed symmetry.

Other fMRI studies have compared brain activation patterns among individuals with and without dyslexia (Shaywitz et al., 1998). They found that the brain activation patterns in people with dyslexia are under-activated in the posterior brain regions and over-activated in the anterior regions. This provides a neurological connection to the phonological difficulties associated with dyslexia (Shaywitz et al., 1998). fMRI and PET studies have also shown that the brain's left hemisphere in people with dyslexia is not activated in the same way as in people without dyslexia (Dulude, 2012). There are impaired patterns of brain activity in the left temporal partial and interior frontal lobes (Brown et al., 2001).

Overall, neuroimaging techniques will remain valuable tools for dyslexia research, as their results can support the findings from other methodologies (Fiez and Petersen, 1998).

2.4 Symptoms of Dyslexia

Symptoms of dyslexia differ from one person to another (Alsobhi et al., 2014; National Health Service, 2021), and the forms and degrees of severity of the difficulties also vary among individuals (Al-Wabil et al., 2006). As a result, most individuals with dyslexia have specific needs and different experiences of learning (Vaughn and Linan-Thompson, 2003; Alsobhi et al., 2014; Jones, 2015).

Many early symptoms of dyslexia exist before children enter school, such as poor performance in phonological processing skills (Eden, 2016) and difficulty in decoding words when starting reading (Understood Team, 2018b). Decoding words (which means matching letters to sounds) is the first step towards reading accurately and fluently.

As mentioned earlier, dyslexia's symptoms differ from one person to another. From the educational view, symptoms of dyslexia that can be used when identifying dyslexia at different ages are outlined below.

Symptoms of dyslexia in pre-school individuals can include:

- Delay in speech development compared to their peers, such as being unable to pronounce long words correctly and jumbling between letters; for example, *helicopter* as *hecilopter* (Brazier, 2020; National Health Service, 2021).
- Difficulties in using spoken language to express themselves, inability to put sentences together and difficulty in remembering information such as numbers, colours and alphabets (National Health Service, 2021).
- Struggling to learn new words (Understood Team, 2018b).
- Difficulties in recognising letters and matching them to their sounds (Understood Team, 2018b; Brazier, 2020).

Symptoms of dyslexia in individuals in primary school can include:

- Phonological awareness difficulties: inability to recognise the phonemes that make up the complete word and how variations in these phonemes lead to the creation of other words (Kamala, 2014; Brazier, 2020; National Health Service, 2021).

- Confusing directions (up-down, right-left, yesterday-tomorrow) (Brazier, 2020; National Health Service, 2021).
- Difficulties in learning and remembering sequences, such as alphabets and days of the week (National Health Service, 2021).
- Difficulties in writing and spelling that include one or a combination of the following problems:
  - Inconsistent and unpredictable spelling that causes difficulties in recognising letters and words (Kamala, 2014; National Health Service, 2021).
  - Letter and number reversal, for example, *b* instead of *d* and *9* instead of *6* (Pirani et al., 2013; Kamala, 2014; Brazier, 2020; National Health Service, 2021).
  - Good when answering questions orally but difficulty when asked to write answers down (National Health Service, 2021).
  - Poor handwriting and slow writing speed (Kamala, 2014; National Health Service, 2021).
  - Difficulty in copying written words from the board and the need for more time to complete written work (National Health Service, 2021).
- Difficulties in reading that include one or a combination of the following problems:
  - Slow reading, frequent stopping and mistakes when reading aloud. These problems are due to difficulties in either combining the sounds of a word or extracting the sounds (Pirani et al., 2013; Kamala, 2014; National Health Service, 2021).
  - Difficulty in reading familiar words such as *cat*, skipping over small words such as *to* (Kamala, 2014; Understood Team, 2018a) and confusing the letter order in a word (Kamala, 2014; National Health Service, 2021).

Symptoms of dyslexia in individuals in intermediate and secondary schools:
In addition to previous symptoms, learners may have the following symptoms:

- Avoiding reading and writing when possible (Understood Team, 2018a; National Health Service, 2021) and becoming frustrated when reading (Understood Team, 2018a).
- Not reading at the expected grade level (Kamala, 2014; Understood Team, 2018b).
- Difficulty in writing and organising reports or essays (National Health Service, 2021).
- Always preferring multiple-choice questions over short answer or fill-in-the-blank (Understood Team, 2018b).

- Having trouble in expressing their ideas even though they may have the knowledge (Understood Team, 2018a; National Health Service, 2021).
- Experiencing the following symptoms due to issues in short-term memory:
  - Many spelling errors (Understood Team, 2018a,b; National Health Service, 2021).
  - Difficulty in remembering things such as telephone numbers or PINs (National Health Service, 2021) and common abbreviations (Understood Team, 2018a).
  - Difficulty in revision for exams (National Health Service, 2021).

In addition, individuals with dyslexia have difficulties in concentration and may feel mentally exhausted after a period of struggling to read or write (Brazier, 2020). They may also have difficulty with time management tasks and organisational skills (Abdullah et al., 2009), and they are often demotivated and experience low self-esteem (LaFrance, 1997).

Although dyslexia affects people in different ways, on the plus side, individuals with dyslexia have a variety of abilities and strengths. They can be considered to have a gift or talent (Davis and Braun, 2011). Different researchers have highlighted some common positive characteristics of people with dyslexia, including musical ability, flexibility in problem-solving, imagination (Waterfield, 2002), an ability to gain information through physical senses (LaFrance, 1997), intuition and creative thinking (Amesbury, 2007).

According to West (2005), some studies noted that people with dyslexia are often represented in creative occupations such as engineering, art, medicine, mathematics or science. Some well-known people with dyslexia have made significant contributions in their fields: Thomas Edison, Albert Einstein and Isaac Newton (Stein, 2001; Sekovanić et al., 2012).

To sum up, the symptoms of dyslexia vary from one person to another. Each individual has a different pattern of strengths and difficulties. Therefore, early identification of dyslexia followed by intervention based on specific needs and strengths may be required to compensate for their weaknesses and achieve positive learning outcomes (Karolyi et al., 2003; Everatt et al., 2008).

2.5 Classifications of Dyslexia

The first person who suggested a classification for developmental dyslexia was the educational psychologist Helmer Myklebust in 1965 (Friedmann and Coltheart, 2016). Myklebust indicated that developmental dyslexia can be divided into **auditory dyslexia** and **visual dyslexia**. Auditory dyslexia is a difficulty in reading due to the inability to acquire the auditory equivalents of letters, while visual dyslexia is a difficulty in visualising letters mentally (Friedmann and Coltheart, 2016).

Boder (1973), a paediatric neurologist, characterised Myklebust's auditory dyslexia and visual dyslexia in more detail. Myklebust's auditory dyslexia is known as **dysphonetic dyslexia**, which means the inability to sound out and blend a word's letters and syllables. These days, this type is called **developmental phonological dyslexia** (Friedmann and Coltheart, 2016). In contrast, Boder (1973) referred to Myklebust's visual dyslexia as **dyseidetic dyslexia**, which is an issue in reading irregular words, and nowadays is called **developmental surface dyslexia** (Friedmann and Coltheart, 2016).

Various classifications of dyslexia exist. Much research has attempted to classify dyslexia to understand their difficulties and then provide suitable solutions. Broadly, dyslexia can be classified by:

- **Symptoms** (Alsobhi et al., 2014).
- **Difficulties that individuals with dyslexia may face** (Jones, 2015).
- **Impairments in components of the reading model and the connections between these components** (Friedmann and Coltheart, 2016).

These different classifications are presented in the following sections.

2.5.1 Classification Based on Symptoms

Some researchers considered the classification of Ingram, which classifies dyslexia according to three groups of symptoms (Alsobhi et al., 2014):

1. **Visuo-spatial difficulties**: difficulties in the following:
   - Letter recognition and guessing a letter by its shape rather than its context.
   - Differentiating between letters, phrase orders and reproducing them.
   - Confusion in reversible letters, such as *b* and *d*, and they may also read words backwards, such as *saw* instead of *was*.
2. **Speech sound difficulties**: difficulties in understanding spoken language, which leads to the following challenges:
   - Breaking words into syllables.
   - Sentence forming.
3. **Correlating difficulties**: writing difficulties due to the inability to link a letter to its appropriate speech, especially monosyllabic words.

2.5.2 Classification Based on Difficulties

In contrast to the previous classification of dyslexia based on symptoms, other classifications of dyslexia are based on the difficulties faced by people with the condition (Jones, 2015):

1. **Hearing processing dyslexia**: experiences loss of attention, noise distraction and forgetting instructions.

2. **Phonological dyslexia**: difficulty with processing phonemes and splitting a word into syllables (as **speech sound difficulties** in Ingram's classification (Alsobhi et al., 2014)).

3. **Slow-speed processing dyslexia**: experiences slow information processing when studying in the classroom, reading a book or writing a story or homework.

4. **Visual processing dyslexia**: experiences inaccurate copying and confusion in reversible letters such as *b* and *d* (as **visuo-spatial difficulties** in Ingram's classification (Alsobhi et al., 2014)).

Another attempt was made to classify dyslexia into the following types (Brazier, 2020):

1. **Phonological dyslexia**: difficulty in dividing words into syllables and in matching sounds to their written forms. These problems are the same as **phonological dyslexia** in Jones (2015)'s classification. This type is also known as **auditory dyslexia** or **dysphonetic dyslexia**.

2. **Surface dyslexia**: difficulty in recognising a word by sight, which makes learning and remembering words hard. This type is called **dyseidetic** or **visual dyslexia**.

3. **Rapid naming deficit**: difficulty in naming a letter or number quickly.

2.5.3 Classification Based on Impairments in Reading Model Components

Another approach to classifying dyslexia is based on impairments in different components of the reading model and connections between these components (Friedmann and Coltheart, 2016). The dual-route model for single-word reading results from work in neuropsychology over the past four decades. This model has been chosen in this research because it provides a way to predict different types of developmental dyslexia. The model is widely used and has been proven effective (Annett, 1996).

We will first describe the different components of the dual-route model for single-word reading in the following section. Then, the different types of dyslexia based on impairments in different components within this model are presented.

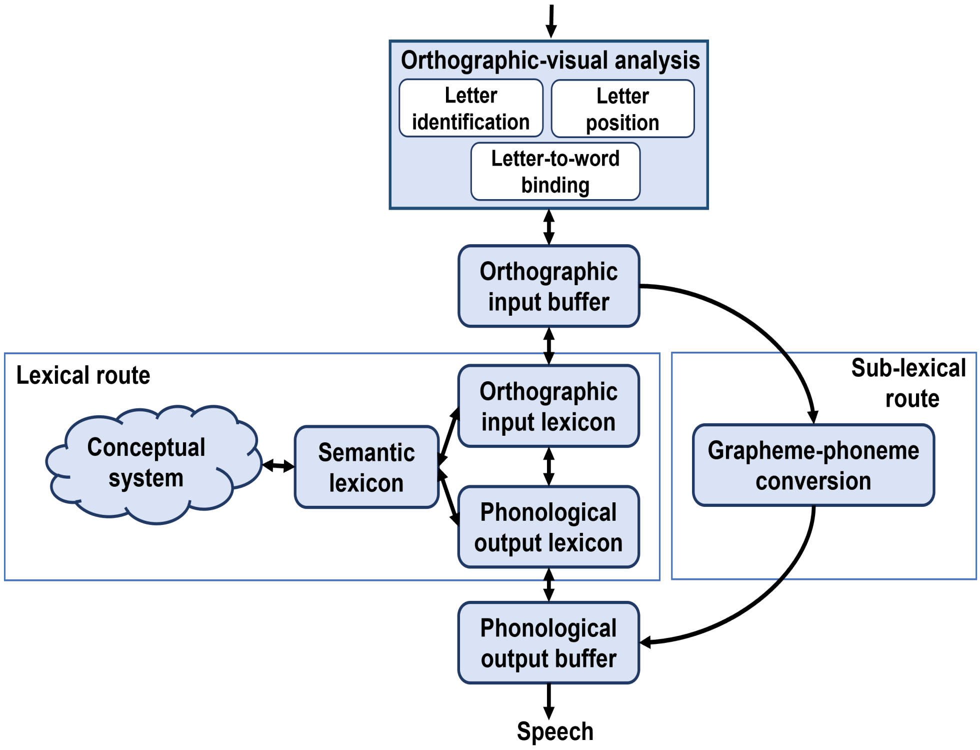

Figure 2.1: The dual-route model for single-word reading (Friedmann and Coltheart, 2016).

2.5.3.1 The Dual-Route Model

The process used to read a word according to the dual-route model is depicted in Figure 2.1.

1. The written word is analysed through the **orthographic-visual analysis system** with the following sub-stages:

    - **The abstract letter identification sub-stage**: involves identifying the letter. A letter is stripped of its size and font and identified as an abstract letter without its name or sound.
    - **The letter position encoding sub-stage**: encodes the position of each letter in the target word relative to the first and last letter positions in the word.
    - **The letter-to-word binding sub-stage**: reading typically involves a word in the context of other words. Therefore, this sub-stage attenuates the words around the target word and binds its letters together. This enables the identification of the letters as part of a specific word.

2. The output of the **orthographic-visual analysis system** will be held in the **orthographic input buffer**, a short-term memory. This buffer is responsible for morphological decomposition (decomposing the target word to its stems). For example, the word *birds* is decomposed to *bird*, enabling the word to be in a form that facilitates the search process in the **orthographic input lexicon**. This stage is called the **pre-lexical** stage.

3. At this point, the word has been decomposed into two parts: its stem *bird* and its affix *-s*. The stem activates the relevant entry in the **orthographic input lexicon**, while the affix activates its corresponding entry and meaning by searching through the **phonological output buffer**. For example, the *-s* in *birds* means a plural.

4. There are two routes for information stored in the **orthographic input buffer**: **lexical** and **sub-lexical**. The **lexical route** allows readers to read known words (words already stored in their lexicons) quickly and accurately. The **sub-lexical route** allows readers to read non-words or new words that are not found in their lexicons.

5. If the **lexical route** is used, then the following stages are included:

   - The **lexical route** starts with the **orthographic input lexicon**. This lexicon organises the words based on their frequency. Therefore, accessing and reading more frequent words is faster than words with lower frequency. However, this lexicon does not have sounds or the meaning of the words; instead, it contains pointers to them.
   - The information flows from the **orthographic input lexicon** to the **phonological output lexicon** to access the phonological form of a written word. The **phonological output lexicon** contains phonological information, such as number of syllables, stress position, the vowels and consonants of the word. As the **orthographic input lexicon** and the **phonological output lexicon** are directly connected, the reader can convert the written word to its phonological representation accurately and quickly.
   - In the final stage, the **phonological output buffer** that is shared with the **sub-lexical route** is accessed. This short-term memory buffer is responsible for storing the phonological information until its production is completed, assembling units into larger ones to create the whole word and adding affixes to their stems to reconstruct complex words.

6. Comprehension of the word is achieved through the path between the **orthographic input lexicon** and the **conceptual semantic system**. The relevant entry in the **semantic lexicon** is activated by the **orthographic input lexicon**, and the corresponding concept in the **conceptual system** will be activated. The **conceptual system** stores the concepts to achieve an understanding of written words, objects and pictures. The **semantic lexicon** acts as a central system with pointers between each entry to its phonological and conceptual representations.

7. The **lexical route** is used to read known words; this route has nothing to offer when reading words that are not in the lexicons. In this case, a different route, the **sub-lexical route**, is

used to read unknown words (non-words and new words). The **sub-lexical route** includes two stages:

- First, the target word is passed through the **grapheme-to-phoneme conversion**. The letters are parsed into letters, a group of letters or into graphemes. For example, the letter *c* and *h* in the word *chair* are parsed as a single grapheme producing a single phoneme.
- Second, the grapheme-to-phoneme rules are applied, and the **phonological output buffer** is used to collect the resulting phonemes and group them to create the full string of the word.

To conclude, skilled readers use both routes when reading aloud, as explained below:

- If the written word is known, it will be read through the **lexical-phonological route**, and the **conceptual-semantic system** will be used for comprehension.
- If the target word is a non-word or a new word, the **sub-lexical phonological route** is used.
- Finally, if the target word has low frequency and exists in the **orthographic and phonological lexicons**, then it will take longer to search for it in each lexicon and hence, it will be read with the same speed in each route, **lexical and sub-lexical routes**, in parallel. The **phonological output buffer** will deal with the results of the two routes together. Two outcomes are possible:
  - If the two routes produce the same output, there will be no problems, and the **phonological output buffer** will handle both outputs.
  - If the two routes provide a different output, there will be a clash in the **phonological output buffer** leading to a delay in reading aloud. For example, the word *castles* could be read with a silent *t* through the **lexical route**, but it could also be read by pronouncing *t* through the **sub-lexical route**.

Having described the components of the dual-route model, the following section presents different types of dyslexia based on impairments in this model.

2.5.3.2 Types of Dyslexia Based on Impairments in the Dual-Route Model

The two main classes of developmental dyslexia are based on impairments in the reading model's components or connections between them: **peripheral dyslexia** and **central dyslexia** (Friedmann and Coltheart, 2016). Each type has five main sub-types explained in the following paragraphs.

Peripheral Dyslexia Peripheral dyslexia results from deficits in the **orthographic-visual analysis** stage. It has the following sub-types:

1. **Letter position dyslexia (LPD)**: people with this sub-type can identify the letters correctly, but they fail in encoding the order of the letters within a word. The main symptom is letter migration within a word, especially the middle letters, while the first and last letters rarely change locations. The migrations could occur in vowels and consonants, root letters and affixes, and affects adjacent letters more than non-adjacent ones. The migrations affect both words and non-words, especially when the target word is migratable (when the letter position error creates an existing word like *cloud*, which could be read as *could*).
   The lexicality effects on the rate of letter migrations errors are explained below:

   - The orthographic-visual analyser provides information about letter position. If the order of the middle letters is unknown, then the input to the orthographic input lexicon will activate an entry that matches incomplete information. For example, the word *form*, an input says that *f* is the first letter, *m* is the last one, and there are *o* and *r* in some order in the middle. Thus, both *form* and *from* will be activated and allow the migration error to occur.
   - If the target word is *frog*, which is non-migratable, then only *frog* will be activated because the word *forg* does not exist.
   - If a non-word like *talbe* is the target, then the visual analyser will provide the lexicon with letter identities but without the order of middle letters. In this case, the word *table* will be activated in the orthographic input lexicon.

   The frequency effects on the rate of letter migrations errors are explained below:

   - If the target word is *salt*, then the information will be: *s* is the first letter, *t* is the last one, and *a* and *l* in the middle in some order. The word *salt* is more frequently used than *slat*, so it will be activated and read correctly, even though the letter positions are encoded incorrectly.
   - If the word *slat* is the target, then the word *salt* will be activated because it is more frequently used than *slat*, leading to incorrect reading due to migration errors.

   Another error that LPD can cause is omitting repeated letters, such as reading *baby* as *bay* due to a deficit in encoding letters' position within a word, which leads to deleting one of the repeated letters.

LPD can be found in Arabic, English, Hebrew, Italian and Turkish. However, LPD can be diagnosed easily in Hebrew because it has many migratable words. Diagnosis of LPD in readers of English requires a particular list of migratable words. There are fewer letter-position errors in Arabic compared to Hebrew because each letter has a different form in different positions within a word. Accordingly, for diagnostic purposes, migratable words in which migration does not change letter form should be used.

2. **Attentional dyslexia**: people with this sub-type can identify the letters and positions correctly within a word, but they fail in encoding the position of letters between words. For example, *cane love* can be read as *lane love* or *lane cove.* Letters may migrate from a word above, below, left or right of the target word. Migration is more likely to happen if it results in an existing word. Other effects are related to the length of words. Migration errors occur more between longer words than shorter ones. Also, it occurs more between words that differ in more letters than those that differ in only one letter.

   Attentional dyslexia can cause the omission of an instance of a letter that appears in the same position in two words. For example, *clay plan* could be read as *clay pan.* Also, people with attentional dyslexia fail to bind letters to words and then do not distinguish between two letters. As a result, they cannot realise that there are two instances of *l*, and one instance will be omitted.

   Like LPD, attentional dyslexia has been found in different languages, such as English, Arabic, Hebrew, and also in Italian and Turkish. This sub-type of dyslexia is easy to diagnose because there is a high probability of creating existing words due to between-word migration. In Arabic, the letters have different shapes in different positions within a word. Accordingly, some migration will be prevented, thus decreasing the rate of between-word migration.

3. **Letter identity dyslexia**: this sub-type results from a deficit in the function that creates abstract letter identities. Individuals with letter identity dyslexia are unable to access the abstract letter's identity from its visual form. Therefore, they have difficulties naming a letter, matching different cases of letters such as *A* and *a* and identifying the name and sound of a written letter.

   Note that individuals with letter identity dyslexia do not experience any visual deficit. They can match different sizes of the same letters and copy letters correctly.

4. **Neglect dyslexia**: people with this sub-type neglect either the left or right side of a word or sentence. Depending on the level of occurrence of neglect, neglect dyslexia is categorised into two classifications:

- Word level: letters on the neglected side are omitted, added or substituted. This is due to orthographic-specific deficits and not related to visuo-spatial attention.

- Text/sentence level: omission of whole words on the neglected side due to visuo-spatial neglect effects.

Neglect dyslexia can be classified based on the side where neglect occurs: left and right. Left neglect is more common than right neglect.

Only the word level of developmental neglect dyslexia (known as **neglexia**), has been discussed so far in previous research. Neglexia usually neglects the left side of a word by omitting, adding or substituting letters on that side. This frequently happens if the result is an existing word.

Left neglect has been identified in Arabic and Hebrew. Right neglect has been identified in Turkish.

5. **Visual dyslexia/ orthographic input buffer dyslexia**: people with this sub-type experience a deficit in the output of the orthographic-visual analyser. This deficit affects all orthographic-visual analyser functions: letter identification, letter position encoding and letter-to-word binding. As a result, it involves letter identity errors and letter migration errors between and within words.

   Visual dyslexia can be distinguished from other previous sub-types as follows:

   - **Letter identity dyslexia**: visual dyslexia differs from this sub-type in that it involves letter omissions and substitutions as in letter identity dyslexia, but visual dyslexia also includes migrating letters between and within words.

   - **LPD**: visual dyslexia differs from this sub-type in that it involves letter omissions and substitutions, as well as letter migrations between words and not only letter migrations within words, as is the case with LPD. Moreover, letter migrations within words in visual dyslexia can occur in exterior and middle letters and not only in the middle, as in LPD.

   - **Attentional dyslexia**: visual dyslexia differs from this sub-type in that it involves letter omissions, substitutions and migrations within words and not only between words as in attentional dyslexia.

   - **Neglexia**: visual dyslexia differs from this sub-type, where neglect errors occur on all sides of a word, not only on one side, as in neglexia.

A summary of all the above types of peripheral dyslexia is presented in Table 2.1.

Table 2.1: Types of peripheral dyslexia.

Dyslexia type	Definition
LPD	Ability to identify the letters correctly, but they fail in encoding the order of the letters within a word.
Attentional dyslexia	Ability to identify the letters and positions correctly within a word, but they fail in encoding the position of letters between words.
Letter identity dyslexia	Inability to access the abstract letter's identity from its visual form.
Neglect dyslexia	Neglecting either the left or right side of a word or sentence.
Visual dyslexia/ orthographic input buffer dyslexia	Experiencing a deficit in the output of the orthographic-visual analyser, that affects all orthographic-visual analyser functions: letter identification, letter position encoding and letter-to-word binding.

Central Dyslexia Central dyslexia is a reading impairment that results from deficits in the later stages of reading, in the **lexical** and **sub-lexical routes**. It has the following sub-types:

1. **Surface dyslexia**: this sub-type results from a deficit in the lexical route, forcing readers to use the sub-lexical route through grapheme-to-phoneme conversion when reading aloud, causing the following problems:

    - Making errors when reading irregular words like *receipt, stomach* that include a silent letter or a letter that is pronounced using a phoneme that is different from the phoneme produced by grapheme-to-phoneme conversion.
    - Making errors when reading words that lead to ambiguous conversion to phonology like *bear*, which could be read as *beer*.
    - Making errors when reading words with more than one syllable, especially in languages in which the stress is determined lexically and not orthographically and in languages that do not specify all vowel letters in the orthography like Arabic and Hebrew.

    To read words correctly and overcome the previous errors, the lexical, word-specific knowledge should be accessed. However, this information is stored in the lexical route, specifically in the orthographic input lexicon, but this route is impaired, leading to misreading words. In contrast, regular words are read correctly using the sub-lexical route because they have one pronunciation, even if they are infrequent. Also, people with surface dyslexia can read non-words normally via the sub-lexical route.

    Surface dyslexia affects comprehension due to an impairment in the orthographic input lexicon. Readers must use the sub-lexical route to accomplish comprehension as follows:

    - A word is generated in the phonological output buffer based on grapheme-to-phoneme conversion.

- The phoneme sequence in the phonological output buffer is produced. Then, the conceptual-semantic system is accessed through the following phonological input components: the phonological input buffer and the phonological input lexicon.

Now, the correct comprehension of non-homophonic words like *dog* or *paper* is accomplished. However, understanding homophonic words is difficult. For example, the words *which* and *witch* cannot be distinguished due to deficits in the orthographic input lexicon.
Surface dyslexia also affects reading speed, causing a slower reading process than normal, even if the word is read correctly via the sub-lexical route. This is because each letter in the word is converted to its phoneme sequentially rather than reading the whole word via the lexical route.
The lexical route is a multi-component route, so any deficit in its components or connections will lead to surface dyslexia. Several patterns of surface dyslexia exist:

- The orthographic input lexicon or access to it via the orthographic-visual analyser is impaired. In this case, the lexical decision of pseudohomophones is affected. An example is deciding whether *anser* is a word or not. Also, the understanding of homophones and potentiophones is affected (for example, it is difficult to determine if the word *whether* is a question word or relates to temperature).
- The orthographic input lexicon is not impaired, but its output connection to the semantic lexicon and the phonological output lexicon is impaired, which might affect the understanding of homophones.
- The connection between the phonological output lexicon and the orthographic input lexicon is impaired. In this case, **inter-lexical surface dyslexia** appears. Here, reading aloud will be affected, while homophone comprehension and the lexical decision will be fine.
- A deficit exists in the phonological output lexicon itself. In this case, word production is affected in the context of reading, naming and spontaneous speech.

2. **Phonological dyslexia**: people with this sub-type experience deficits in the sub-lexical route, leading to the use of the lexical route. Phonological dyslexia causes difficulty in reading non-words, while words already stored in the orthographic input lexicon and phonological output lexicon can be read correctly. People with this form of dyslexia cannot read new words and face difficulties when they begin to read because every word is considered a new word. They need more time to learn to read. They master reading when words are stored in

the orthographic input lexicon.

Based on the point of a deficit in the sub-lexical route, phonological dyslexia can be classified into the following:

- **Letter-to-phoneme conversion phonological dyslexia**: people with this type have a deficit in single letter conversion into phonemes. This leads to difficulty in reading single letters along with reading non-words. This type is the most basic form of phonological dyslexia.
- **Multi-letter phonological dyslexia**: people with this type have a deficit in reading multi-letter graphemes, but it does not affect single letter pronunciation. They have difficulty with the conversion rules that are applied to multiple letters. An example is pronouncing *a* in *mat* and *mate*.
- **Phonological-output-buffer phonological dyslexia**: this type is the most frequent. Readers have a deficit in the stage after the conversion process. The phonological output buffer is responsible for receiving the conversion's output, blending and holding it until the production is completed. Individuals with this type do not have difficulty reading single letters and single graphemes but do have difficulties in reading long words and non-words. Moreover, non-words are affected more gravely than words because words can be supported via activation from the phonological output lexicon, while non-words cannot. Also, as the phonological output buffer is responsible for assembling morphologically complex words, individuals with this type have a deficit in reading these words either by omitting or replacing the non-base morphemes.

3. **Vowel letter dyslexia (VLD)**: people with this type experience replacing, omitting, adding and transposing vowel letters as a result of a deficit in the sub-lexical route that is responsible for processing vowels. Thus, they read *bit* as *bat*, *boat* or *but*. These errors occur only when reading vowel letters and not in the vowel phonemes during speech production.
   Because the deficit is in the sub-lexical route, individuals have difficulties when reading new words and non-words, but they can read correctly through the lexical route.
   VLD is more common in Arabic and Hebrew because their orthographies allow for omission or transposition of vowel letters.

4. **Deep dyslexia**: people with this type experience the production of semantic errors in reading, such as reading *lime* as *sour* or *lemon*. They also experience morphological errors, such as reading *played* as *play* and visual errors, like reading *gum* as *game*. These errors force

individuals to read via meaning due to damage in both the sub-lexical grapheme-to-phoneme conversion route and the lexical route between the orthographic input lexicon and the phonological output lexicon.

Deep dyslexia has been identified in Arabic and English. However, Arabic is a diglossic language where the spoken language is different from the standard written language. As a result, individuals with deep dyslexia read a word by looking at it, understanding it and naming it based on its meaning or visual images. This leads to reading a word as a spoken vernacular term rather than the standard word that was written. An example is reading the standard Arabic word *dar*, which means *house*, as its vernacular *bet*.

5. **Access to semantics dyslexia**: this type, which is sometimes referred to as **direct dyslexia**, has some abilities, such as reading new words and non-words fluently and accurately. People with this condition can also read many kinds of words aloud, including low-frequency words, irregular words and morphologically complex ones. However, they cannot understand written words despite correctly reading aloud. The correct reading indicates that both the lexical route between the orthographic input lexicon and the phonological output lexicon and the sub-lexical route are preserved. The following deficits could cause the misunderstanding of written words:

    - A deficit in the connection between the semantic lexicon and the orthographic input lexicon. The deficit only affects the comprehension of written words, while reading non-words and single words aloud, understanding heard words and word production are not affected.
    - A deficit in either the semantic lexicon or the conceptual system. In this case, individuals have difficulties understanding words they both read or hear.

A summary of all the above types of central dyslexia is presented in Table 2.2.

To conclude, different classifications of dyslexia exist: 1) Ingram, which classifies dyslexia according to symptoms, 2) difficulties of dyslexia that people face and 3) impairments in components of the reading model and the connections between these components. In this research, the dual-route model was chosen because it provides a way to predict different types of developmental dyslexia, is widely used and has proven effective (Annett, 1996).

Ten types of dyslexia have been identified due to impairments in different components and connections between them in the reading model. In Hebrew, **LPD** and **surface dyslexia** are the most frequent types, followed by **attentional dyslexia** and **VLD** (Friedmann and Coltheart, 2016). In Arabic, seven types of dyslexia are identified: **LPD, VLD, attentional dyslexia, neglect**

Table 2.2: Types of central dyslexia.

Dyslexia type	Definition
Surface dyslexia	Making errors when reading irregular words and words with more than one syllable.
Phonological dyslexia	Experiencing difficulty in reading non-words, new words and face difficulties when they begin to read.
VLD	Experiencing replacing, omitting, adding and transposing vowel letters.
Deep dyslexia	Experiencing the production of semantic errors in reading, and morphological errors, and visual errors.
Access to semantics dyslexia	Experiencing difficulty in understanding written words despite correctly reading aloud.

dyslexia, visual dyslexia, surface dyslexia and **deep dyslexia** (Friedmann and Haddad-Hanna, 2014). **LPD** and **VLD** are the most frequent types (Friedmann and Haddad-Hanna, 2014; Al-Dawsari and Hendley, 2022); therefore, they are targeted in this research.

2.6 Dyslexia Across Different Languages

A phonological deficit is widely acknowledged as a primary cause of reading difficulties for people with dyslexia (Abu-Rabia et al., 2003; Katzir et al., 2004; Layes et al., 2019). The relationship between reading skills and phonological processing skills differs across languages as these skills are mainly determined by the characteristics of the language, including its orthography and linguistic structure. Thus, dyslexia can be considered to be a language-dependent learning disability and is affected by the orthography and structure of a language.

Despite the different types of orthography, either transparent (shallow) or non-transparent (deep), cases of dyslexia appear in all languages (Béland and Mimouni, 2001). However, Elbeheri et al. (2006) have observed that differences in the orthographies of languages influence the way the learning difficulty reveals itself across spelling, reading and phonology. Specifically, according to Spencer (1999), readers of languages with transparent orthographies, such as Turkish, Italian, Spanish, German and Greek, face fewer difficulties in reading than those of languages with non-transparent orthographies such as English, Dutch and French.

However, in languages with both transparent and non-transparent orthography, such as Arabic and Hebrew, readers depend on the type of orthography they encounter when deciding whether to use either lexical or non-lexical methods (Béland and Mimouni, 2001). Non-transparent orthographic languages cause problems due to ambiguity when processing words (Abu-Rabia, 2012). In fact, people without dyslexia rely on their familiarity with the lexicon and context of the word to read, which may be difficult for those with dyslexia (Gal, 2002).

The following sections describe dyslexia in English and then in Arabic because dyslexia in Arabic is targeted in this research.

2.6.1 Dyslexia in English

Alphabetic systems are mainly based on one-to-one mapping between phonemes and graphemes. However, some languages, such as English, deviate from this principle (Spencer, 2000). In the English orthography, the number of letters (26) is considered smaller than the number of phonemes (44), according to the International Phonetic Alphabet (IPA) (Spencer, 1999; Helland and Kaasa, 2005). English has multiple links between letters and phonemes (Lipka et al., 2005). For example, some letters are used to present different phonemes; the letter *o* expresses at least 10 phonemes: (/ʌ/ *love*, /ʊ/ *good*, /ɒ/ *cough*, /ɔɪ/ *oil*, /ə/ *actor*, /uː/ *moon*, /ɔː/ *floor*, /əʊ/ *dough*, /aʊ/ *cow*, /wɑː/ *memoir*) (Cook and Bassetti, 2005).

More than one letter is used to represent some phonemes, such as *ch* and *oi* in *choir* (Miles, 2000), and some letters have no sounds at all such as *b* in *lamb* (Draffan, 2002). In addition, there is no correspondence between the order of the information expressed in the letters and the order of phonemes in the word (Cook and Bassetti, 2005). For example, *e* in *dime* shows that the preceding *i* is pronounced as the free vowel /ai/ instead of the checked vowel /i/ (Cook and Bassetti, 2005). The primary syllable structure in English is consonant-vowel-consonant (CVC). However, some function words, such as *at* and *on*, have no initial defining consonant (Miles, 2000).

Due to the irregularities and no one-to-one mapping between graphemes and phonemes in English, the prevalence of dyslexia in this language increases (Spencer, 2000). Furthermore, people with dyslexia in English face difficulties in spelling, reading and writing due to this non-transparent orthography (Spencer, 1999; Goswami, 2002). Three cognitive processes are required to develop the reading process in English: phonological processing, working memory and syntactic awareness (Lipka et al., 2005). The phonological process is the most critical skill for reading English, and it can cause a series of difficulties beginning with the awareness of words as units of phonemes (Lipka et al., 2005). This process includes different levels of phonological awareness, which is an important skill for English reading (Miles, 2000; Mishra and Stainthorp, 2007), because the non-transparency of the link between the phonetic system of English and its orthography decreases its phonological recoverability (Gholamain and Geva, 1999).

According to Goswami (2002), establishing phoneme-based phonological representations in English among children without phonological deficits may take a long time. To learn to read English, children must develop multiple strategies in parallel, such as whole-word recognition and grapheme-phoneme recoding (Goswami, 2002). All these strategies affect the speed of development of phonological awareness skills and grapheme-phoneme recoding skills, which are expected to develop slowly in children with dyslexia due to their phonemic deficit (Goswami, 2002).

2.6.1.1 The English Alphabet and Writing System

In the English writing system, there are constraints on where combinations of letters can occur in words (Cook and Bassetti, 2005). For example, the combination of letters *tch* is a word-final combination as in *match*, and *ch* is utilised as its word-initial equivalent, as in *charm* (Cook and Bassetti, 2005). The combination *ck* cannot occur at the beginning of words, but it can occur in the middle as in *packet* or at the end of a word as in *pack*, and this is not related to the /k/ sound that may be found in other words (Treiman and Bourassa, 2000).

Another aspect of the writing system in English is the orientation of writing on the page: English is normally written from left-to-right in rows and top-to-bottom on the page (Cook and Bassetti, 2005). In addition, English distinguishes between alphabet forms: lower-case 'a b c', upper-case 'A B C' and italics '*a b c*' (Cook and Bassetti, 2005). It also utilises a space between words to separate them. For children with dyslexia, the space between words is not a major problem. However, they find difficulties in distinguishing word boundaries, as in the phrase *in the foreground*, which they can write as *intefregound* (Miles, 2000). Doubled letters and their single mates represent the same phoneme as in *later* and *latter* (Ehri, 2005). However, this can complicate spelling (Cook, 1997).

2.6.2 Dyslexia in Arabic

According to Elbeheri et al. (2006), it is essential to understand the relevant linguistic features of a specific language to understand and identify dyslexia in that language. Dyslexia in Arabic is the focus of this research because there is a paucity of research targeting dyslexia in this language (Alsswey et al., 2021), despite it being a widely spoken language with a considerable rate of dyslexia (El Kah and Lakhouaja, 2015; Benmarrakchi et al., 2017b; Alghabban and Hendley, 2020a; Al-Dawsari and Hendley, 2022).

Arabic is the official language of 22 countries in the Middle East (Elbeheri et al., 2006), and it is spoken by more than 230 million people (Boumaraf and Macoir, 2016). Arabic script plays a role in the development of dyslexia among children (El Kah and Lakhouaja, 2018). The fluency of reading Arabic depends on many factors, such as the visual form of words (Boumaraf and Macoir, 2016), phonology, morphology and diglossia (Abu-Rabia and Taha, 2005). All these factors can contribute to the manifestation of dyslexia among Arab speakers (Abu-Rabia and Taha, 2005).

2.6.2.1 The Arabic Alphabet and Writing System

The Arabic language consists of 28 letters that represent 34 basic phonemes. All 28 letters are consonants and represent a letter-sound alphabetical system, but some letters also serve as long vowels (Abu-Rabia, 1997). Unlike many other alphabetic languages, Arabic does not have upper- and lower-case variations (Elbeheri et al., 2006), which means the shape of letters is consistent. Also, Arabic is a bi-directional language because the letters are written and read from right to left

(Abu-Rabia and Sammour, 2013), while numbers go from left to right (Elbeheri, 2005).

In the Arabic script, letters are connected by means of ligatures, which is a cursive style (Elbeheri and Everatt, 2007). Six letters of 28 (ا ، د ، ذ ، ر ، ز ، و) are one-way connecting letters (letters joining to preceding ones only), leaving the remaining 22 letters as two-way connectors (letters can join to preceding and following letters) (Al-Wabil et al., 2006). Spaces within a text can be categorised as: 1) those that represent word boundaries and 2) those that occur within words between two-way connecting letters and one-way connecting letters (Elbeheri et al., 2006, 2011). With these two spaces and no capital letters, determining the word boundaries can be difficult in Arabic script (Elbeheri, 2005). This requires an Arabic reader to be able to differentiate between the spaces within a word and the spaces representing boundaries between words (Al-Wabil et al., 2006). According to Elbeheri (2005), readers with dyslexia may experience additional difficulties because one-way and two-way connecting letters and their influence on the identification of word boundaries have a negative impact on their ability to read.

Each letter has a different form based on its position within a word (initial, medial, final and as an isolated form) (Elbeheri and Everatt, 2007; Elbeheri et al., 2011). However, in all cases, the essential shape of the letter is maintained (Abu-Rabia and Sammour, 2013). For example, the letter (س) (in English *s*), has the following forms: (سـ) as the initial form, (ـسـ) as the medial form, (ـس) as the final form and (س) as the isolated form. However, the six letters (ا ، د ، ذ ، ر ، ز ، و) keep their shapes in words and are not joined to other following letters (Boumaraf and Macoir, 2016).

Another essential characteristic of the Arabic script is using dots to distinguish graphemes (Elbeheri and Everatt, 2007). The Arabic script consists of 17 basic letters, and the remaining 11 letters are made up by adding dots that vary in position and number (Elbeheri et al., 2011). These dots (one, two or three) are significant to differentiate between the Arabic letters (Elbeheri and Everatt, 2007), and they are an integral part of a letter and cannot be omitted, even when the text is non-vowelised (Boumaraf and Macoir, 2016). For example, the letters (ب، ت، ث) have the same shapes, but they differ in the number and position of dots within each letter. As a result, Arabic readers have a considerable challenge distinguishing between individual letters (Mahfoudhi et al., 2011).

Arabic script uses the letters *(ال) al* as a definite article, which is similar to *the* in English. It is connected to the beginning of a word to identify it. The identification letters have two types of phonemes: silent and spoken, according to the context of use. This feature adds additional difficulty for readers with dyslexia (AlRowais et al., 2013).

Arabic has a special letter called *Hamza* (ء), which denotes the glottal stop. It represents two types of phoneme: silent or spoken (Elbeheri, 2004). Some linguists consider *Hamza* as an independent grapheme, and in this case, there would be 29 letters in the Arabic alphabet instead of 28, but others consider *Hamza* to be a diacritical mark (Elbeheri, 2004).

In Arabic, short vowels are not part of the alphabet (Abu-Rabia, 1997), and they are represented by diacritical marks (small diagonal strokes above or below letters that assist a reader in pronunciation) (Abu-Rabia, 1997; Elbeheri et al., 2011). The diacritical marks are: fat-ha /a/, a small diagonal line above the letter, such as (دَ) /da/; kasra /i/, a small diagonal line below the letter, such as (دِ) /di/; and damma /u/, a small curl-like diacritic placed above the letter, such as (دُ) /du/ (Abu-Rabia and Sammour, 2013). Also, there is a fourth diacritical mark called sukun (a small circle placed over the letter that resembles a zero), which represents the absence of a vowel, such as (دْ) /d/ (Boumaraf and Macoir, 2016). Arabic also has three long vowels represented by extended letters (letters denoting sound extension of short vowels) (Boumaraf and Macoir, 2016). They are alef /a:/, such as (دا) /da:/; yaa /i:/, such as (دي) /di:/; and waw /u:/, such as (دو) /du:/ (Abu-Rabia and Sammour, 2013).

One of the main characteristics of Arabic orthography is that it can be either transparent or non-transparent. In the transparent orthography, both vowels (short and long) and consonants are presented (vowelised version). Therefore, the relationship between letters (graphemes) and sounds (phonemes) is a simple one-to-one relationship. This vowelised version is usually present in children's books, the Holy-Quran and dictionaries (Abu-Rabia and Sammour, 2013). In the non-transparent orthography, the short vowels are omitted, and only the long vowels and consonants are presented (non-vowelised version) (Elbeheri et al., 2011; Abu-Rabia and Sammour, 2013), resulting in a complex relationship between sounds and letters (Abu-Rabia, 2019). The non-vowelised version is used in most texts (Abu-Rabia and Sammour, 2013), and there is a preference for non-vowelised script, especially after initial literacy learning (Elbeheri et al., 2011). While skilled and adult readers can read non-vowelised texts, the context is considered an essential semantic facilitator to identify homographic words (Abu-Rabia, 1997). Almost every word can be a homograph in a passage (verb, noun, conjunction), and they represent different meanings (Abu-Rabia, 1997). Many words in Arabic are written similarly (share the same orthographic units) but are pronounced differently and have a different meaning if they are put in a sentence or are vowelised (Abu-Rabia, 2012). This causes a different process of morphological lexicon arrangement (Abu-Rabia, 2019). For example, one homograph is (كتب), where the pronunciation and meaning depend on the context or if used with short vowels, as in the following example (Béland and Mimouni, 2001):

- (كَتَبَ) means *he wrote* when pronounced as *kataba.*

- (كُتِبَ) means *it was written* when pronounced as *kutiba*.
- (كُتُبْ) means *books* when pronounced as *kutub*.

It has been argued that using short vowels has a positive effect on Arabic reading, but they can negatively impact words by increasing their visual complexity (Mahfoudhi et al., 2011; Elbeheri et al., 2011). Short vowels help readers to pronounce Arabic words accurately, especially for learners at the beginning of their education and also for learners who are struggling to read (Abu-Rabia and Taha, 2006). Usually, after the fourth grade, Arabic readers are expected to read texts without short vowels, which is a challenge (Abu-Rabia, 2012). This is supported by Al-Wabil et al. (2006), who state that reading non-vowelised text requires the reader to read non-existent short vowels, which is an additional cognitively demanding skill.

2.6.2.2 The Morphological Aspects of Arabic

Arabic is a Semitic language with a morphological structure in verbs and nouns (Friedmann and Haddad-Hanna, 2014). Arabic morphology is composed of two abstract units: root and pattern (Abu-Rabia et al., 2003), and an Arabic word is formed by combining these two units (Boumaraf and Macoir, 2016). The roots represent the basic morphemes (Abu-Rabia et al., 2003), and they are either triliteral (three consonants) or quadrilateral (four consonants). While roots are an abstract entity, not phonological units (Abu-Rabia, 2012), the pattern is the vocalic model on which the root molds to form the word (Boumaraf and Macoir, 2016).

There are two types of structure in Arabic morphology: derivational and inflectional (Abu-Rabia et al., 2003). Derivational morphology produces nouns from roots incorporated in nominal templates, while verbs are constructed from a trilateral root that is incorporated in verbal templates (Friedmann and Haddad-Hanna, 2014). The derivational morphology refers to various derivatives that are formed by: 1) adding short vowels to roots, where the phonological process maintains the orthographic order of the root, 2) adding vowel letters between the root consonants (infixes), where the phonological pattern breaks the orthographic order of the root and 3) adding vowel letters as prefixes or suffixes (Abu-Rabia, 2012). Many derivatives look identical (homographs) when they are written in their unvowelised form (Abu-Rabia and Siegel, 1995).

While the derivational morphology consists of roots and patterns, the inflectional morphology is built by attaching prefixes and suffixes to a word (Abu-Rabia, 2012). The verbs in the inflectional morphology system are systematic, and they consider number, person, gender and time. For example, adding suffixes to the basic verb pattern will form the past tense of that verb. Meanwhile, the inflectional morphology of the present and future tenses of a verb is constructed by the addition of prefixes and sometimes suffixes (Abu-Rabia, 2012). The nouns in the inflectional morphology system consider gender (masculine and feminine) and number (singular and plural).

A summary of all the above features of Arabic that could affect people with dyslexia and a comparison of these features with English features is presented in Table 2.3.

Table 2.3: Summary of linguistic features of Arabic and English.

Affected skills	**Features**	**Arabic**	**English**
Spelling, writing and reading skills	Cursive style (letters being joined together by means of ligatures)	Yes.	Yes (but rare use).
	Orthography	Transparent (shallow) and non-transparent (deep).	Non-transparent (deep).
	Including diacritical marks	Yes (14 diacritical marks represent the short vowels).	Use for a few words.
	Different forms of each letter	Yes (each letter has between two to four different forms based on its position: initial, middle, final and isolated).	No.
	Dots with letters (making up more letters with dots at different locations and with different numbers).	Yes (some letters have the same shapes and are differentiated in the number and/or position of the dots).	No.
	The glottal stop *Hamza*	Two types of Hamza: one silent and one spoken.	The glottal stop appears as an allophone of /t/.
Spelling and writing skills	Includes disconnected letters	Yes (six letters have one-way connecting).	Yes (all letters are disconnected).
	Writing direction	Bi-directional (left to right for numbers and right to left for text).	Left to right.
Reading skills	Easy to distinguish words boundaries	No (there are two types of space: space within the same word and word boundary spaces).	Yes.
	Number of phonemes compared to number of letters	34 phonemes 28 letters.	44 phonemes 26 letters.
	Readers after initial learning grades can ignore short vowels in reading materials	Yes.	No.
	Homograph language (two words are homographs if they have the same spelling but different meaning)	Yes (in words without diacritical marks).	Yes.
	Some stress is needed when pronouncing some letters	Yes (a morphological stress depending on the syllable structure of the word).	Yes (Use as a free phoneme).
	Using full stops for acronyms and abbreviations	No.	Yes.
	Using the definite article to identify the word by connecting to the beginning of it	Yes (using (ال) *al*, sometimes are silent and sometimes spoken).	Yes (using *the*).

2.7 Dyslexia Across Cultures

Language is viewed as a cultural trait and a way of defining the identity of a cultural group. Culture profoundly affects language, a critical element of why people with dyslexia struggle with language acquisition. Language is influenced by many cultural factors, but only two are discussed here due to their crucial influence on people with dyslexia.

One cultural factor that affects speakers of a language is **variety in the language**: different ways of speaking the same language. The variety of a language can interfere with the phonological difficulties of dyslexia. It is common for one language's speakers, especially within a large culture, to have many ways of using the language. These ways are referred to as varieties. For example, English is spoken differently within the United Kingdom, within the United States, and within other English-speaking countries, and English is spoken differently between these countries. Also, English has many dialects, and each one belongs to a different subculture.

Similarly, there are many variations of Arabic across countries in the Middle East (Elbeheri et al., 2006). The variation of Arabic has an impact on the manifestation of dyslexia in this language (Friedmann and Haddad-Hanna, 2014). There are two varieties of Arabic. The first variety is Spoken Arabic (SA) *Ammiyya* (Makhoul, 2017), which is used in everyday speech by Arab speakers and is the native language of an Arabic-speaking child (Mahfoudhi et al., 2011). The second variety is Modern Standard Arabic (MSA) *Fusha* (Mahfoudhi et al., 2011; Makhoul, 2017), which is the prestigious style of the language that is used in schools and also for reading, speaking, writing and in formal communication (Ayari, 1996). MSA differs from spoken language in phonology, vocabulary, morphology, grammar and syntax (Ayari, 1996). Therefore, MSA can be considered a second language (Friedmann and Haddad-Hanna, 2014).

Bhatia (1983) observed that there is a systematic association between the rate of learning a language and the distance between the standard language and its variations. Therefore, the variations of a language are considered an essential factor in development phonological representation (Silliman et al., 2002). In addition, according to Silliman et al. (2002), children can be less responsive to explicit phonological processing due to variation of the language; thus, they are then more likely to be diagnosed as having a learning disability. Moreover, Elbeheri et al. (2006) argue that language variation needs to be considered in the assessment process, especially when accurate articulation processes are required. Consequently, language variations tend to increase the complexity and assessment of phonological processes.

Another cultural factor is the **different writing systems** of each culture. Johansson (2006) has shown that dyslexia has been encountered in all languages. Reading performance depends on the phonological system and, because each language differs in the way in which phonology is represented by orthography and in its writing system's constraints, dyslexia manifestation differs across languages as well (Ziegler and Goswami, 2005). Moreover, Paulesu et al. (2001) reveal that dyslexia manifestation depends on the language's orthography. They found that in transparent orthographies, such as Italian, the reading performance is less affected than in non-transparent orthographies, such as French and English. In addition, in languages with two types of orthography, such as Hebrew and Arabic, Béland and Mimouni (2001) report different reading performance, depending on orthography.

In logographic languages, such as Chinese, every single character represents a complete word (Johansson, 2006). As a result, many characters are required to write all the words in this language in contrast to alphabetic languages such as Arabic and English. Therefore, the learning process to read a logographic language requires remembering visual patterns, which increases cognitive load. A higher prevalence of dyslexia exists in the English-speaking world compared to the Chinese, which reflects the greater need for phoneme processing in English (Butterworth and Tang, 2004).

To sum up, many cultural factors influence language and thus play an important role in how individuals with dyslexia struggle to learn to read a language. Two factors – variations in the language and the different writing systems – are discussed due to their crucial influence on individuals with dyslexia.

2.8 Comorbidities of Dyslexia

Comorbidity of dyslexia with other developmental disorders, such as developmental coordination disorder, attention-deficit/hyperactivity disorder (ADHD) and language impairment, is common (Gooch et al., 2014). Comorbidity refers to the co-occurrence of two or more different disorders/conditions within one person at a greater rate than is predicted by chance (Bonavita and De Simone, 2008). Gooch et al. (2014) argue that understanding how symptoms of different disorders co-occur in preschool students is significant to develop learning models and, therefore, helps in understanding how comorbidities affect the children's learning.

Dyslexia seems to mostly co-occur with ADHD and motor deficits (Gillberg, 2010; Peterson and Pennington, 2015). Studies mention that between 25–40% of people with dyslexia have ADHD and vice versa (August and Garfinkel, 1990; Willcutt and Pennington, 2000).

Dyslexia also co-occurs with two other language development disorders: speech sound disorder and language impairment (Peterson et al., 2009). Speech sound disorders are characterised by difficulties with accurate, clear production of the language's sounds, while language impairment is characterised by difficulties in developing a language's vocabulary and grammar. The comorbidity between dyslexia and dyscalculia (mathematical disabilities) in primary schools is roughly 25% (Landerl and Moll, 2010). Therefore, children with dyslexia often struggle in school and also have other difficulties.

Likewise, some children with dyslexia have other behavioural problems such as poor self-control, poor engagement in tasks, anxiety and depression and attention problems (Russell et al., 2015). They also have difficulties with social functioning. In particular, children with dyslexia often have poor social skills, fewer relationships with their peers and less prosocial behaviour (Parhiala et al., 2015).

The comorbidity between dyslexia and autism spectrum disorder (ASD) is more complex. Previous studies have pointed out that children with ASD often have well-developed word reading skills (Ostrolenk et al., 2017; Johnels et al., 2019). These reading skills vary widely, and children with ASD tend to have dyslexia-like difficulties (Åsberg and Dahlgren Sandberg, 2012).

To sum up, dyslexia does not always appear to be a standalone specific learning disability. It often seems to be linked to other neurodevelopmental disorders (Brimo et al., 2021). However, the nature of these overlaps and to what extent they can impact the population remains unclear (Brimo et al., 2021).

2.9 Interventions for Dyslexia

Dyslexia creates challenges in the performance of certain day-to-day activities, such as reading or spelling, affecting individuals' academic success (Sternberg and Sternberg, 2012). Early intervention is essential to reduce individuals' long-term difficulties, encourage potential success in schools and workplaces and avoid anxiety and depression.

Various interventions involve parents, teachers, schools and technology. Parents play a considerable role in helping their children improve their reading process (National Health Service, 2018a). For example, they can choose their children's favourite books and the appropriate place to read. They can also read books to their children, which in turn helps in improving their listening skills and increasing their vocabulary. Moreover, they can read favourite books repeatedly to ensure their children understand and discuss together what has been read.

Teachers provide a variety of interventions for learners with dyslexia, such as understanding the diverse needs of individuals and building effective relationships with them (Glazzard, 2010), providing each learner with a teaching strategy tailored to their needs (National Health Service, 2018b; Layes et al., 2019) and using an individualised plan for each learner (Béland and Mimouni, 2001). Some teachers may focus on learners' preferred learning styles (such as kinaesthetic and visuo-spatial (Exley, 2003)). It is claimed that the multisensory strategy is one of the primary methods of teaching and training for learners with dyslexia (Ahmad et al., 2012). Teaching strategies should use more than one sense (eyes, hands, ears and lips (Kamala, 2014)) to include all routes to the brain (Mee, 1998) and attract the attention of learners as they struggle with concentration (Ahmad et al., 2012). A multisensory approach improves retention of the material.

One method of school intervention is to provide various accommodations for learners with dyslexia, including eliminating penalties for misspellings, reading assessment questions aloud and giving learners with dyslexia more time to read the required tasks (Walker, 2014).

The use of technology facilitates the daily lives of individuals with dyslexia, encourages their academic success and leads to higher confidence and self-esteem (Sbai et al., 2018). The range of available technological tools is steadily growing. Available technological interventions can be classified into four types based on the main goal to be achieved (Rauschenberger et al., 2019):

- **Education support**: aims to teach individuals with dyslexia a new subject to acquire new knowledge in that subject, such as teaching phonemic awareness to enhance their reading skill.
- **Assistive support**: aims to help individuals with dyslexia compensate for a specific difficulty and work independently, such as using a spell checker to overcome spelling difficulties.
- **Training support**: aims to provide activities to develop knowledge of an already-taught subject, such as giving additional activities for training individuals with dyslexia to enhance their spelling or word reading skills.
- **Assessment support**: aims to assess and identify the difficulties and needs of individuals with dyslexia.

There are some reading applications for people with dyslexia such as Amazon Kindle, Apple Books and Google Play Books (Rauschenberger et al., 2019). These applications provide the ability to customise the font, size and spacing. Other tools use text-to-speech to support reading through speed control, such as MultiReader (Petrie et al., 2005). Some tools support writing skills by using spelling checkers, like Real Check, to overcome spelling difficulties (Rello et al., 2015).

Dyslexia screening tools can assess learners' cognitive skills. For example, Dytective (Rello et al., 2018) and Lexercise Screener (Lexercise, 2016) can be used to detect individuals with dyslexia in English.

Some intervention applications aim to provide a playful environment to engage individuals with dyslexia, such as Galexia (Serrano et al., 2016) and Game-Collection (Gaggi et al., 2017).

To sum up, being excluded from a technology is a significant disadvantage. People with dyslexia have difficulties throughout their lives. Technological interventions can help those with dyslexia to improve their skills and daily activities.

2.10 Conclusion

Dyslexia, neurobiological in origin, is a specific learning disability that is characterised by difficulties in spelling, reading and writing. However, individuals with dyslexia have a variety of strengths. The condition can be linked to genetic markers, and it can be considered a result of a deficit in the left hemisphere of the brain that is responsible for the reading process. Different ways of classifying dyslexia exist, including systems based on symptoms and difficulties. However, the classification based on impairments in components of the dual-route model of reading is the most accurate because it results from a collection of neuropsychologists' work over the past four decades and has proven effective in predicting different types of dyslexia. Consequently, this is the approach adopted in this research. In general, dyslexia is a complicated disorder with no agreed definition. In addition, there are different theories regarding the causes and symptoms of dyslexia. As dyslexia is a language-dependent learning disability, its severity varies between language orthographies. When reading in a language with a transparent orthography, such as Spanish, Turkish, Italian, German and Greek, readers face fewer difficulties than when reading in a language with non-transparent orthographies, such as Dutch, French and English. Much research has been conducted about dyslexia in English. The irregularity in mapping between graphemes to phonemes in English has increased the prevalence of dyslexia in this language.

Arabic dyslexia differs from English dyslexia. Different features of Arabic contribute to the manifestation of dyslexia in this language, such as two types of orthography (transparent and non-transparent), the cursive style of the script, different forms of each letter depending on its position within a word, bi-directionality, diacritic marks and similarity in some letters shapes with a difference in the number and position of dots within the letter. There has been limited research targeting dyslexia in Arabic, despite its popularity as a widely spoken language with a significant rate of dyslexia. Therefore, dyslexia in Arabic is targeted in this research.

Culture affects language, and thus, cultural traits can contribute to difficulties associated with dyslexia. Examples include varieties of language within the culture and the different orthography/ writing systems of each culture. Therefore, due to the influence of culture, individuals with dyslexia struggle to learn to read a language. There is a need to develop appropriate support, assessment and training for individuals with dyslexia based on the culture of that language.

There is overlap between dyslexia and other developmental disorders and conditions such as ADHD, language impairment, motor skills and other behavioural and social difficulties. It is important for teachers to be aware of learners who have two or more neurodevelopmental disorders in order to provide an effective learning environment. Generally, the nature of these overlaps and their extent in the population are under debate.

Various interventions exist for people with dyslexia. Among these interventions, technology has a growing acceptance as alternatives to the traditional methods to make life easier for individuals with dyslexia. Because learning is critical and continues throughout an individual's life, this research focuses on using technology in the learning perspective. Each learner with dyslexia has different characteristics, reading difficulties and learns differently (Friedmann and Haddad-Hanna, 2014; Friedmann and Coltheart, 2016). It is important to consider these differences to provide an effective learning environment and enhance learning. This is achieved by adaptive electronic learning (e-learning). Adaptive e-learning systems harmonise the learning process with the needs of individuals with dyslexia and benefit all learners (Alsobhi et al., 2015a). The next chapter will focus on adaptive e-learning by discussing learning theories and e-learning and ending with adaptive e-learning for people with dyslexia.

Chapter 3

Learning Background

3.1 Introduction

The previous chapter discussed the foundations of dyslexia. Learning is important, and each learner with dyslexia has different needs. Adaptive electronic learning (e-learning) aims to improve the learning process by customising the learning environment to different learners' preferences and needs, to create a unique experience not available in traditional e-learning. This chapter introduces adaptive e-learning by discussing the common learning theories of how individuals learn and how these theories support the learning process.

The chapter also examines the evolution of e-learning as it has become more popular with the advent of new technologies. Next, the chapter presents the definition of e-learning, its different terms and some examples of current e-learning systems. Then it presents the concept of adaptation in e-learning. The fundamental components in an adaptive e-learning system have been presented, followed by some approaches and metrics to evaluate the effectiveness of adaptive e-learning systems. Finally, some adaptive e-learning systems that target people with dyslexia are reviewed and, in particular, this research investigates their effectiveness and highlights some current issues that should be addressed in future research.

This chapter is based on the content published in the following paper: Alghabban and Hendley (2022b).

3.2 Learning Theories

3.2.1 Introduction

Educational researchers and learning psychologists have defined learning in various ways. Some researchers view learning as a process, while others describe it as a product (Alexander et al., 2009). According to Alexander et al. (2009), learning can be both a product and a process. They define learning as a process that reflects change in real time and as a product when referring to learning outcomes (Alexander et al., 2009).

Finding a single, universally agreed definition of learning is difficult. However, different definitions of learning have certain aspects in common. For example, Bransford et al. (2000) stated that learning is gaining knowledge and modifying behaviours and attitudes. Another definition formulated by Driscoll (2002) states that learning is a persistent change in a learner's performance. However, all these definitions overlap in some respects. This can be summarised in the following: *'learning is an enduring change in behaviour, or in the capacity to behave in a given fashion, which results from practice or other forms of experience'* (p. 3) (Schunk, 2012). This definition yields the following learning features: learning involves a change in a person's state that is permanent over time and occurs as a result of learners' experiences. According to Alexander et al. (2009), these state changes may be emotional, psychological and/or social.

Various factors affect learning, such as the materials that need to be learned, the learning environment in which it occurs, the learners' knowledge level and characteristics, and teachers or facilitators (Anderson, 2008). Engagement and motivation are other factors that contribute to learning outcomes (Keller, 1987). Motivation manifests itself in behavioural, emotional and cognitive engagement in learning tasks, which increases the time spent and, therefore, affects learning outcomes (Fredricks et al., 2004).

The learning process is complex. Researchers have attempted to explore how the learning process occurs and what factors affect it. To answer these questions, three fundamental, broad learning theories have emerged. These theories are behaviourism, cognitivism and constructivism (Ertmer and Newby, 1993). In addition, with the emergence of the Internet and social interactions, a new model has emerged based on these theories: connectivism (Goldie, 2016). Even though these theories describe learning differently, there is some overlap between them (Schunk, 2012). A summary of these learning theories is presented in Table 3.1.

Table 3.1: A summary of learning theories.

Learning theory	**Definition**
Behaviourism	Focusing on human behaviour and ignoring the mental processes behind that behaviour.
Cognitivism	Focusing on how a learner receives, organises, stores and retrieves information from their memory.
Constructivism	Learning occurs when learners construct new knowledge by interacting with prior knowledge (experience) and the surrounding environment to build their interpretations and experiences.
Connectivism	An extension of constructivism for online learning.

The following sections describe these theories in detail.

3.2.2 Behaviourism

Behaviourism theory focuses on human behaviour and ignores the mental processes behind that behaviour (Bechtel and Graham, 1999). It considers the learner as a black box and ignores the learner's mind (Mergel, 1998). It assumes that learning occurs when a specific response is made to a given stimulus and how it can be maintained and strengthened (Winn, 1990). For example, when the teacher asks, $2 + 4 = ?$, the learner replies, *6* (Ertmer and Newby, 1993). The mathematical equation is the *stimulus* and the correct *response* is 6. Essentially, this theory focuses on reward or punishment for new behaviours (Winn, 1990). In the case of a reward, the learner is more likely to repeat the same behaviour when confronted with similar situations. Conversely, a punishment will make the learner avoid similar situations in the future.

The behaviourist approach assumes that the learner is a passive recipient of knowledge and transferring knowledge effectively is the responsibility of the teacher or expert (Mayer, 1997). The teacher should assess learners' prior knowledge to identify the starting point of teaching (Mayer, 1999). Also, the teacher's primary tasks are to design effective learning content (Ertmer and Newby, 1993), transfer the knowledge to the learner (Mayer, 1999), strengthen the link between the stimulus and response and identify the response from learners (Winn, 1990). Although both stimulus and learners are considered essential, the stimulus receives the most significance over the learners themselves (Mayer, 1999). According to Winn (1990) and Ertmer and Newby (1993), this theory is useful and effective for explanation, illustration and recall purposes. However, as learners participate passively in the process of learning, this theory does not explain high-level skill acquisition, such as critical thinking and problem-solving strategies.

3.2.3 Cognitivism

As a learning theory, behaviourism is based on what can be observed rather than focusing on mental processes. It became clear that there were gaps in this theory; therefore, a new focus on cognitive processes emerged.

In contrast to behaviourism, where learning is about behaviour change, cognitivism sees learning as an internal process (Siemens, 2005). It emphasises knowledge acquisition and the mental process of the learner (Mayer, 1999). It focuses on how a learner receives, organises, stores and retrieves information from their memory (Stepich and Newby, 1988) and assumes that the learner engages in these activities (Winn, 1990). According to this theory, the learner plays an active role (the learner's mind acts as a processor of information) in the learning process. The prior knowledge of learners should be considered in the learning process (Ertmer and Newby, 1993). Teachers are responsible for assessing learners' knowledge and experiences before teaching and for organising and presenting information in different ways to make it easier for learners to process information

(Winn, 1990; Ertmer and Newby, 1993). In addition, teachers should consider that outcomes may vary between learners due to differences in their prior abilities and knowledge (Ertmer and Newby, 1993). During learning, active practice by learners with appropriate feedback is also important.

Cognitivism focuses on complex cognitive processes, for example, critical thinking, language development, problem-solving strategies and information processing (West et al., 1991). There is some similarity between behaviourism and cognitivism. For example, both theories have the same primary goal: to effectively transfer knowledge to learners (Winn, 1990; Ertmer and Newby, 1993). Both theories believe that learners' prior knowledge and environmental factors influence the learning process (Ally, 2004). Also, both behaviourism and cognitivism emphasise the significance of providing appropriate feedback when needed during the learning process. In the case of cognitivism, feedback is used to support the interaction with the brain, while behaviourism uses feedback to promote the required response from learners (Ally, 2004). They differ in that cognitivism is concerned with what learners know and how they know, instead of what they do and how they respond, as in behaviourism (Winn, 1990; Ertmer and Newby, 1993).

3.2.4 Constructivism

Theories of behaviourism and cognitivism both assume the world is real and external to the learners, and learning occurs when learners internalise knowledge (Winn, 1990; Ertmer and Newby, 1993). In contrast, constructivism does not ignore the existence of the external world. Instead, it views learning as knowledge construction (Mayer, 1999) and is based on the idea that learning occurs when learners construct new knowledge by interacting with prior knowledge (experience) and the surrounding environment to make their interpretations and experiences (Bruner, 1966; Mergel, 1998).

Constructivism requires the learners to utilise what they have learned rather than simply remembering the material (Mayer, 1999). Learners play a very active role by controlling the learning process and constructing knowledge by processing, integrating, elaborating and synthesising information in their minds (Mayer, 1999). In constructivism, identifying the learning context and the prior knowledge of learners is essential (Jonassen, 1991).

Teachers play the role of a facilitator by designing an experience that meets learners' prior experiences and presenting the information in different formats to fit the varied needs of learners (Mayer, 1999). In addition, they assess learners' knowledge by presenting various and new problems that differ from what learners have already learned (Winn, 1990; Ertmer and Newby, 1993).

Constructivism is based on learner-centric instructional approaches that support relatively independent, self-directed learning and immediate application of the knowledge gained (Moore, 1989). However, this theory lacks the concept of structured learning, which can both be positive and negative. Novice learners who depend on well-structured learning environments may find it challenging, but it can benefit advanced learners who perform well in less-structured environments (Jonassen, 1991). Additionally, this theory emphasises learner control, which is not always a productive approach. Sometimes, teachers must direct learners to find connections between new information and what they already know (Ertmer and Newby, 1993). As a result, misconceptions may develop among learners without teachers' guidance, leading to confusion. Therefore, a learner's knowledge acquisition should be adaptive, considering the following three critical factors: learning environment, abstract concepts and concrete experiences (Brown et al., 1989).

Behaviourism, cognitivism and constructivism were developed before online learning became widely used (Ally, 2004; Siemens, 2005). These learning theories suggest that the process of learning occurs inside the learner's mind without considering the knowledge and information that are stored in databases and shared via the Internet and technology (Siemens, 2005). The American Society for Training and Documentation (ASTD) estimates that knowledge doubles every 18 months (Siemens, 2005). The learners cannot gain access to all this knowledge and experience everything (Kop and Hill, 2008). The growth of knowledge resources and improvements in technology have created a need for a new theory that describes how the learning process is affected by these factors (Kop and Hill, 2008). Connectivism was developed in response to this need (Goldie, 2016).

3.2.5 Connectivism

Connectivism draws influences from constructivism and is considered an extension of it for the digital age (Siemens, 2005). It describes how Internet technologies enable learners to learn and share information. It assumes that knowledge can reside outside of learners, such as in databases over the Internet (Goldie, 2016). Learning can happen by connecting nodes (information sources) in a network, and these nodes can be large or small. Learning relies on the decision of learners about what to learn based on their learning capacity (Kop and Hill, 2008). According to this theory, knowledge and learning can include a diversity of opinion (Goldie, 2016).

In connectivism, the learning process is circular with the learners as the starting point (Siemens, 2005). After connecting to the network, learners find the information they need and modify that information according to their beliefs. Then they can share their new realisations by connecting to the network again (Downes, 2008). This circular process enables learners to remain up-to-date in their field (Siemens, 2005). In the learning process, learners play a very active role because they are at the centre of this process. They should decide what to learn and how to connect with it (Tschofen and Mackness, 2012).

The role of the teacher in connectivism is changed. Learners must find information based on their needs and interests and communicate with others (Goldie, 2016), while the teacher guides them to the most beneficial and suitable courses. The teacher has an essential role in learning (Goldie, 2016). For example, the teacher can suggest a list of online courses, and learners can choose their preferred one.

3.2.6 Summary

Learning is a continuous process that has been defined in different ways. Many definitions have common aspects and can be combined into one definition. Learning is an enduring change in the learner's state that can be emotional, psychological and social. The change occurs as a result of other forms of learner's experience or knowledge acquisition (Schunk, 2012).

The learning process can be explained by various fundamental theories. For example, in behaviourism, learning is about changing a learner's behaviour. The observable behaviour shows whether or not learners have learned, and it ignores what is going on in their minds. The teacher's role here is to transfer knowledge and strengthen the association between the stimuli and responses. However, learning can be more than a behaviour change. As a result, a shift to cognitivism has taken place. Cognitivism assumes that learners play an active role in learning, where they receive, store, process and retrieve information. Critical thinking and problem-solving strategies are complex cognitive processes in which this theory works well.

Recently, constructivism has become increasingly popular. Behaviourism and cognitivism assume that learning occurs inside the learner without considering the outside environment. However, constructivism believes learning cannot be isolated from the learning context. Instead, learners develop their experiences and interpretations by interacting with their environmental context. With emergent technologies, constructivism inadequately explains the whole learning process. As a result, connectivism has developed. Connectivism describes online learning, one of the current, popular ways of learning. In the context of online learning, learners can choose courses based on their interests and preferences and interact with the courses any time and from anywhere. The learners join a community with many nodes (different sets of information), gain a better understanding of the new knowledge and share their knowledge with others (Siemens, 2005; Downes, 2008).

Developers must be familiar with these different approaches to learning to select the most appropriate learning strategies. Also, what works for advanced learners may not be suitable for novices. The selected learning approach may depend on the learning context. It should facilitate deep processing of information, motivate learners, meet their different needs and characteristics, and support them during learning (Ally, 2004).

The context of learning is changing radically. The process of teaching and learning is no longer restricted to a traditional classroom environment, due to the advent of e-learning technologies (Pal and Vanijja, 2020). E-learning, covered in the following section, has gained broad acceptance in many educational fields and become a popular tool for people with and without dyslexia as it provides interactivity anywhere and at any time.

3.3 E-Learning

3.3.1 Introduction

The emergence of technologies and the Internet has changed learning and how content is delivered (Anderson, 2004). The concept of distance learning has emerged, where learners and teachers can be separated geographically. However, distance learning as a concept is not new; it has been used and applied since the early 18th century (Brown, 2007). First, teachers delivered educational content to the learners by mail/post, television programs and radio transmission (Anderson, 2000). As personal computers have become more common, they have gradually been integrated into educational settings. Initially, teachers used these computers to build educational courses using word processors and spreadsheets. Educational content was distributed on DVDs and CDs (Cantillon et al., 2017).

With the emergence of web technologies and the Internet, online learning environments have been created to support formal and informal learning contexts for local and remote learners. The different terms that exist for online learning are often used interchangeably and overlap to some extent, making it hard to develop an accurate definition (Moore et al., 2011; Verma and Rizvi, 2013). Among the most common terms for online learning are e-learning, networked learning, Internet learning, computer-assisted learning, web-based learning, distributed learning and distance learning (Ally, 2004). Each of these terms implies that the learners can be at a distance from the teachers and use some type of technology to access and share materials and interact with peers and teachers (Ally, 2004).

Moore et al. (2011) tried to tease out the differences among the three most common terms: *distance learning*, *online learning* and *e-learning*. In their view, distance learning is the most common term used to describe a learning process in which learners are geographically distant from their teachers. In distance learning, computers are used to transmit instructional materials. Distance learning is an umbrella term that includes online learning, e-learning, online collaborative learning, technology-based learning and web-based learning.

The second common term is online learning, which is described as the most recent version of distance learning (Benson, 2002; Conrad, 2002). It is difficult to define the concept of online learning; it has no single definition. It can include all of the previous types of learning (Moore et al., 2011). Oblinger and Oblinger (2005) described the online learning concept as 'wholly' online learning, where learning environments enable learners and teachers to interact with content in a non-traditional way and provide them with connectivity and flexibility (Anderson, 2004). Carliner (2004) defines online learning as: *'learning and other supportive resources that are available through a computer'* (p. 1) (Carliner, 2004).

The third most common terminology is e-learning, which originated during the 1980s. E-learning is usually used to refer to online learning (Carliner, 2004). A simple definition of e-learning, presented by Holmes and Gardner (2006), describes online access to materials and content from anywhere at any time. Another definition suggests that it can be any form of educational material accessible via a computer (Carliner, 2004). Although e-learning can deliver material using computers, there is an argument that it must also consider the learner and learning process (Ally, 2004). Ally (2004) defines e-learning as: *'the use of the Internet to access learning materials; to interact with the content, instructor, and other learners; and to obtain support during the learning process, in order to acquire knowledge, to construct personal meaning, and to grow from the learning experience'* (p. 17) (Ally, 2004). Rodrigues et al. (2019) provide a recent, comprehensive literature review that defines e-learning as: *'an innovative web-based system based on digital technologies and other forms of educational materials whose primary goal is to provide students with a personalised, learner-centred, open, enjoyable and interactive learning environment supporting and enhancing the learning processes'* (p. 95) (Rodrigues et al., 2019). The term *e-learning* is used throughout this thesis due to its popularity in recent related research (Rodrigues et al., 2019).

In light of recent developments in e-learning technologies, learners can access online material from anywhere and at any time, which provides more flexible learning opportunities. This feature is significant for learners who have other responsibilities or jobs (Anderson, 2008). Previous literature shows the benefit is not restricted to accessing the learning environment but also improving the quality and outcome of learning and reducing the cost of learning delivery (Hamidi and Chavoshi, 2018; Panigrahi et al., 2018). According to Linn (1996), learners in an e-learning environment achieve the same or even better results than they would have if they were in a traditional classroom.

E-learning systems can enhance collaborative learning by providing opportunities for learners to interact with others and with teachers through discussion tools like chat rooms and forums. E-learning systems offer different interactivity levels. For example, it is possible for learners to read material, take notes, take quizzes and run simulations, which cannot always be achieved in traditional classrooms. Moreover, teachers can update e-learning material at any time, and learners can receive the update immediately (Anderson, 2004).

E-learning may be asynchronous or synchronous. In asynchronous e-learning, teachers can record lectures and save them. Then learners can access and review the material at any time. In synchronous e-learning, both learners and teachers are available online simultaneously, and they have live interactions (Anderson, 2004). In both types of e-learning, learning content is available at all times, and learners can access it freely (Knowles and Kerkman, 2007).

These benefits of e-learning make it attractive to learners, teachers and educational organisations (Welsh et al., 2003).

3.3.2 Implications of Learning Theories in E-Learning

Currently, all educational institutions are adopting e-learning due to its benefits for learners and teachers. Using technologies for learning allows the convenience of access at any time and anywhere. Nevertheless, whether a specific delivery technology can improve learning is still debated (Clark, 2001; Beynon, 2007). The technologies are simply a medium to deliver materials and do not affect learners' achievement. Learning is influenced more by instruction strategies of learning materials and the content than the technology used to deliver instruction. Therefore, teachers should explicitly know the learning theories, how learners learn and the implications of these theories in e-learning systems. Further, the e-learning materials should be appropriately designed to promote learning and engage learners.

As discussed in Section 3.2, it is necessary to explore the implications of different learning theories for e-learning. Connectivism has developed with the emergence of e-learning. However, Ally (2004) showed the importance of considering different combinations of theories when designing e-learning material due to their overlap. For example, behaviourism principally considers learner behaviour and responses and ignores the mental processes of learners. Learners' behaviour is observed and assessed to measure their understanding and achievements (Bechtel and Graham, 1999). This approach to learning was the basis for early computer-based learning systems (Ally, 2004). Based on the behaviourist approach, the design of an e-learning system must explicitly state the learning outcomes for each lesson, so that learners can judge whether they meet their learning objectives. Learning material should be sequenced appropriately in e-learning systems, such as from simple to complex and from knowledge to application. Tests and assessments can be included in e-learning systems to check learners' achievement and provide appropriate feedback to monitor their progress and take remedial action, if necessary (Ally, 2004).

Psychologists and educators began to insist that the behaviourist approach cannot be used to observe or measure all forms of learning. Instead, they focused on cognitive processes; therefore, a shift from a behavioural orientation to a cognitive orientation has occurred (Ertmer and Newby, 1993). The cognitivism theory sees learning as an internal process and focuses on how the minds of learners receive, structure, store and retrieve information (Schunk, 2012). E-learning systems are impacted by cognitivism by emphasising various learning strategies. For example, important information must be highlighted and presented properly on the page to capture the attention of learners. In addition, e-learning materials should be designed to match learners' current knowledge level to link new information with their existing knowledge level (Ally, 2004). People with dyslexia have additional problems with memory capacity (Jones, 2015); therefore, learning material should be divided into small units and presented in a proper sequence to accommodate this problem.

Another aspect of cognitivism theory that relates to e-learning is to accommodate individual differences by providing materials based on their preferences and needs (Cassidy, 2004). E-learning systems must include a variety of information modes, such as verbal, visual and textual. Motivation and engagement are essential in cognitivism theory because they improve learning outcomes (Ertmer and Newby, 1993). E-learning systems can incorporate various motivational strategies to motivate learners during the learning process such as gaining their attention at the beginning of the lesson and keeping it during the lesson, explaining the importance of the lesson and how it can benefit them and letting them know how they are doing by providing feedback (Keller, 1987). People with dyslexia have different needs and preferences; therefore, considering these differences is important to enhance their learning (National Health Service, 2018b; Layes et al., 2019). Presenting material in different modes is one of the primary methods of teaching people with dyslexia (Ahmad et al., 2012; Reid, Gavin, 2015). Motivating them in the learning process is significant as they are often demotivated and experience low self-esteem (LaFrance, 1997).

In constructivism and connectivism, knowledge is constructed rather than conveyed through instruction (Duffy and Cunningham, 1996). Constructivist and connectivist approaches emphasise the learner's experience resulting from their interactions with the learning environment and consider their minds as processors for retrieving information, reasoning and reflecting (Ertmer and Newby, 1993). Following these approaches, interactive activities should be included in e-learning systems to facilitate knowledge construction. It is the learners' responsibility to learn and construct their own knowledge, and this may not be fully supported in traditional classes where teaching material matches the teacher's preferences, ignoring the differences among individuals and their needs. By contrast, e-learning systems are capable of tailoring the content to meet the different needs of learners by considering different characteristics such as knowledge level, skills and learning style (Ally, 2004). Cooperative and collaborative features are also used (Magnisalis et al., 2011). These features give learners opportunities to reflect on information, learn from each other and have control over their learning process (Lin and Hsieh, 2001).

3.3.3 Examples of E-Learning Systems

3.3.3.1 E-Learning Systems for Non-Disabled Learners

A number of recent, free and widely used e-learning systems for non-disabled learners have been adopted by schools, colleges, military organisations and business organisations to manage learning (Hauger and Köck, 2007). One commercial e-learning system is **Blackboard**[1], which was developed in 1997 (Brown, 2007). It aims to support learning, provide real-life interactions between teachers and learners, virtual classrooms and online assessment (Hauger and Köck, 2007). However, the development of Blackboard was not based on any specific learning theories; instead, its evolution came from a need to provide better e-learning material and communications to learners (Brown, 2007).

Another example is **Moodle**[2], an open-source and free e-learning system developed by Martin Dougiamas in 2002 (Brown, 2007). This e-learning system was developed based on the constructivist approach (Brown, 2007). It provides different features such as design and management of learning courses, file management services, collaborative activities, tracking learners' progress and self assessment (Thakkar and Joshi, 2015). More than 300 million learners from over 242 countries are currently registered on Moodle (Moodle, 2021).

In 2008, **massive open online courses (MOOCs)** were coined as another class of e-learning system (Waldrop, 2013). A free course in artificial intelligence offered by Stanford University in California in the summer of 2011 attracted almost 160,000 learners from all over the world, which caused MOOCs to explode in popularity (Waldrop, 2013). More than 270,000 registered learners use MOOCs (Sinclair et al., 2015), and many commercial providers offer interactive MOOCs (Thakkar and Joshi, 2015) such as Edx[3], Coursera[4], FutureLearn[5] and Udacity[6].

Each of the many different e-learning systems offers these common services: creating learning materials with simple authoring tools, linking to external resources and tracking learners' progress (Brown, 2007). These systems provide collaborative features among learners and social tools such as blogs and chat rooms, and the ability to create online exams with automatic scoring.

3.3.3.2 E-Learning Systems for Learners with Dyslexia

Some studies have contributed to the use of e-learning systems to educate, train and assist learners with dyslexia. Most studies designed and developed game-based techniques with different evaluation methods. **Sasupilli et al. (2019)** developed an educational game for mobile devices called 'Let's find letters' to educate children with dyslexia in the Hindi and English alphabets, focusing

[1] https://www.blackboard.com/
[2] https://moodle.org/
[3] https://www.edx.org/
[4] https://www.coursera.org/
[5] https://www.futurelearn.com/
[6] https://www.udacity.com/

on letter recognition problems. The game is validated positively by three experts using a questionnaire prepared based on Nielsen's usability heuristics evaluation technique. However, it was not used and evaluated by children to measure its impact on their learning performance. **Ouherrou et al. (2018)** developed an interactive learning game called 'FunLexia' for Arabic-speaking children with dyslexia. The game was also evaluated by experts using Nielsen's usability heuristics. A five-question questionnaire was used to collect feedback from experts and 11 children. The findings showed the game was fun and enjoyable and could promote the learning process. The evaluation, however, was limited because the game was not evaluated to measure its impact on children's learning performance.

Another Android-based game was developed to educate children with dyslexia in the Arabic alphabet, and deaf children in the Arabic sign language **(EL_Rahman, 2021)**. The game was evaluated in terms of acceptance by four learners, three parents and two specialists. The results showed that 78% of the participants liked the application. However, an evaluation to measure its impact on children's learning performance was not conducted.

Al-Rubaian et al. (2014) designed serious games using a brain–computer interface (BCI) to develop phonological processing skills in Arabic. They described the conceptual design of the games with an overview of the software development framework. However, the games' evaluation was left for later studies. **Broadhead et al. (2018)** proposed a gamified 3D framework implementing a multisensory approach as an intervention to support teaching reading skills (phonics) for English learners with dyslexia in primary school. The implementation and evaluation of the framework were left for later studies.

Much research has designed games to support training for learners with dyslexia. For example, the 'DytectiveU' game aims to train Spanish children with dyslexia in reading and writing by providing different exercises **(Rello et al., 2017)**. However, an evaluation to measure its impact on children's learning performance was not conducted. **El Kah and Lakhouaja (2018)** contributed a set of games for Arabic children to overcome the difficulties of dyslexia and dysgraphia. The effectiveness of the games was evaluated by 46 learners, including six learners with dyslexia, 20 learners with substandard academic performance and academic delay, and 20 learners without learning difficulties. Pre- and post-tests were used before and after using the games. These tests focused on reading and spelling skills. The results showed the potential benefits of using the games in enhancing the learning process. However, the study was conducted with a small number of learners with dyslexia, leading to an inability to derive a conclusion. A further study by **Al-Ghurair and Alnaqi (2019)** aimed to improve the short-term memory of Arabic-speaking children with dyslexia using a story theme in a standalone game-based application. Specialists observed 21 children while they used the game to evaluate its usability in terms of user satisfaction, learnability, efficiency and performance. Children's opinions were obtained after using the game. They found that children were satisfied and engaged with the theme. However, the application was not evaluated to measure its impact on children's learning performance. **Aljojo (2020)** conducted a study on identifying and understanding words by Arabic learners with dyslexia. A puzzle game-based application with eye-tracking and chatbot features (Aljojo et al., 2018) was used to analyse learners' interactions. The study revealed that the accuracy and speed of visual word recognition, and their understanding increased. However, there was a lack of clarity and proper discussion regarding the findings.

Some studies developed training applications with different evaluation methods. **Arteaga et al. (2018)** proposed a software process model to develop a training application to help Spanish children with dyslexia in primary school. The model includes a user-centred approach with teachers, software engineers, psychologists and learners. A case study was conducted with a small number of participants (five children with dyslexia) to evaluate the accessibility and usability factors. The findings revealed that the application was easy to use. However, an evaluation to reflect its impact on children's learning performance was not conducted.

There are multiple studies on developing systems to assist learners with dyslexia. **Noor et al. (2017)** developed the Children's Storybook Reading System (StoBook) using radio frequency identification (RFID) technology for children with dyslexia in Malay. The system motivates and allows children to learn with fun by moving their eyes and hands to place the pictures and syllable cards during their interaction with the system. However, they relied on teachers' and children's feedback without evaluating its impact on children's learning performance. **Pang and Jen (2018)** explored engagement of secondary school learners with and without dyslexia in an online collaborative learning environment in Malay. Learners were assigned to complete a collaborative task using a forum, text chat and video conferencing. The study revealed that text chat mode and forums were unsuitable for learning discussion, especially for learners with dyslexia who could not respond quickly.

Burac and Cruz (2020) developed a mobile assistive application in English named Individualised Reading Enhancing Application for Dyslexia (IREAD). Three modules are included in the application: a module for reading and writing lessons, an evaluation module and a module for the history/reports. The overall usability of the application was assessed positively by teachers (using a questionnaire). However, IREAD has not been evaluated by learners to assess its impact on their learning performance.

For assisting learners with dyslexia in Arabic, **Benmarrakchi et al. (2017b)** proposed a set of practical guidelines based on learners' spelling errors in online content. These guidelines covered four areas: visual ability, phonological processing skills, orthographical similarity and cognitive processing for promoting accessibility related to online content for learners. However, the evaluation of these guidelines was not included. Similarly, **Aldabaybah and Jusoh (2018)** proposed a set of usability features for designing assistive tools for Arabic learners with dyslexia. As assessed by an expert, the proposed features improved usability and enhanced learning.

Table 3.2 presents a representative overview of such existing e-learning systems for learners with dyslexia and enumerates for each system the intervention type, the target language and the evaluation method.

Table 3.2: Examples of e-learning systems for learners with dyslexia.

Author(s) and year	**Intervention type**	**Target language**	**Evaluation**
Sasupilli et al. (2019)	Educational	English and Hindi	Expert feedback
Ouherrou et al. (2018)	Educational	Arabic	Expert and learner feedback
EL_Rahman (2021)	Educational	Arabic	Specialist, parental and learner feedback
Al-Rubaian et al. (2014)	Educational	Arabic	N/A
Broadhead et al. (2018)	Educational	English	N/A
Rello et al. (2017)	Training	Spanish	N/A
El Kah and Lakhouaja (2018)	Training	Arabic	Pre- and post-test experimental design
Al-Ghurair and Alnaqi (2019)	Training	Arabic	Observation
Aljojo (2020)	Training	Arabic	Observation
Arteaga et al. (2018)	Training	Spanish	Teacher and learner feedback
Noor et al. (2017)	Assisting	Malay	Teachers and learners feedback
Pang and Jen (2018)	Assisting	Malay	Observation
Burac and Cruz (2020)	Assisting	English	Questionnaire
Benmarrakchi et al. (2017b)	Assisting	Arabic	N/A
Aldabaybah and Jusoh (2018)	Assisting	Arabic	Expert feedback

Although e-learning systems enable interaction between learners and systems at any time and anywhere, several drawbacks exist. Based on the review of e-learning systems, the diversity of learners with dyslexia is not sufficiently considered. Individuals differ in their preferences, goals, personalities, knowledge, skills, background and learning styles. Furthermore, the profile of a single learner changes over time. For instance, knowledge and skills can increase as an effect of learning (Hauger and Köck, 2007). It is possible for traditional e-learning systems, for example, to present material that matches a particular objective of the lesson. However, they fail to consider the different characteristics of learners when providing learning material that meets their needs

(Brusilovsky, 2012). Instead, there is no variation in content or presentation for learners (Hauger and Köck, 2007; Sun et al., 2008). Moreover, the large amount of material may overwhelm learners if they do not know what to study. All these issues affect the learning process negatively and lead to dissatisfaction, increased dropout rates and affect the learning gain (Sun et al., 2008).

The transition from traditional e-learning to adaptive e-learning, covered in the following section, has addressed some of these limitations.

3.4 Adaptive E-Learning

3.4.1 Adaptation

The term adaptation in the context of user-system interaction is defined as a process of tailoring something so that it meets the user's needs (Brusilovsky, 2001). For example, instructional strategies can be adapted to meet the needs of different characteristics of learners, such as preferences and learning styles. The term personalisation is similar to adaptation (Jameson, 2007); to personalise means to design something to meet an individual's needs (Blom, 2000). Systems that adapt based on different characteristics of users, such as skills and preferences, are known as user-adaptive or adaptive systems (Evers et al., 2010).

Jameson (2007) defines an adaptive system as: *'an interactive system that adapts its behaviour to individual users on the basis of processes of user model acquisition and application that involve some form of learning, inference or decision making'* (p. 106) (Jameson, 2007). Adaptive systems can be described as: *'the technological component of joint human-machine systems that can change their behaviour to meet the changing needs of their users, often without explicit instructions from their users'* (p. 1008) (Feigh et al., 2012).

Two terms are often used interchangeably for adaptation: *adaptable* and *adaptive*. However, these terms are different. An adaptable system is a system that can be customised by the user to their own preferences during the interaction process (Jameson, 2007). For example, the user can set the time of presenting feedback after every three tasks rather than after each one. An adaptive system refers to the dynamic and static customisation that a system makes based on the characteristics and performance of different users. One example is dynamic adaptation of when the feedback occurs based on the user's attention (Vasilyeva et al., 2007). Because it is important to distinguish between adaptable and adaptive phenomena, it is the researcher's task to determine how to define adaptation in the system and under which principles it will work.

The primary aim of adaptive systems is to meet individuals' needs as closely as possible (Maravanyika et al., 2017). Another goal of adaptation is to increase users' satisfaction and the system's usability (De Bra, 2008). Hence, the ultimate aim of adaptation is to enhance individuals' experience over time (Maravanyika et al., 2017).

Brusilovsky (1998) defines three essential stages that must be accomplished in order to adapt any system (see Figure 3.1). In the first stage, the system collects data about the users, which is the basis for the user modelling. These data can be any preferences or characteristics of the users. The next stage is applying the user model to provide an adaptation effect. Finally, the system keeps track of the user and updates the user model based on user actions.

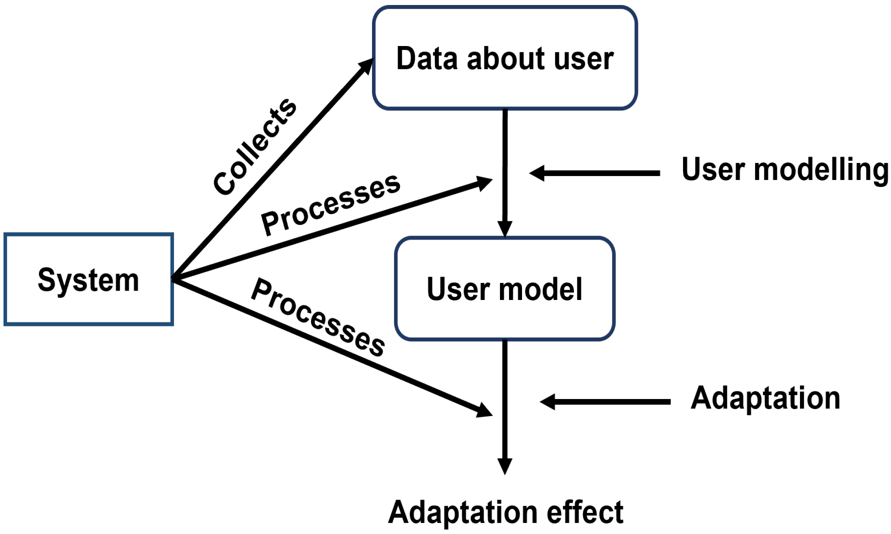

Figure 3.1: The stages of adapting a system (Brusilovsky, 1998).

To adapt a system, it is crucial to plan this system properly, understand its benefits and whether applying adaptation is valuable. Therefore, the core of adaptive systems reflects some fundamental questions that must be answered before performing adaptation. These questions are (Knutov, 2012):

- **Why?** Why do we need adaptation?
- **What?** What can we adapt?
- **To What?** What features/attributes can be adapted to?
- **When?** When can we apply adaptation?
- **Where?** Where can we apply adaptation?
- **How?** How do we adapt?

The first question, **Why?**, initiates the adaptation process by articulating the main goals and objectives of designing an adaptive system. This question mainly refers to the significance of adaptation. The second question, **What?**, emphasises the domain model to be adapted to different needs of users. The third question, **To What?**, is related to the user model. The user model presents, stores and maintains the users' attributes. These attributes can be stable, such as background, learning style and personality, or dynamic, such as the users' interest, emotion and experience. Other characteristics related to the environment can be considered in the adaptation, such as the devices and physical environment. The fourth question, **When?**, is related to when the adaptation should be performed. The adaptation can occur at the early stages of the system design, compilation time or at run time (Motti and Vanderdonckt, 2013). Therefore, it is necessary to identify whether the adaptation process will be dynamic and changeable during using the system or static and completed before using the system. The fifth question, **Where?**, defines the context and the area of the application domain to which adaptation can be applied. Adaptation can be applied in any system with different interfaces and a vast amount of information for different users; most recent studies relate to e-learning systems, online-help systems and information retrieval systems (Maravanyika et al., 2017; Shershneva et al., 2019; Mohssine et al., 2021). These systems have different interfaces and roles for different users. As an example, an adaptive information system contains a large amount of information that may not be relevant to all users. Therefore, it is important to adapt the information presentation to the knowledge or role of the users. Another example is shopping websites, such as Amazon[7] and eBay[8]. They customise product suggestions based on users' browsing history and recent purchases. Finally, the last question, **How?**, helps determine how adaptation can be applied by considering different methods and techniques in the adaptation process and how they will be implemented in the system.

Adaptive technology is used in many areas, including healthcare, e-learning and e-commerce. This research focuses on adaptation in the e-learning sector, which will be covered in the following section.

3.4.2 Adaptive E-Learning Systems

Adaptive e-learning systems have gained the attention of many researchers in recent years. An adaptive e-learning system aims to meet learners' needs (Brusilovsky, 1998), which is an enhancement to the 'one-size-fits-all' approach (Maravanyika et al., 2017), by adapting the traditional learning approach to these different characteristics. Therefore, it increases learners' learning outcomes and motivation and enhances their progress.

Any adaptive e-learning system must include three fundamental models (Wu et al., 2001). They are 1) a learner model, 2) a domain model and 3) an adaptation model. These models are described in the following sections.

[7]https://www.amazon.com/

[8]https://www.ebay.com/

3.4.2.1 Learner Model

As illustrated in Figure 3.1, the first step in adaptation is collecting information about users to build the user model. Self (1998) defines a learner model as: *'what enables a system to care about a student'* (p. 352) (Self, 1998). Learner modelling is an important element in adaptive e-learning systems that must be considered when adapting these systems (Sosnovsky and Dicheva, 2010; Tadlaoui et al., 2016).

The learner model can represent and maintain several characteristics of learners, such as knowledge, learning styles and skills, as a source to provide adaptation (Essalmi et al., 2010). Learner characteristics can be dynamic or static. Static characteristics, such as age, native language, culture and gender, are set before interacting with the system and usually remain unchanged unless the learner changes them. Dynamic characteristics are obtained from learners' behaviours and interactions with the system. The system constantly updates these characteristics during system interactions based on the data collected (Schiaffino et al., 2008; Chrysafiadi and Virvou, 2013).

The learner modelling includes three different phases: 1) defining what is being modelled (learner model dimensions), 2) defining how to represent the learners' characteristics (learner model representation) and 3) defining how to obtain the learners' characteristics (learner model elicitation). The following paragraphs provide a brief explanation of these phases.

1) What is Being Modelled (Learner Model Dimensions) The core of adaptation is based on the assumption that every learner has different characteristics. The most significant characteristics with regard to adaptation are:

- **Demographic information**

  In some systems, it is important to identify the demographic information of users. This information includes age, gender, native language and culture. Adaptation based on users' demographic information is widely used in ubiquitous adaptive applications, e-commerce systems and education systems (Sosnovsky and Dicheva, 2010).

- **Background**

  Background is defined as: *'relevant experience gained outside the system, prior to using it'* (p. 34) (Sosnovsky and Dicheva, 2010). It may not be relevant to the domain that will be learned (Nguyen and Do, 2008; Sosnovsky and Dicheva, 2010). In contrast to knowledge, the background model is coarse-grained and usually static (does not change over time).

- **Interests**

  Another characteristic that can be included is users' interests. Users' interests are essential in adaptive systems that deal with huge amounts of information, such as commercial recommendation systems and adaptive search engines (Nguyen and Do, 2008). This element was not used in early research into adaptive e-learning systems because it changes frequently. However, this situation has changed in the past 10 years, and some adaptive systems focus on users' interests (Ghaban, 2019).

Modelling users' interests requires distinguishing between short-term and long-term interests. Short-term interests are usually dynamic; they express the users' interests during a session but are ignored by the end of the session. In contrast, long-term interests are more stable; they are expressed by the user before working with the system, or they evolve slowly while the user works with the system (Sosnovsky and Dicheva, 2010).

- **Individual traits**

  An individual trait is an attribute or characteristic that defines a person as an individual (Nguyen and Do, 2008). Individual traits are stable, either unchangeable or changing only over a long period (Brusilovsky, 2001). Individual traits are typically extracted via specially designed psychological tests (Brusilovsky and Millán, 2007). Cognitive style, learning styles and personality traits are all examples of individual traits that are commonly used in adaptive e-learning systems (Cercone, 2008).

  Cognitive style means an individual's preferred approach to organising and processing information (Riding and Rayner, 1998). It describes how learners perceive, think, remember and solve problems (Isaksen et al., 2003). For example, one cognitive style dimension is wholist-analytic (Riding and Rayner, 1998). The wholist-analytic approach refers to how learners organise and structure information. Individuals described as analytics prefer to process the information in parts, whereas individuals described as wholists prefer to process the information as a whole.

  Learning style can be defined as the way learners prefer to learn. It is similar to cognitive style, but it has a narrow focus on learning (Brusilovsky and Millán, 2007). Different models exist for classifying learning styles. For example, a popular learning style approach is Felder–Silverman (Alshammari, 2016). One dimension in this approach, for example, is input modality (visual-verbal), which classifies learners based on their preferences for how information should be presented to them. Verbal learners process and understand written and spoken information easily, while visual learners prefer learning with charts, figures and diagrams (Ghaban, 2019).

  Personality traits are a set of characteristics that distinguish an individual and control how that person thinks, feels, communicates and interacts with others (McCrae and Costa, 2003). Different models exist to explain personality. The most widely used model is the big five model (Barańczuk, 2019). Personality traits can be classified into different dimensions. One dimension, for example, is introvert-extrovert. Individuals who are extroverted are described as more energetic, excited and engaged with social interactions than introverted individuals. Curry (1983) shows the relationship between the three traits by using the onion model (see Figure 3.2). The model has three layers, and each individual trait corresponds to a specific layer. Classification in this model is based on the degree to which the preferences represented by each layer remain stable over time. The outer layer represents instructional preference, which is how learners learn (learning style). This layer frequently changes as it is affected by external factors. The middle layer represents information processing approaches (cognitive style). Over time, this layer has greater stability than the outer layer. The inner layer represents personality, which is the most stable trait over time (Curry, 1983).

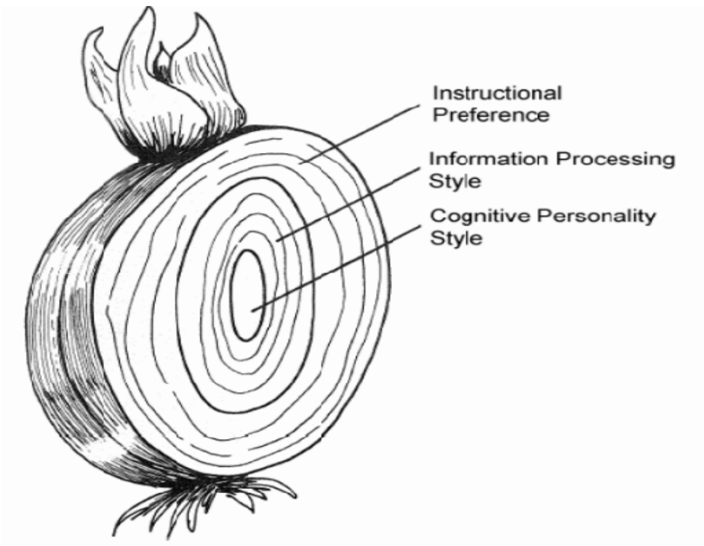

Figure 3.2: Curry's onion model, taken from (Wolf, 2007).

- **Knowledge**

  The most common adaptive parameter is learners' knowledge (Felder and Silverman, 1988; Brusilovsky and Millán, 2007; Essalmi et al., 2010; Sosnovsky and Dicheva, 2010). Several well-known learning theories emphasise that knowledge level is an essential element of instruction (Ertmer and Newby, 1993). An individual's level of knowledge is determined by their ability to recall, understand and apply specific information relevant to a particular topic (Brusilovsky and Millán, 2007). It can be represented by a single value on some scale: qualitatively, such as novice, average and expert, or quantitatively using a score. The main issue with this representation is that the knowledge level of a learner is different across the domain.

For example, in teaching word processing, the learner may be an expert in editing a formula, but a novice in text annotation. Because of this shortcoming, structural models are used. In structural models, the domain is divided into segments, and the learner's knowledge level is mapped into each segment independently. The overlay model is a popular structural model in which knowledge is represented as a subset of a domain model. The model then stores an estimation of the learner's knowledge (Sosnovsky and Dicheva, 2010). This model is discussed under **How to Represent the Learners' Characteristics**.

It is important to consider that the learners' knowledge is a changing characteristic. The learner's knowledge can either decrease (forgetting) or increase (learning). This means any adaptive e-learning system relying on knowledge must recognise the changes in the learner's knowledge and then update the learner model accordingly (Brusilovsky and Millán, 2007).

All previous characteristics are related to any learner. However, this research targets learners with dyslexia, and they have specific characteristics, such as dyslexia type. This research focuses on dyslexia type as an adaptive characteristic to investigate the benefits of adaptation for learners with dyslexia. The type of dyslexia (covered in Section 2.5.3.2) can be considered as an individual trait because it identifies the individual with dyslexia and is stable throughout their life.

This research also focuses on knowledge level as another adaptive characteristic to investigate the benefits of adaptation for learners with dyslexia. This research refers to skill level rather than knowledge level. Knowledge is learning principles of a subject, while skill is applying that knowledge in a context. According to Sun and Peterson (1997), learners learn generic and declarative knowledge first, and then, they turn such knowledge into usable, specific procedural skills by practising. This research targets training young learners with dyslexia in reading skills. The learners already have the basic, formal knowledge and, by practising, they develop it into specific skills that can be applied subconsciously rather than through conscious reasoning.

2) How to Represent the Learners' Characteristics (Learner Model Representation)

The learner model representation discusses how the learners' characteristics can be represented and modelled in the learner model. Different techniques can be used to construct a learner model. The most common learner modelling techniques in adaptive e-learning are overlay and stereotype (Sosnovsky and Dicheva, 2010; Chrysafiadi and Virvou, 2013).

The overlay model is the most commonly used learner model. It is frequently used to represent learner knowledge (Chrysafiadi and Virvou, 2013). The overlay model is based on the assumption that the learner model is a subset of the domain model, designed by the teacher or expert, because a learner might have correct, but incomplete knowledge of the domain (Chrysafiadi and Virvou, 2013).

With an overlay model, each element in the domain is assigned a Boolean value (yes or no), which indicates whether a learner knows that element or not. In its modern form, it uses a qualitative measure (poor, average, good) or quantitative measure (the probability that the learner knows the concept) (Brusilovsky and Millán, 2007; Martins et al., 2008). The overlay model approach requires that the domain model represents individual concepts and topics. Therefore, its complexity mainly depends on the granularity of the structure of the domain model and the estimation of the learner's knowledge (Martins et al., 2008).

Overlay models are widely used due to their precision and flexibility (Sosnovsky and Dicheva, 2010). They can be dynamically and easily tailored to the learners' knowledge (Sosnovsky and Dicheva, 2010). This technique is commonly used to represent learners' skills, knowledge and sometimes interests (Sosnovsky and Dicheva, 2010). However, it has some drawbacks. One is that it does not represent incorrect knowledge or misconceptions that a learner may have acquired (Chrysafiadi and Virvou, 2013). Additionally, the model cannot represent other factors, such as learners' personalities and behaviour (Chrysafiadi and Virvou, 2013). This is why many adaptive e-learning systems combine the overlay model with other approaches.

Another popular representation of a learner model is the stereotype model. It classifies users who share certain characteristics into groups (called stereotypes) (Martins et al., 2008). Every stereotype contains the common knowledge about a group of learners. This model assigns a new learner to a related stereotype if there is a match between the learner's characteristics and that stereotype (Chrysafiadi and Virvou, 2013). One advantage of using this model is that the knowledge about a learner can be inferred based on stereotype(s) without explicitly eliciting this knowledge from each learner (Sosnovsky and Dicheva, 2010). Another feature of this model is that it allows the learner model to be initiated quickly, so adaptation is provided immediately (Chrysafiadi and Virvou, 2013).

However, this model has some shortcomings. Construction of stereotypes is done by hand before any users interact with the system, and updating the stereotypes should be done explicitly by a designer. Moreover, to use stereotypes, the users must be divided into groups and such groups may not exist. In addition, it is difficult to use the stereotype model to represent fine-grained characteristics, such as knowledge level or skills (Sosnovsky and Dicheva, 2010).

3) How to Obtain the Learners' Characteristics (Learner Model Elicitation) This phase describes how learners' characteristics are identified. There are two common approaches to obtaining learner modelling information: explicit and implicit approaches (Zigoris and Zhang, 2006; Gauch et al., 2007; Sosnovsky and Dicheva, 2010). In explicit approaches, the system asks learners to provide information about their characteristics and interests directly. This can be done by filling out questionnaires, conducting surveys or conducting a pre-test to assess learners' knowledge level (Paredes and Rodriguez, 2002). Reliable psychological tests can also be used to elicit learners' traits explicitly. For example, the learning style inventory tool can be used to identify learners' learning styles. In this research, both dyslexia type and reading skill level are identified by using reliable diagnostic tests.

The implicit approaches obtain learners' information implicitly. For instance, the system observes learners' behaviours and interactions (Schiaffino et al., 2008), such as tracking time spent to finish a specific lesson, the number of clicks on a specific page and the speed to finish a task (Gauch et al., 2007).

Information obtained from learners must be aggregated and analysed to find a common pattern and to generate an adaptive version for each learner. The analysis process of the learners' patterns can be done automatically by feeding the learner behaviour into one of the machine-learning algorithms, such as classification and clustering, or manually by observing their behaviour. In the classification technique, each class must be predefined before assigning learners. However, this is not easy to accomplish and creates challenges. Therefore, most adaptive systems use clustering, where learners with similar characteristics and behaviours are grouped into one class without any need to predefine the classes (Kobsa et al., 2001).

3.4.2.2 Domain Model

The domain model is the backbone/heart of adaptive e-learning systems. It contains the structure of the curriculum and the elements of knowledge related to a specific application domain (Aroyo et al., 2006; Brusilovsky, 2012). According to previous research (Wu et al., 2001; Knutov, 2012), this model consists of a set of concepts and their relationships. Concepts are abstract items of information from the application domain. Depending on the application domain and the designer's choice, a concept can be atomic (represents one piece of domain knowledge) or divided into small sub-concepts (smaller fragments of domain knowledge that represent a piece of information) (Brusilovsky, 2012; Knutov, 2012; Motti and Vanderdonckt, 2013).

The elements in the domain model have different names in different systems, such as knowledge elements/items, concepts, learning outcomes, learning objects or topics. However, in all cases, they represent primary fragments of domain knowledge (Brusilovsky, 2012).

The concepts and relationships between concepts in a domain model can be represented by using different techniques. One technique is the set model or vector model. In this technique, the concepts of knowledge are independent and have no internal structure. However, even though this technique is simple, it is very effective in maintaining a detailed picture of knowledge in a powerful platform that supports adaptation in large systems (Nguyen and Do, 2008). The main issue with set or vector models is that there is no connection between concepts. When a user model links to a chosen concept, it is difficult to determine how to move to the next concept (Brusilovsky and Millán, 2007). Different techniques have been proposed to address the previous issue, such as the network model. This model is popular in adaptive e-learning systems (Alshammari, 2016). It provides a flexible, easily understood representation of concepts with an arbitrary number of levels (a hierarchical network). Concepts are represented as nodes, and the relationships that connect them are represented by arcs (Mustafa and Sharif, 2011).

3.4.2.3 Adaptation Model

The adaptation model bridges the gap between the domain and learner models by creating the best match according to the learners' characteristics and objectives (Alshammari et al., 2014). The adaptive model has two distinct but complementary dimensions: logic and action (Paramythis and Loidl-Reisinger, 2003). The specification of logic is responsible for relating information in domain and learner models and deciding whether adaptation is required. The specification of actions refers to specifying the steps needed by the system to achieve a given adaptation.

The adaptation model for most e-learning systems can be based on the following adaptation techniques: adaptive presentation and adaptive navigation support (Mustafa and Sharif, 2011), following the updated adaptation taxonomy of Brusilovsky (2001) (see Figure 3.3).

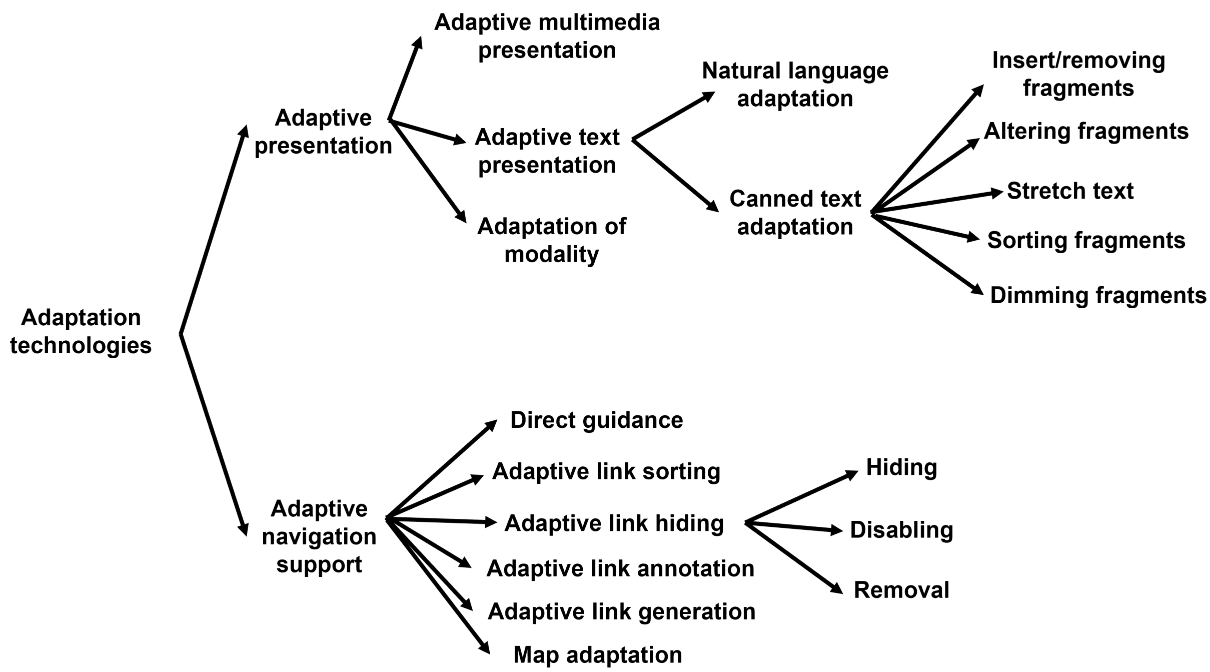

Figure 3.3: The updated taxonomy of adaptive system techniques (Brusilovsky, 2001).

Adaptive presentation aims to adapt the content based on learners' characteristics. For example, for novice learners, preliminary concepts must be presented and learned, while expert learners should be provided with more advanced concepts. Some adaptive e-learning systems under this approach consider the learners' preferred learning method. Some learners prefer to practise, while others prefer to learn theoretical concepts. For example, Alshammari et al. (2015a) indicate that intuitive learners prefer theories and principles (abstract concepts), while sensory learners prefer problem solving and examples (concrete information).

As shown in Figure 3.3, adaptive presentation has three groups: text adaptation, multimedia adaptation and adaptation of modality. Text adaptation and modality adaptation have received much attention in recent years. There are different techniques for text adaptation (Bunt et al., 2007). Among those techniques, which are commonly used in adaptive e-learning systems, are altering, inserting and removing fragments based on learners' characteristics. Sorting fragments and stretching text keep the same content available for the learner but suggest focusing on a portion of it.

Adaptation of modality adapts between different types of media, such as from text to audio, from images to text or from video to images, based on learners' preferences, abilities and learning styles (Kobsa et al., 2001). For example, some learners may better engage verbally, while others prefer charts and figures.

Different adaptive representation techniques can also be applied to adapt multimedia. For example, an image can be scaled to fit a specific screen.

The second adaptation technique is adaptive navigation support, which helps learners navigate the domain space. Learners' navigation can be influenced through suggested or enforced navigation (Knutov, 2012). The enforced approaches alter the structure of recommended links in a way that forces the learner to select a link among a predefined set of links. The suggested navigation approaches provide a list of suggestions for appropriate links rather than restrict the learner, as is the case in enforced approaches. These approaches help the learner decide which links are appropriate and which ones are not, but the learner is not forced to follow these recommendations.

One of the most common enforced approaches used in adaptive e-learning systems is direct guidance (Mustafa and Sharif, 2011). It suggests the next best node(s)/pages to be presented for learners (Brusilovsky, 2007). However, the drawback of direct guidance is that the system does not support learners who do not want to follow the system's suggestions. Therefore, it can be used with other adaptive navigation approaches (Brusilovsky, 1998).

Link annotation and link sorting are the most commonly used methods of suggested navigation support in adaptive e-learning systems (Mustafa and Sharif, 2011). The concept behind the link annotation approach is to provide some type of annotation to the links, allowing the learner to decide which links are appropriate. This approach reveals more about the current status of the nodes/pages behind the annotated links. Most annotations consist of icons and changing font sizes and colours (De Bra and Ruiter, 2001; Brusilovsky, 2007). The link sorting approach prioritises the page links based on the learner model, where the more relevant links are shown closer to the top of the page. However, this technique makes the order of links unstable: the order of links changes each time the user accesses the page (Brusilovsky, 2007).

Some adaptive e-learning systems use different technologies to support navigation. eTeacher is one example of an adaptive e-learning system that uses direct guidance and link annotation (Schiaffino et al., 2008). LearnFit uses direct guidance (El Bachari et al., 2011). The Adaptive Hypermedia Architecture (AHA!) uses a combination of stretching text, link sorting and direct guidance (Stash et al., 2006).

To sum up, the data from domain and learner models must be available to inform the adaptation model in adaptive e-learning systems. The adaptation model can adapt presentation, navigation, modality and the structure of material according to learner characteristics. There is a great deal of challenge in choosing which adaptive approaches are most appropriate in the different classifications of adaptive presentation and navigation. The next challenge is how and when the system provides adaptation in various cases, especially when integrating two or more learner characteristics.

3.4.3 Adaptive E-Learning Evaluation

Mulwa et al. (2011) define evaluation as: *'the process of examining the product, system components or design, to determine its usability, functionality and acceptability'* (p. 139) (Mulwa et al., 2011). An evaluation of an interactive system ensures that it meets users' requirements, behaves as expected and provides reliable services (Weibelzahl, 2003). Accordingly, the main goals of the system evaluation are (Dix et al., 2003):

- To assess the functionality of the system – whether the system complies with the requirements of the users and how effectively it supports the tasks.
- To assess the impact of the interface on users, covering aspects of usability, such as how easy the system is to learn and how satisfied the user is with the system.
- To determine if there are problems with the system and any possible improvements by detecting unexpected behaviour and any inconsistencies between the design of the system and what users expect.

The methodologies for evaluating adaptive e-learning systems were adopted from the human–computer interaction (HCI) evaluation methodologies (Gena, 2005). One key evaluation approach in HCI that has been adopted for evaluating adaptive e-learning systems is the user-centred evaluation approach, as users are the main target of the system and the main source of information

(Gena, 2005; Mulwa et al., 2011). User-centred evaluation refers to the process of evaluating the effectiveness, usability and value of a system for its intended users (Van Velsen et al., 2008). Different evaluation approaches and metrics exist to evaluate adaptive e-learning systems. These are covered in the following sections.

3.4.3.1 Evaluation Approaches

Different user-centred, evaluation approaches exist. One approach is **formative evaluation**. Formative evaluation is mainly conducted at the early stages of designing the adaptive system before the actual implementation, to improve the system (Worthen, 1990; Fitzpatrick et al., 2015). This approach was applied in a study conducted by Triantafillou et al. (2003) to evaluate Adaptive Educational System based on Cognitive Styles (AES-CS) using focus groups and expert opinion. Another approach is **summative evaluation**. It is conducted after the system implementation to decide whether a system should be continued and expanded (Worthen, 1990; Fitzpatrick et al., 2015). This approach has been applied in assessing the learner responses to questions in the Full Option Science System (FOSS) (Nielsen et al., 2008). The distinction between formative and summative approaches is illustrated as: *'when the cook tastes the soup, that's formative evaluation; when the guest tastes it, that's summative evaluation'* (p. 19) (Scriven, 1991).

The final approach is **experimental evaluation** or **controlled experiment** (Weibelzahl, 2001; Gena, 2005). This approach evaluates the system's effectiveness and usability with real users in structured settings to reflect more controlled situations (Weibelzahl, 2001; Gena and Weibelzahl, 2007). In adaptive e-learning systems, an experimental evaluation approach is valuable to provide evidence of the system's effectiveness and the usefulness of adaptation (Weibelzahl, 2001; Gena, 2005; Brown et al., 2009; Mulwa et al., 2011). For example, Alshammari (2019) evaluates the effectiveness of adapting gamification elements in an e-learning system in terms of learning gain using the experimental evaluation approach. Another study conducted by Ghaban and Hendley (2018) used this approach to assess learners' motivation, learning gain and satisfaction.

The experimental evaluation approach can be used to assess the usability issues of the system (Jameson, 2007). For example, Alshammari et al. (2016) and Orfanou et al. (2015) used this approach to evaluate the usability of the system.

There are two approaches to designing experimental evaluations: between-subjects and within-subjects. In a between-subjects procedure, an experimental group is assigned to a treatment condition, and a control group is assigned to a non-treatment condition (Gena, 2005). The experimental group interacts with the adaptive version of the system, and the control group interacts with the non-adaptive version (Gena and Ardissono, 2004; Ghaban and Hendley, 2018). The number of groups is dependent on the number of independent variables. In a within-subjects procedure, each subject experiences all the treatment conditions. For example, subjects interact with both the adaptive and non-adaptive versions of the system (Bontcheva, 2002).

3.4.3.2 Evaluation Metrics

Different metrics have been proposed for the evaluation of adaptive e-learning systems. Among these metrics are learning gain, learner satisfaction and perceived level of usability. These metrics are used broadly to evaluate adaptive e-learning systems in previous studies (Hung et al., 2009; Alshammari, 2016; Wu et al., 2017; Alshammari, 2019; Ghaban and Hendley, 2020; Alghabban and Hendley, 2022b). The following paragraphs explain these metrics in detail.

Learning Gain Learning gain is a term used to describe the changes and improvement in learning outcomes after a specific intervention (Pickering, 2017). It represents how much a learner learns after interacting with the learning system.

Pre- and post-tests are commonly used to measure learning gain (Gena, 2005; Akbulut and Cardak, 2012; Pickering, 2017; Wu et al., 2017). Before interacting with the system, learners are given a pre-test to assess their pre-existing knowledge level. After completing the course, they are given a post-test to assess how much they have gained. The difference between the two scores reflects the effectiveness of the adaptive system (Gena, 2005).

Learning gain can be assessed directly after finishing the course to determine how much learners gain (short-term learning gain) (Wu et al., 2017; Alshammari, 2019; Ghaban and Hendley, 2020). It can also be assessed after a period of time has elapsed, by conducting a follow-up test, to determine whether learning gain is persistent (long-term learning gain) (Alshammari, 2016; Ghaban, 2019).

Another critical metric is whether content learned can be generalised to another context (Nist and Joseph, 2008). It reflects the ability of learners to apply what they have learned to new material (Lo et al., 2011). However, little research has examined knowledge generalisation (Kozlowski et al., 2001). Therefore, a measure of generalisation is another metric for evaluating the effectiveness of adaptive e-learning systems (Alghabban and Hendley, 2022b). Generalisation can be assessed using material in the pre- and post-tests that varies systematically in terms of similarity level to the material used in the intervention (Daly III et al., 1996).

As this research targets learners with dyslexia, assessment of learning gain for adaptive e-learning systems based on learner needs is crucial (Alghabban and Hendley, 2022b). It reflects how much learners have learned, whether their learning gain is persistent and whether their learning gain can be generalised.

Learner Satisfaction Learner satisfaction is another metric that is considered as a predictor of a system's effectiveness (Gatian, 1994). Satisfaction refers to the pleasure that a user feels when they perform an action or receive something needed to perform an action (Shee and Wang, 2008). In the HCI field, the success of a specific information system is associated with the satisfaction of the users (Delone and McLean, 2003). Learner satisfaction is affected by several factors, such as engagement and motivation to interact with the system. It is also associated with the extent to which users believe the system they interact with matches their needs (Shee and Wang, 2008). A high level of satisfaction can contribute to high motivation and engagement as it reflects the quality of the learners' experience (Alshammari et al., 2014).

Standardised questionnaires can be used to assess end user satisfaction after they have used a system (Gena, 2005). Several tools are available for assessing learner satisfaction, such as those of (Bailey and Pearson, 1983; Read et al., 2002; Wang, 2003; Mahdavi et al., 2008; Jung, 2014). Among these tools, the e-learner satisfaction (ELS) tool (Wang, 2003) is a commonly used tool to assess learner satisfaction in adaptive e-learning (Alshammari et al., 2015b; Ghaban and Hendley, 2020). ELS is a validated and reliable questionnaire consisting of 17 items related to four different factors: learning content, system interface, learning community and personalisation (Wang, 2003). These items have 7-point Likert scales ranging from *strongly disagree* to *strongly agree* (Wang, 2003). ELS measures learners' overall satisfaction in addition to satisfaction related to each of the four factors (Wang, 2003). ELS can be adapted to fit a specific research need (Wang, 2003) and is, therefore, widely used for a variety of e-learning systems (Siritongthaworn and Krairit, 2006; Shee and Wang, 2008; Alshammari et al., 2015b; Ghaban, 2021). It also can be adapted to be used by children (Alghabban and Hendley, 2020b; Alghabban et al., 2021; Alghabban and Hendley, 2022a, 2023).

For children, presenting the Likert scale from *strongly disagree* to *strongly agree* is not useful because of the difficulty they encounter in understanding and interpreting it (Read and MacFarlane, 2006). One widely used alternative instrument is the Smileyometer (Read et al., 2002; Read and MacFarlane, 2006) (see Figure 3.4). It uses pictorial representations based on a 1-5 Likert scale that enables children to indicate their feelings by choosing one face. It can be adapted to any tool (Shields et al., 2003; Naidu, 2005). Moreover, it is easy to use, quick to complete and does not require any writing (Alghabban and Hendley, 2022b).

Measuring the degree to which learners with dyslexia are satisfied with the adaptive e-learning system is useful. It allows them to directly indicate whether they perceive the system as suitable for their needs. If the system meets their needs and characteristics, they will be more satisfied and motivated, which in turn affects learning effectiveness (Alghabban and Hendley, 2020b).

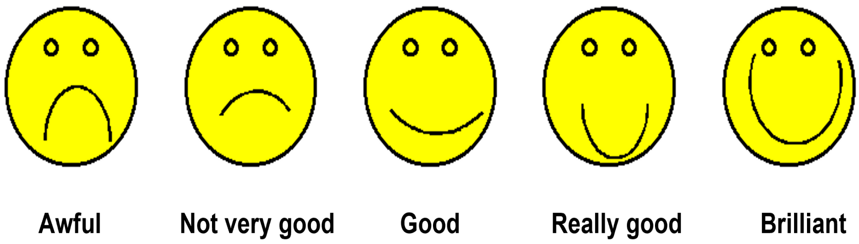

Figure 3.4: The Smileyometer (Read et al., 2002; Read and MacFarlane, 2006).

Perceived Level of Usability Usability is defined as: *'the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use'* (p. 2) (International Organization for Standardization, 1998). According to MacFarlane et al. (2005), usability is an essential factor in determining whether a system facilitates knowledge acquisition. For example, if users perceive that a system is very difficult to use, then this may affect how well they can gain knowledge from it (Anjaneyulu et al., 1998; Rodrigues et al., 2019). Learners who perceive a high level of usability when interacting with an e-learning system will be happier, more engaged and more motivated, resulting in higher learning outcomes (Ardito et al., 2006; Zaharias and Poylymenakou, 2009). Investigating usability involves examining the perceived level of usability when providing adaptation as a measure of the ease of use and learnability of a system that reflects how satisfied users are with the interaction experience (Alghabban and Hendley, 2022b).

The perceived level of usability can be assessed by asking end users to assess the system's usability after use by means of standardised usability questionnaires. There are several tools available for assessing the perceived level of usability of users, such as those of (Brooke, 1996; Edwards and Benedyk, 2007; Finstad, 2010). Among these, the system usability scale (SUS) questionnaire (Brooke, 1996) is commonly used to assess the perceived usability of adaptive e-learning systems (Harrati et al., 2016). SUS has a high degree of validity and reliability (Bangor et al., 2008) and is a valid tool for comparing the usability of two or more systems (Peres et al., 2013). Furthermore, it can be adapted for different contexts (Peres et al., 2013). When using SUS, reliable results are evident even with small samples (Tullis and Stetson, 2004). It also can be adapted to be used by children (Alghabban and Hendley, 2020a; Putnam et al., 2020; Alghabban and Hendley, 2021, 2022b; Naidu, 2005).

The SUS contains 10 mixed-tone items on a 5-point Likert scale from *strongly disagree (1)* to *strongly agree (5)*. The odd numbers items have a positive tone, and the even numbered items have a negative tone.

According to Zaharias and Poylymenakou (2009), few studies critically assess the perceived level of usability. This is particularly the case in dyslexia despite the fact that the perceived level of usability is one crucial factor that should be considered when evaluating adaptive e-learning systems (Alshammari, 2016). It has been argued that, for learners with dyslexia, assessment of the usability of a system is an effective way to measure their attitude to their learning (Alghabban and Hendley, 2022b). Assessment allows them to indirectly measure whether they perceive the system as suitable for their needs. It also ensures that the intended users of a system are able to do the intended tasks in an effective, efficient and satisfactory manner (Aljojo et al., 2018).

To sum up, different evaluation approaches exist to evaluate adaptive e-learning systems to achieve a particular goal. The aims of the evaluation should be identified to choose appropriate metrics. Among these approaches, the experimental evaluation is the most commonly adopted, as it assesses effectiveness and usability issues of adaptive e-learning systems in more controlled and structured settings (Gena, 2005). Therefore, this approach has been used in this research. Learning gain, learner satisfaction and perceived level of usability metrics have also been assessed in this research.

3.4.4 Examples of Adaptive E-Learning Systems

3.4.4.1 Adaptive E-Learning Systems for Non-Disabled Learners

Several adaptive e-learning systems for non-disabled learners are reviewed in this section, and the adaptive parameters for each system have been identified.

Some adaptive systems adapt learning material to the knowledge level of learners. For example, **the ELM-ART system**, one of the most influential adaptive e-learning systems (Brusilovsky, 1998; Weber and Brusilovsky, 2001), adapts material to learners' knowledge level. The last version of ELM-ART, from 2001, is still used to learn the programming language Lisp (Weber and Brusilovsky, 2016). The **InterBook system** was designed to complement ELM-ART as an authoring tool to create and present learning material adapted to learners (Brusilovsky et al., 1998). Another example is **SQL-Tutor**, which personalises learning concepts of SQL according to learners' knowledge level (Mitrovic, 2003). The system was primarily designed to enhance traditional classroom learning in blended learning environments and may not be suitable as a standalone e-learning system.

Other adaptive systems incorporate learning style as a learner characteristic that drives adaptation. For example, one of the early systems that adapt based on learning style is **CS383** (Carver et al., 1999). It is based on the Felder–Silverman learning style model and adapts material related to a computer system course. **Alshammari et al. (2015a)** developed an e-learning system that personalises learning material according to the information perception style of the Felder–Silverman model for computer security education. They showed that learners' performance is enhanced when the system provides an adapted sequence of material based on individuals' learning styles. Another system by **Araújo et al. (2020)** integrates learning style using the Felder–Silverman model and personalises learning material.

Several adaptive e-learning systems combine more than one learner characteristic to drive content adaptation. For example, in **ActiveMath**, the mathematical content is adapted based on learners' knowledge, goals and media preferences (Melis et al., 2001). It provides personalised content via a web browser. **INSPIRE** is another system that personalises material related to a computer architecture course in an e-learning environment by taking into account the learner's knowledge level and learning style (Papanikolaou et al., 2003). It considers the Honey and Mumford learning style model and learners' knowledge level to generate adaptive lessons. **Alshammari and Qtaish (2019)** also report an adaptive e-learning system based on knowledge level and learning style. The system recommends relevant learning material according to the intuitive and sensory dimensions of the Felder–Silverman learning style model. In addition, one recent example of an acceptable, web-based, adaptive e-learning system is proposed by **Hariyanto and Köhler (2020)**. It integrates both learners' knowledge level and learning style. It adapts the learning material according to four dimensions of the Felder–Silverman learning style model: active–reflective, sensing–intuitive, visual–verbal, and sequential–global.

The literature review reveals that much research has been done on adapting the learning content based on different characteristics of learners. Adaptive e-learning is becoming more important and practical for non-disabled people.

3.4.4.2 Adaptive E-Learning Systems for Learners with Dyslexia

Some studies have contributed to the use of adaptive e-learning systems to educate, train and assist learners with dyslexia. Some studies have considered learning style as one characteristic in adaptive e-learning systems. For instance, **Benmarrakchi et al. (2017a)** aimed to identify the relationship between learning style and learners with dyslexia. They found a majority of learners with dyslexia (seven of eight) were visual, and all learners (eight) were activist. Then, they developed an adaptive, game-based, mobile-learning (m-learning) system based on this preferred learning style to enhance and support learning in the areas of reading, comprehension, writing, concentration, short-term memory and Arabic orthography. They reported an increase in learners' motivation and performance. However, the evaluation methodology was not included, and the system's effectiveness was unclear. Another study was conducted by **Alghabban et al. (2017)**. The authors developed a cloud-based, m-learning system that enables the manual customisation of the interface and different input and output modes (text, image and audio) according to learners' learning styles. They evaluated the system's learning gain with Arabic learners with dyslexia in primary schools and demonstrated an increase in their reading skills after three months of use.

Some systems consider adaptivity based on dyslexia type. For example, **Al-Dawsari and Hendley (2021)** investigated the benefits of matching learning material based on dyslexia type, specifically vowel dyslexia, on children's learning gain and satisfaction. An experimental study was conducted with Arabic learners with dyslexia in primary schools. Learners were divided into two groups: the matched group with vowel dyslexia and the mismatched group with short vowel dyslexia. Both groups interacted with a training system that matched material to vowel dyslexia to improve their reading skill. Findings indicated that all learners in both groups achieved positive learning gain with no statistically significant difference between the conditions. However, the study was conducted with only 16 participants, leading to an inability to derive a conclusion.

Alsobhi et al. (2015a) proposed a Dyslexia Adaptive E-Learning (DAEL) framework to adapt according to dyslexia type in English. The framework considers four dimensions: presentation, hypermediality, accessibility and acceptability, and user experience. However, no evaluation was conducted. In another study, **Alsobhi et al. (2015b)** used Ontology Web Language (OWL) to personalise educational material and technologies based on dyslexia type in English. The proposed ontology consists of the following classes: course, concept, resource, learner, dyslexia type, learning style and adaptation. The authors attempted to match each type of dyslexia to the dimensions of the Felder–Silverman learning style model, but the validity and effectiveness of the model were not demonstrated.

Learner behaviour is considered an adaptive characteristic in **Abdul Hamid et al. (2017)**. They aimed to collect a set of requirements for designing an adaptive e-learning system that covers spelling, reading, phonology and writing. To do that, they started by conducting various semi-structured interviews to obtain the required information about learners with dyslexia in primary schools. Then, they proposed an adaptive e-learning system based on learners' behaviour that provides different exercises in Malay. However, the system was neither implemented nor evaluated.

Srivastava and Haider (2020) targeted cognitive traits as an adaptive characteristic. They developed a system to improve understanding of the structure of English letters for children with dyslexia. The system determined the cognitive traits of learners and then adapted learning content based on their traits. The proposed system had positive feedback from teachers. However, it had not been evaluated by learners to understand its impact on their learning performance.

Some systems consider adaptivity based on more than one characteristic of learners with dyslexia. For example, **Alsobhi and Alyoubi (2020)** examined the relationship between dyslexia type and learning style to provide better adaptivity of learning material. To do that, they proposed the Dyslexia and Learning Style Model (DLSM) based on the Felder–Silverman learning style model and Ingram classifications for dyslexia. An experiment was conducted with English learners with dyslexia to find the relationship between learning style and dyslexia type. Results revealed that the visual learning style is the most dominant across all types of dyslexia. However, the effectiveness of adapting learning material based on this learning style was not demonstrated.

Benmarrakchi et al. (2017c) proposed an adaptive e-learning system for Arabic that treats each learner as an individual based on their learning styles, cognitive traits, prior knowledge and user experience. The proposed system targets making the learning process more accessible to learners. However, it was neither implemented nor evaluated. **Alsobhi and Alyoubi (2019)** developed a Dyslexia Adaptive E-Learning Management System (DAELMS) to personalise learning material based on English learners' learning style, knowledge level and dyslexia type. The DAELMS system incorporates the following adaptation options: presentation, navigation, curriculum structure and guidance, to align the learners' learning experience with dyslexia type, preferred learning styles and knowledge level. However, the system evaluation and results were not presented.

In addition to the learning style and knowledge level of learners as adaptive parameters, **El Fazazi et al. (2021)** also considered disability types. They proposed an adaptive e-learning architecture based on a multi-agent approach, considering three learner characteristics in English: knowledge level, learning style according to the Felder–Silverman learning style model and three types of disabilities (dyslexia, hearing impairments and visual impairments). The proposed architecture aims to recommend a sequence of learning objects that matches learner profiles. However, it was not evaluated.

Table 3.3 presents a representative overview of such existing adaptive e-learning systems for learners with dyslexia and enumerates for each system the intervention type, the learner characteristics, the target language and the evaluation method.

The previous literature indicates that adaptive e-learning is becoming more important and practical for people with dyslexia in different languages. However, there is still a need for more research in this area as most previous studies have limitations, which are covered in the following section.

3.5 Conclusion

Throughout this chapter, some fundamental theories have been outlined regarding the process of learning and the roles that teachers and learners play. There are overlaps between these theories. Behaviourism is concerned with the learners' behaviour by addressing their responses to specific stimuli and ignoring learners' mental processes. In cognitivism, the learners receive, organise, store and retrieve information. Both behaviourism and cognitivism assume the world is external to the learners and ignore the outside world's role. On the other hand, constructivism suggests that learners interact with the learning environment and interpret their experiences with the world to

Table 3.3: Example of adaptive e-learning systems for learners with dyslexia from reviewed literature.

Author(s) and year	Intervention type	Learner characteristics	Target language	Evaluation
Benmarrakchi et al. (2017a)	Educational	Learning style	Arabic	N/A
Alghabban et al. (2017)	Educational	Learning style	Arabic	Pre- and post-test experimental design
Al-Dawsari and Hendley (2021)	Training	Dyslexia type	Arabic	Pre- and post-test experimental design
Alsobhi et al. (2015a)	Educational	Dyslexia type	English	N/A
Alsobhi et al. (2015b)	Educational	Dyslexia type	English	N/A
Abdul Hamid et al. (2017)	Training	Learners behaviour	Malay	N/A
Srivastava and Haider (2020)	Training	Cognitive traits	English	Teacher feedback
Alsobhi and Alyoubi (2020)	Educational	Dyslexia type and learning style	English	N/A
Benmarrakchi et al. (2017c)	Educational	Learning style, cognitive traits, knowledge level and user experience	Arabic	N/A
Alsobhi and Alyoubi (2019)	Educational	Dyslexia type, learning style and knowledge level	English	N/A
El Fazazi et al. (2021)	Educational	Learning style, knowledge level and disabilities	English	N/A

gain knowledge. Finally, connectivism describes how Internet technologies enable learners to learn and share information. It suggests that learning occurs through experiences that can be shared via technologies. Knowing the differences between these learning approaches is crucial to carefully selecting the most appropriate approach or combination of approaches.

This chapter has also discussed e-learning and the implications of learning theories in e-learning. E-learning refers to any educational material that can be delivered by technology. It enables the broader community to access content at any time from anywhere. Several popular traditional e-learning systems were reviewed, followed by a focus on reviewing the strengths and weaknesses of existing traditional e-learning systems for people with dyslexia in different languages. Many attempts have been conducted to build and evaluate traditional e-learning systems for learners with dyslexia. However, there are several issues regarding these studies. As mentioned in (Alghabban and Hendley, 2020a,b; Al-Dawsari and Hendley, 2021), these systems do not consider different characteristics of individuals with dyslexia; instead, they tend to provide the same learning content in the same sequence to all learners and ignore the different needs and expectations of the different learners. This may make the learning process less effective and more time-consuming and leads to dissatisfaction. Thus, it affects learning performance. Therefore, the content presented should be different based on individual learners' characteristics.

Adaptivity in e-learning systems addresses the challenge of the 'one-size-fits-all' approach in traditional e-learning systems. In the context of e-learning systems, adaptation means tailoring the educational environment to meet the needs of the user. An adaptive e-learning system consists of three major components: the domain model, the learner model and the adaptation model. The primary goal of adaptive e-learning systems is to meet individuals' different needs and characteristics to enhance their learning experience.

Some common approaches and metrics to evaluate the effectiveness of adaptive e-learning systems have been presented. Among these evaluation approaches, the experimental evaluation is the most valuable as it assesses effectiveness and usability issues of systems in more controlled and structured settings (Gena, 2005). Metrics, including learning gain, learner satisfaction and perceived level of usability, have also been covered.

With the current shift to adaptive e-learning systems, this chapter has reviewed existing adaptive e-learning systems for non-disabled people and existing adaptive e-learning systems for people with dyslexia in different languages. Some attempts at adaptation based on characteristics of learners with dyslexia have been conducted. These characteristics include learning style, preferences, knowledge level, learner behaviour and dyslexia type. However, there is still a need for more research as most of these studies lack carefully designed and controlled experimental evaluations, which leads to difficulty in interpreting the effectiveness of the proposed systems (Alsobhi et al., 2015a,b; Benmarrakchi et al., 2017c; Abdul Hamid et al., 2017; Alsobhi and Alyoubi, 2019, 2020; El Fazazi et al., 2021). A carefully designed and controlled evaluation of adaptive e-learning systems could be more significant than simply proposing new and novel systems (Gauch et al., 2007). Most studies that included an evaluation relied on collecting informal feedback (Srivastava and Haider, 2020) or did not report the evaluation methodology (Benmarrakchi et al., 2017a), which leads again to difficulty in evaluating the effectiveness of the systems. Those studies that used more formal evaluation evaluated the system with a small number of participants (Al-Dawsari and Hendley, 2021), which leads to an inability to derive a conclusion.

Individuals with dyslexia have different characteristics (Friedmann and Haddad-Hanna, 2014; Friedmann and Coltheart, 2016). Dyslexia type and knowledge level are most significant characteristics of learners (Felder and Silverman, 1988; Essalmi et al., 2010; Klašnja-Milićević et al., 2011; Friedmann and Haddad-Hanna, 2014; Friedmann and Coltheart, 2016). There is, therefore, a strong argument that an e-learning environment should apply different teaching approaches based on these two characteristics (Alghabban et al., 2021). A few studies have investigated the significance of adaptation based on the learner's knowledge level (Benmarrakchi et al., 2017c; El Fazazi et al., 2021), dyslexia type (Alsobhi et al., 2015a,b; Alsobhi and Alyoubi, 2020; Al-Dawsari and Hendley, 2021) or the combination of them (Alsobhi and Alyoubi, 2019). However, all these studies have the same limitation: they have not been implemented and evaluated to reflect the impact of adaptation according to these two characteristics, leading to difficulty in evaluating the proposed system's effectiveness and drawing reliable conclusions. Although the effect of adapting based on dyslexia type is formally evaluated in (Al-Dawsari and Hendley, 2021), the evaluation was conducted with a small number of participants to derive a conclusion. Examining the effect of adapting based on dyslexia type, knowledge level and the combination of them followed by an empirical evaluation that assesses learning gain (short-term learning gain, persistence of that gain, and the generalisability to new material), learner satisfaction and perceived level of usability, has received limited attention (Alghabban and Hendley, 2020a,b, 2021; Alghabban et al., 2021; Alghabban and Hendley, 2022a). However, these metrics are important indicators of a learning system's quality and effectiveness (Gatian, 1994; Kuo et al., 2013; Alghabban and Hendley, 2022b).

Overall, research that draws upon the theoretical understanding of dyslexia and uses this to derive adaptive e-learning is very limited (Alghabban et al., 2021). Where this has been investigated, the evaluation of its effectiveness is very limited, and whether adaptation based on characteristics of learners with dyslexia is valuable or not remains unclear. Therefore, the next chapter will cover how these issues are addressed in this research.

Chapter 4

A Framework for Evaluating the Effectiveness of Adaptation Based on Dyslexia Characteristics

4.1 Introduction

The previous chapter explored the theoretical foundations of learning that determine how people learn and how learning theories can enhance their learning. It also reviewed the background of electronic learning (e-learning) and various aspects of adaptivity, as well as their implications in the learning field for people with dyslexia. Some current research issues were identified.

This chapter presents the proposed framework for evaluating the impact of matching learning material based on the characteristics of learners with dyslexia to address current research issues. Later, it presents an overview of the methodology used to achieve the research's aims.

4.2 Motivation

As mentioned in the previous chapter, adaptive e-learning systems offer more flexibility and adaptability to the unique needs of people with dyslexia (Alghabban and Hendley, 2020a). In turn, this enhances the learning experience of the learners by providing them with the best possible support throughout the learning process (Wu et al., 2017; Alghabban and Hendley, 2020b).

An in-depth critical analysis of the previous literature on dyslexia and adaptive e-learning was presented in the previous chapter, and several issues were outlined. Research that draws upon the theoretical understanding of dyslexia and uses this to derive adaptive e-learning is very limited (Alghabban et al., 2021). Where adaptive e-learning for people with dyslexia has been investigated, the evaluation of its effectiveness is very limited. Therefore, this research aims to investigate the impact of matching learning material based on the different characteristics of learners with dyslexia by conducting three carefully designed and controlled experiments with an empirical evaluation in terms of learning gain, learner satisfaction and perceived level of usability. This research considers the following:

- **Dyslexia characteristics**: this research targets **dyslexia type** and **knowledge level** because these two characteristics of learners are significant in education (Felder and Silverman, 1988; Essalmi et al., 2010; Klašnja-Milićević et al., 2011; Friedmann and Haddad-Hanna, 2014; Friedmann and Coltheart, 2016). Also, the impact of adaptation based on learner's dyslexia type, knowledge level or the combination of them is still under-investigated, and its benefits are unclear (Alghabban and Hendley, 2020a,b; Al-Dawsari and Hendley, 2021; Alghabban and Hendley, 2021; Alghabban et al., 2021; Alghabban and Hendley, 2022a). This research refers to **skill level** rather than knowledge level. Knowledge is learning the principles of a subject, while skill is applying that knowledge in a context. According to Sun and Peterson (1997), learners learn generic and declarative knowledge first and then turn such knowledge into usable, specific procedural skills by practising. This research targets training young learners with dyslexia in reading skills.

- **Domain**: different domains can be targeted in the intervention for learners with dyslexia, such as spelling, reading, or writing. This research targets reading because it serves as a basic building block for learning (Bastug, 2014), and it is one of the language skills whose development has been most intensively investigated in previous research (Silva-Maceda and Camarillo-Salazar, 2021).

- **Intervention type**: the aim is to train learners with dyslexia through reading activities on previously studied reading skills for the following reasons: 1) to improve their reading and 2) there is growing evidence that training can help improve reading abilities for children with dyslexia (Tallal et al., 1998; Fostick et al., 2014; El Kah and Lakhouaja, 2018; Wang et al., 2019; Layes et al., 2019). The majority of their formal, basic knowledge is already acquired, and by practising, they develop that knowledge into specific skills that can be applied subconsciously rather than through conscious reasoning.

- **Design**: the design is based on theory and practice and adopts the dual-route model for single-word reading (described in Section 2.5.3.1) to determine the different types of dyslexia. Also, this research draws on practice in schools.

- **Language**: the study targets dyslexia in Arabic because little research targets dyslexia in this language (Alsswey et al., 2021), despite it being a widely spoken language with a considerable rate of dyslexia (El Kah and Lakhouaja, 2015; Benmarrakchi et al., 2017b; Alghabban and Hendley, 2020a; Al-Dawsari and Hendley, 2022).

- **Participants**: the study targets learners with dyslexia in primary schools due to ease of access to them to conduct experiments. This research focuses on **letter position dyslexia (LPD)** and **vowel letter dyslexia (VLD)** as they are the most frequent and common in Arabic children with dyslexia (Friedmann and Haddad-Hanna, 2014; Al-Dawsari and Hendley, 2022). This research targets three reading skills: **reading letters with short vowels (S1)**, **reading words with Sakin letter(s)**[1] **(S2)** and **reading words with short vowels and Sakin letter(s) (S3)**. These are the basic reading skills upon which other skills are built, and they are appropriate to the target participants.

- **Evaluation**: the research uses a carefully designed and controlled experimental evaluation approach for evaluating the effectiveness of adaptation. As mentioned in Section 3.4.3.1, this approach with real users is the most valuable approach to evaluating adaptive e-learning systems (Weibelzahl, 2001; Gena, 2005; Brown et al., 2009; Mulwa et al., 2011). This approach represents realistic learning situations as closely as possible through a fairly controlled procedure. This research also measures learning gain of word reading, learning gain of word understanding, learner satisfaction and the perceived level of usability. Details of experiments and metrics are covered later in this chapter.

4.3 An Overview of the Research

As mentioned in the previous chapter, whether adaptation based on the characteristics of learners with dyslexia is valuable or not remains unclear. This research aims to address this under-investigated gap. In particular, this research aims to investigate and understand whether matching learning material to different characteristics of learners with dyslexia is beneficial or not. It does this in a controlled way, which then allows the researcher to conclude whether adaptation is beneficial or not. This leads to the research questions and hypotheses that have been addressed in this research regarding the impact of matching learning material based on the characteristics of learners with dyslexia. Details of the research questions and hypotheses are covered in the following Section 4.4.

To investigate the impact of matching learning material to **dyslexia type** and **reading skill level**, this research conducted a series of experiments using different learner characteristics. These experiments were evaluated in terms of learning gain of word reading, learning gain of word understanding, learner satisfaction and perceived level of usability.

[1]The Sakin letter has a sukun above it (represented by a small circle), which is a letter without a vowel.

It should be noted that conducting a single experiment to investigate the impact of matching learning material based on dyslexia type and reading skill level characteristics is not feasible in the context of this work. Conducting one experiment will require more participants and more training time because it requires more experimental conditions in addition to the difficulty in controlling these conditions. Therefore, three experiments, each with its own objectives and hypotheses, were conducted to independently examine the impact of adaptation based on these two characteristics.

In the first experiment, this research investigated the impact of matching learning material based on dyslexia type on the learners' short- and long-term learning gain of reading seen words, long-term learning gain of understanding seen words, learner satisfaction and perceived level of usability (details of these metrics are covered later in Section 4.5.2).

In the second experiment, this research investigated the impact of matching learning material based on reading skill level on the learners' short-term learning gain of reading seen and unseen words, learner satisfaction and perceived level of usability.

After understanding the impact of matching learning material based on dyslexia type and reading skill level separately, this research conducted the third experiment to understand the impact of matching learning material based on the combination of both characteristics on the learners' short- and long-term learning gain of reading seen and unseen words, short- and long-term learning gain of understanding seen words, learner satisfaction and perceived level of usability. Alghabban and Hendley (2022a) claimed that few studies have examined the impact of combining two or more characteristics of a learner with dyslexia in an adaptive e-learning system. Previous research has mainly focused on the impacts of single learner characteristics, such as learning style (Benmarrakchi et al., 2017a) and learner behaviour (Abdul Hamid et al., 2017), while the benefits of adapting for multiple characteristics are rarely taken into account. Even so, Benmarrakchi et al. (2017c), Alsobhi and Alyoubi (2020) and El Fazazi et al. (2021) pointed to the need to consider the various characteristics of learners with dyslexia to improve their learning process.

4.4 Research Questions and Hypotheses

This research addressed three research questions, each with its hypotheses regarding the impact of matching learning material based on the characteristics of learners with dyslexia.

The first question is: **Does matching e-learning material based on dyslexia type improve learning gain compared to non-matched material, and does it achieve a high level of learner satisfaction and perceived level of usability?** Several hypotheses were formulated as follows:

H1.1: Matching learning material to the dyslexia type of learners with dyslexia achieves significantly better *short-term learning gain of reading seen words* compared to non-matched material.

H1.2: Matching learning material to the dyslexia type of learners with dyslexia achieves significantly better *long-term learning gain of reading seen words* compared to non-matched material.

H1.3: Matching learning material to the dyslexia type of learners with dyslexia achieves significantly better *long-term learning gain of understanding seen words* compared to non-matched material.

H1.4: Matching learning material to the dyslexia type of learners with dyslexia achieves significantly better *learner satisfaction* compared to non-matched material.

H1.5: Matching learning material to the dyslexia type of learners with dyslexia achieves significantly better *perceived level of usability* compared to non-matched material.

The second question is: **Does matching e-learning material based on reading skill level improve learning gain compared to non-matched material, and does it achieve a high level of learner satisfaction and perceived level of usability?** Several hypotheses were formulated as follows:

H2.1: Matching learning material to the reading skill level of learners with dyslexia achieves significantly better *short-term learning gain of reading seen words* compared to non-matched material.

H2.2: Matching learning material to the reading skill level of learners with dyslexia achieves significantly better *short-term learning gain of reading unseen words* compared to non-matched material.

H2.3: Matching learning material to the reading skill level of learners with dyslexia achieves significantly better *learner satisfaction* compared to non-matched material.

H2.4: Matching learning material to the reading skill level of learners with dyslexia achieves significantly better *perceived level of usability* compared to non-matched material.

The third question is: **Does matching e-learning material based on a combination of dyslexia type and reading skill level improve learning gain compared to non-matched material, and does it achieve a high level of learner satisfaction and perceived level of usability?** Several hypotheses were formulated as follows:

H3.1: Matching learning material to the dyslexia type and reading skill level of learners with dyslexia achieves significantly better *short-term learning gain of reading seen words* compared to non-matched material.

H3.2: Matching learning material to the dyslexia type and reading skill level of learners with dyslexia achieves significantly better *long-term learning gain of reading seen words* compared to non-matched material.

H3.3: Matching learning material to the dyslexia type and reading skill level of learners with dyslexia achieves significantly better *short-term learning gain of reading unseen words* compared to non-matched material.

H3.4: Matching learning material to the dyslexia type and reading skill level of learners with dyslexia achieves significantly better *long-term learning gain of reading unseen words* compared to non-matched material.

H3.5: Matching learning material to the dyslexia type and reading skill level of learners with dyslexia achieves significantly better *short-term learning gain of understanding seen words* compared to non-matched material.

H3.6: Matching learning material to the dyslexia type and reading skill level of learners with dyslexia achieves significantly better *long-term learning gain of understanding seen words* compared to non-matched material.

H3.7: Matching learning material to the dyslexia type and reading skill level of learners with dyslexia achieves significantly better *learner satisfaction* compared to non-matched material.

H3.8: Matching learning material to the dyslexia type and reading skill level of learners with dyslexia achieves significantly better *perceived level of usability* compared to non-matched material.

4.5 Design

Three experiments were conducted in this research. Each experiment addressed one research question. **Experiment 1** investigated the impact of matching learning material based on **dyslexia type**. **Experiment 2** investigated the impact of matching learning material based on **reading skill level**. **Experiment 3** investigated the impact of matching learning material based on a combination of **dyslexia type and reading skill level**. Each experiment has its tools. A dynamic, web-based e-learning system was built to support these experiments. A summary of the goals and measurements of these experiments is presented in Table 4.1.

Table 4.1: A summary of the goals and measurements of experiments.

Experiments	Goal	Measurements
Experiment 1	Investigating the impact of matching learning material based on dyslexia type.	Short-term learning gain of reading seen words. Long-term learning gain of reading seen words. Long-term learning gain of understanding seen words. Learner satisfaction. Perceived level of usability.
Experiment 2	Investigating the impact of matching learning material based on reading skill level.	Short-term learning gain of reading seen words. Short-term learning gain of reading unseen words. Learner satisfaction. Perceived level of usability.
Experiment 3	Investigating the impact of matching learning material based on a combination of dyslexia type and reading skill level.	Short-term learning gain of reading seen words. Long-term learning gain of reading seen words. Short-term learning gain of reading unseen words. Long-term learning gain of reading unseen words. Short-term learning gain of understanding seen words. Long-term learning gain of understanding seen words. Learner satisfaction. Perceived level of usability.

A between-subjects experimental design approach with a control and an experimental group was used to answer the questions and test the hypotheses. In this approach, each participant in each group experiences only one condition. A between-subjects experimental design approach is more appropriate than a within-subjects design where each participant experiences two different conditions (Gena, 2005; Van Velsen et al., 2008). In a within-subjects experimental design, the participant can carry over the learning effects from one condition to another. However, a between-subjects design approach often requires many participants. Variances between control and experimental groups are possible and can affect the results. Therefore, these variances must be controlled. Variables such as age, grade, and prior knowledge should be controlled before drawing conclusions (Alshammari, 2016). Figure 4.1 illustrates the framework of the experiments (its details are included later in Section 4.7).

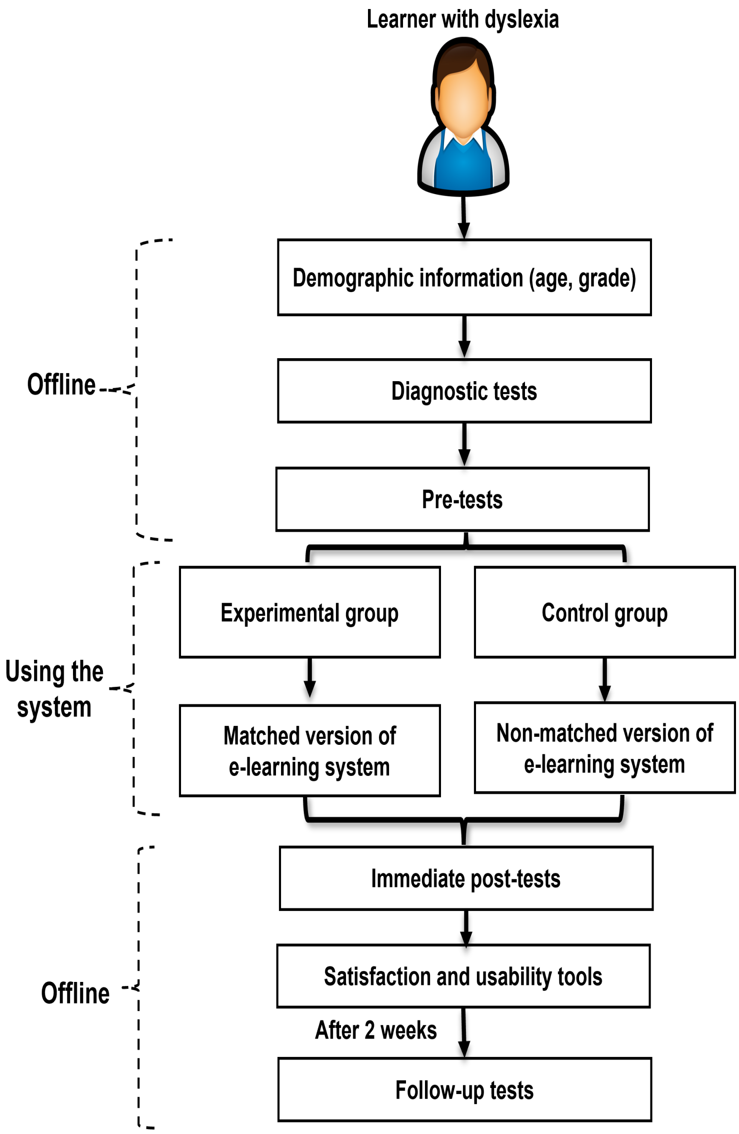

Figure 4.1: The framework of the three experiments.

The experimental group used the matched version of the e-learning system that matches learning material to the targeted characteristic(s) of the learner, while the control group used the non-matched version that provides generic learning material. All other aspects of both versions of the system were the same; the training content was the only difference between them. The following section covers the e-learning system used in both groups.

4.5.1 System

The system trains Arabic learners with dyslexia by providing two versions of reading activities to support the experimental conditions. This research chose to provide reading activities at the word level because word reading is one of the common dyslexia problems reported in the literature about Arabic dyslexia (Al-Sartawi et al., 2001; Al-Wabil et al., 2006). In addition, single-word reading is a strong predictor of reading fluency (Burke et al., 2009). Therefore, including isolated word reading in practice can improve fluency in reading new passages (Lo et al., 2011).

The following sections cover the adaptive e-learning framework upon which the e-learning system was built, the e-learning system architecture, its training material and its interface.

4.5.1.1 Adaptive E-Learning Framework

To investigate the impact of matching learning material based on characteristics of learners with dyslexia, a generic adaptive e-learning framework (see Figure 4.2) is used as a foundation for the design and implementation of the e-learning system used in this research.

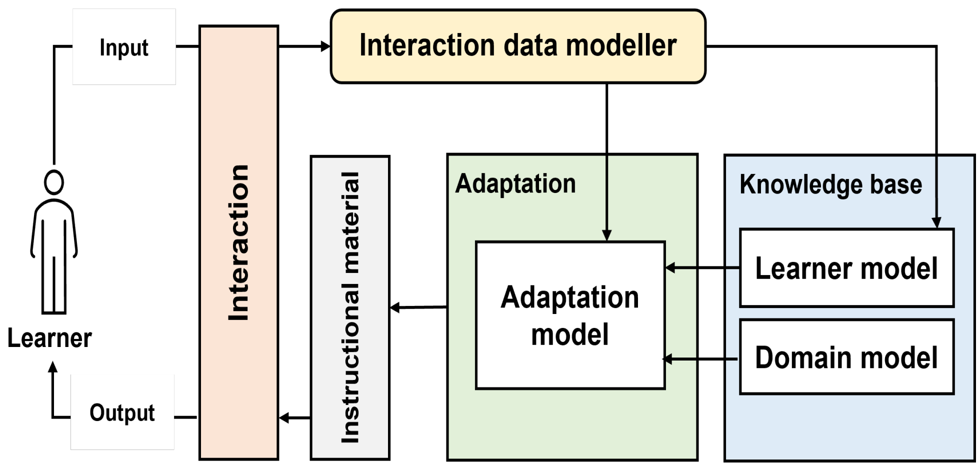

Figure 4.2: A generic adaptive e-learning framework (Alshammari et al., 2015).

Three fundamental models are shown in Figure 4.2: 1) a learner model, 2) a domain model and 3) an adaptation model. The learner model integrates different attributes of learners, such as personality, learning style, and knowledge level. The domain model stores a set of concepts related to the application domain. The adaptation model considers the learner and domain models to adapt the material. The adaptation model initially receives all the necessary data from the learner model. Then, it processes and analyses the received data to determine and deliver the best learning material presented in the domain model to match the characteristics of learners. This model also receives data about learners from the interaction data modeller when they interact with the system. For example, once a learner completes and submits a quiz, the adaptive model instantly analyses the answer to provide adaptive helpful guidance, hints or feedback.

The framework includes two auxiliary components: the interaction module and the interaction data modeller. The interaction module acts as an interface between the learner and the system, facilitating the learner's communication. It presents materials that fit learners' screens and devices. The other component, the interaction data modeller, monitors learners' interactions with the system and updates the learner and adaptation models with this information. Thus, the interaction data modeller registers all the learners' activities, such as the time spent on a page. Then, the modeller updates the data in the learner model to update the learner's history. This modeller also transmits this information to the adaptation model to include recent interaction data in the generation of adaptation.

4.5.1.2 System Architecture

The **Dyslexia Type and Reading Skill Level Training (DTRSLT)** e-learning system was designed and implemented as an instantiation of the adaptive e-learning framework explained in the previous section. The DTRSLT system utilises a simple, three-tier architecture (shown in Figure 4.3), which includes client, server and data storage.

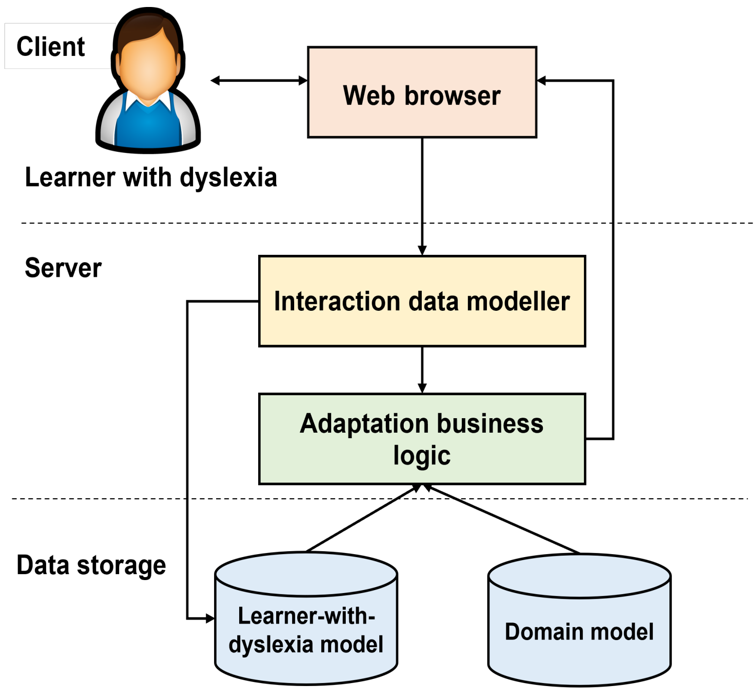

Figure 4.3: The architecture of the DTRSLT system.

Client Tier This tier allows learners to register with the system through the system's browser interface and interact with learning material presented by the system. Every action the learner takes on the interface is sent to the server. For example, when a learner clicks on an activity answer, the action is passed to the server tier, which will then handle the action.

Server Tier This tier includes two components: interaction data modeller and adaptation business logic. The interaction data modeller is responsible for monitoring and identifying learner actions and behaviours with the system interface and feeding these actions to both the learner-with-dyslexia model and the adaptation business logic for updates. For example, when a learner clicks on an activity answer associated with a particular training session, the interaction data modeller will calculate the score of this activity and store the activity number, chosen answer, activity score and the time spent on that activity in the learner's model. When the learner completes all the activities in one training session, the interaction data modeller will calculate the overall score and store it in the learner model. The interaction data modeller also feeds the action data into the adaptation business logic component to consider recent data of the learner interaction with the system when the content is presented.

The adaptation business logic component uses information stored in the domain model and the learner-with-dyslexia model, and data from the interaction data modeller to identify which items of material to present according to learner characteristics. After selecting the material, the adaptation business logic transfers it to the client tier for presentation by the web browser. The adaptation business logic provides matched content (Kobsa et al., 2001; Bunt et al., 2007; Knutov, 2012) as the system matches the content of training material based on the characteristics of the learners. Learners are directed to the next activity using the direct guidance approach.

Data Storage Tier This tier comprises data of both the domain model and the learner-with-dyslexia model. The domain model represents and stores learning material relevant to a particular course, structured in a way that facilitates presenting the most suitable content structure for each learner based on their characteristics. The adaptation business logic component fetches the domain model data when needed to appropriately present the information to each learner.

Figure 4.4 presents an example of the domain model. The model is represented as a hierarchical network composed of five levels (Brusilovsky and Millán, 2007; Alshammari, 2016; Alghabban and Hendley, 2020b). The first level is the root of the domain model structure, which is the course *reading*. Each course consists of several concepts on a particular topic that are addressed in the second level. Each concept is divided into instructional units (IUs) at the third level. These IUs address one specific element of the concept and are classified as simple, intermediate or advanced. Each IU is made up of several learning objects (LOs) at the fourth level. Finally, the fifth level contains small fragments of learning material content for each LO. It includes an activity directly related to that particular LO to enhance its core content. This fulfils the principles of the cognitivism learning theory by dividing the concepts into small parts and sorting them from easy to difficult (Ally, 2004). This presentation method ensures that learners will not get bored while receiving the course content and the course will be suitable for them.

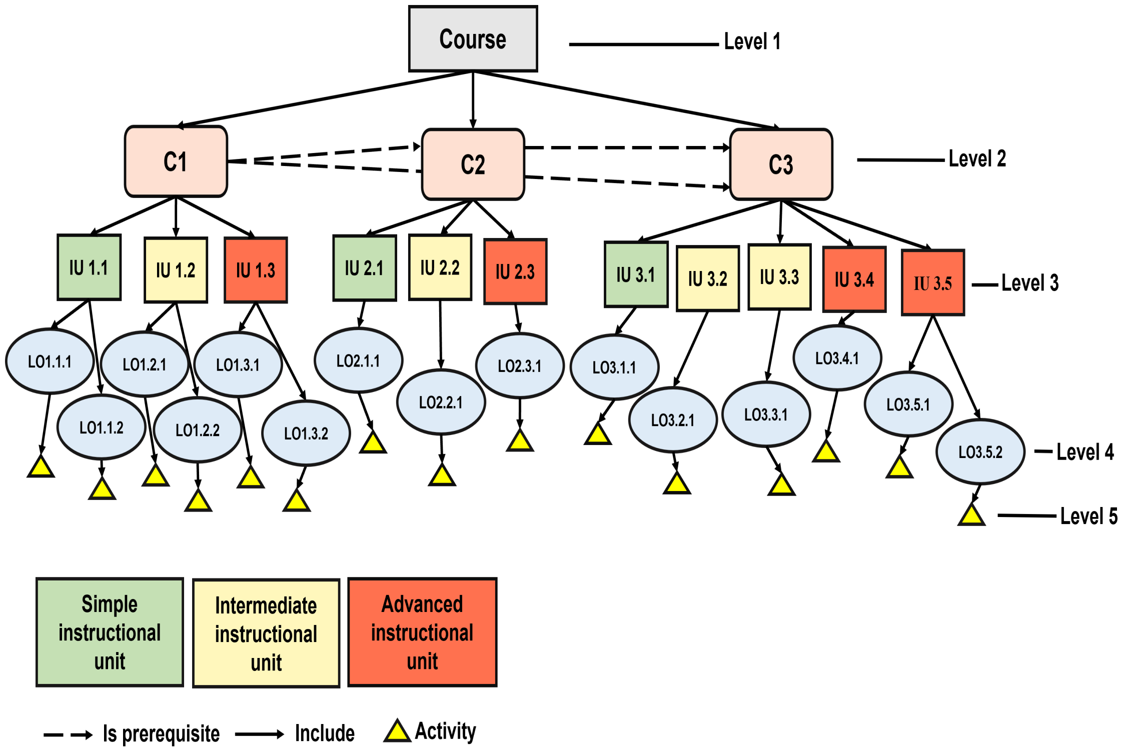

Figure 4.4: An example of the domain model structure (C = concept, IU = instructional unit, LO = learning object).

The content of the reading course, represented in the domain model of DTRSLT, is covered in Section 4.5.1.3.

The learner-with-dyslexia model is part of the data storage tier. It includes the type of dyslexia (LPD and VLD) and the reading skill levels (S1, S2 and S3) to provide matched material. These characteristics were elicited by the diagnostic tests described in Section 4.5.2.2. The learner-with-dyslexia model is initialised when each learner is registered in the system. All of these characteristics (dyslexia types and reading skill levels) are stored in the model and generally remain stable while using the system.

Types of dyslexia are represented by the stereotype technique, which classifies learners who share the same characteristics into groups (stereotypes). There are two stereotypes based on the two targeted types of dyslexia: LPD and VLD. Reading skill levels are represented by the overlay model that assumes the reading skill level of a learner is a subset of the entire domain model. If a learner has already mastered a particular reading skill, the system will not cover the elements for that skill. Instead, it will provide the elements for a skill that the learner needs to master. When a learner finishes answering activities related to a specific LO, the skill level of the related LO is updated, as are its corresponding IU, concept and the course skill levels. The same steps are completed when answering activities of other LOs until all items under a specific skill are finished. Based on learner-system interaction through answering activities, the learner-with-dyslexia model keeps a running update of the skill level of the domain model elements (course, concepts, IUs and LOs). The learner-with-dyslexia model includes some information about learners' behaviour in training sessions, such as time taken to solve each activity within a training session, chosen answers, activity score and overall score for each session. This information is obtained and updated as the learners interact with the system. The adaptation business logic component continually fetches learner-model data to facilitate the delivery of learning material. Figure 4.5 provides an abstract representation of the learner-with-dyslexia model.

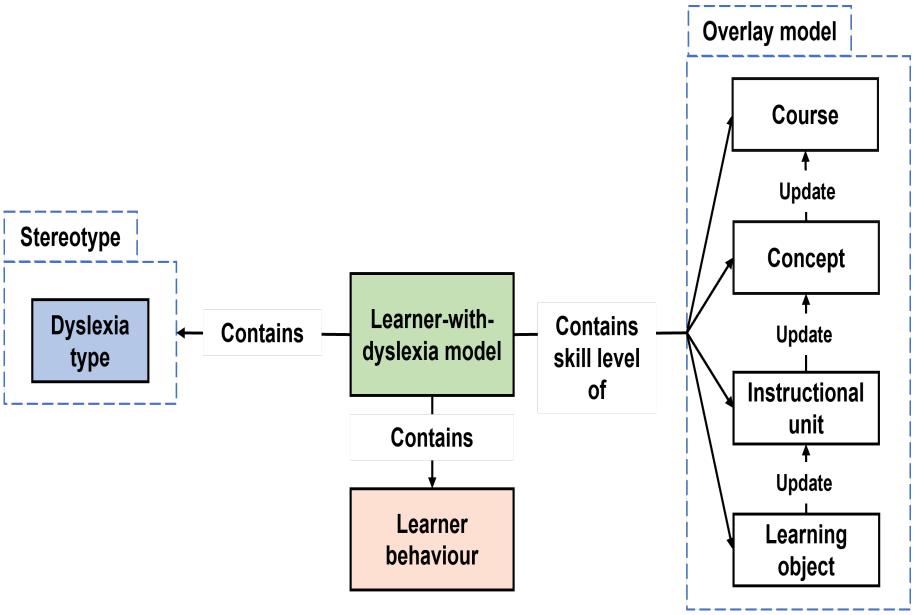

Figure 4.5: An abstract representation of the learner-with-dyslexia model.

As mentioned in Section 4.2, the impact of adaptation based on the characteristics of learners with dyslexia is still unknown from previous research. Thus, this research aims to investigate whether adaptation based on learner characteristics is beneficial. To do this, this research needed to conduct controlled experiments and developed the DTRSLT system to support these experiments. The focus of this research is not on building a dynamic adaptive e-learning system. Instead, it provides a framework that allows these experiments to be conducted based on reliable instruments. Therefore, the learner-with-dyslexia model is instantiated using the reliable, offline diagnostic tests described in Section 4.5.2.2. Reliable diagnostic testing is important in order to be able to build a sound evaluation of the effectiveness of the adaptation.

The DTRSLT system was implemented using several tools: Visual Studio Code[2], Hypertext Pre-

[2]https://code.visualstudio.com/

Processor[3] (PHP), MySQL[4] and Bluehost[5] to host the system. Table 4.2 provides a description of each tool.

Table 4.2: Tools used to implement the DTRSLT system.

Tools	Description
Visual Studio Code	A freeware source-code editor that supports coding, running, testing and deploying different applications.
PHP	A free, popular and server-side scripting language used for developing dynamic content and interactive web applications. It can be run on various servers, such as Internet Information Services (IIS) and Apache, and on many operating systems, including Mac, Windows and Linux. It can be embedded in HyperText Markup Language (HTML) code, which is the markup language for web pages.
MySQL	An open-source relational database management system that uses Structured Query Language (SQL) for database content to manage the data. All data are recorded anonymously using specific identifiers associated with each learner, encrypted and safely saved in a secure database.
Bluehost	A leading web hosting solutions company to host the DTRSLT system. It provides a secure and encrypted connection between clients and the server, which means any information sent between the user browsers and the server will be encrypted; it cannot be intercepted and read during transmission.

4.5.1.3 Training Material

The content of the training material was chosen from the Saudi primary school curriculum, as experiments were conducted in the Kingdom of Saudi Arabia (KSA). Special education experts evaluated the content of the training material and the design of the training activities to ensure they support the critical learning abilities that should be considered for an optimal learning process: recall, understand and apply (Ertmer and Newby, 1993). The training material consists of sets of activities divided into different training sessions.

Table 4.3 summarises the content of training material related to LPD; Table 4.4 summarises the content of training material related to VLD and Table 4.5 summarises the content of training material related to skills: S1, S2 and S3.

Table 4.3: The content for letter position dyslexia (LPD).

Concept	Instructional unit	Difficulty level
Reading two-letter words	Two-letter words with fat-ha /a/ and Sakin letter	Simple
	Two-letter words with kasra /i/ and Sakin letter	Intermediate
	Two-letter words with damma /u/ and Sakin letter	Advanced
Reading three-letter words	Three-letter words with fat-ha /a/ and Sakin letter	Simple
	Three-letter words with kasra /i/ and Sakin letter	Intermediate
	Three-letter words with damma /u/ and Sakin letter	Advanced
Reading four-letter words	Four-letter words with fat-ha /a/ and Sakin letter	Simple
	Four-letter words with fat-ha /a/, kasra /i/ and Sakin letter	Intermediate
	Four-letter words with fat-ha /a/, damma /u/ and Sakin letter	Advanced

[3]https://www.php.net/
[4]https://www.mysql.com/
[5]https://www.bluehost.com/

Table 4.4: The content for vowel letter dyslexia (VLD).

Concept	Instructional unit	Difficulty level
Reading words with alef /a:/	Three-letter words with fat-ha /a/, Sakin letter and alef /a:/	Simple
	Four-letter words with a mix of short vowels, Sakin letter and alef /a:/	Intermediate
	Five-letter words with a mix of short vowels, Sakin letters and alef /a:/	Advanced
Reading words with yaa /i:/	Three-letter words with kasra /i/, Sakin letter and yaa /i:/	Simple
	Four-letter words with a mix of short vowels, Sakin letter and yaa /i:/	Intermediate
	Five-letter words with a mix of short vowels, Sakin letters and yaa /i:/	Advanced
Reading words with waw /u:/	Three-letter words with damma /u/, Sakin letter and waw /u:/	Simple
	Four-letter words with a mix of short vowels, Sakin letter and waw /u:/	Intermediate
	Five-letter words with a mix of short vowels, Sakin letters and waw /u:/	Advanced

Table 4.5: The content for reading skill levels.

Concept	Instructional unit	Difficulty level
Reading letters with short vowels (S1)	Letters with fat-ha /a/	Simple
	Letters with kasra /i/	Intermediate
	Letters with damma /u/	Advanced
Reading words with Sakin letter(s) (S2)	Two-letter words with Sakin letter at the end of the word	Simple
	Three-letter words with Sakin letter (Sakin letter can be either in the middle or the end of the word)	Intermediate
	Four-letter words with two Sakin letters (Sakin letters can be either in the middle or the end of the word)	Advanced
Reading words with short vowels and Sakin letter(s) (S3)	Three-letter words with fat-ha /a/	Simple
	Three-letter words with fat-ha /a/ and kasra /i/	Intermediate
	Three-letter words with fat-ha /a/ and damma /u/	
	Three-letter words with all short vowels	
	Four-letter words with all short vowels and Sakin letters	Advanced

4.5.1.4 Interface

The DTRSLT system trains learners by providing training sessions; each includes several reading activities. Figure 4.6 shows the interface of a training activity of the DTRSLT system through a web browser.

Figure 4.6 shows an image displayed in the middle of the screen, along with three choices. These choices display different words. The number of choices (three) was recommended by special education experts and followed teachers' classroom practice. Also, as claimed by Al-Rubaian et al. (2014) and Aljojo et al. (2018), presenting more than three options increases learners' anxiety. The learner clicks on the image to hear the target word and then clicks on the answer among the three choices (Al-Rubaian et al., 2014). The choices (one correct and two incorrect) are presented close to the screen's lower edge. Upon choosing the correct word, graphical and verbal positive feedback is given (shown in Figure 4.7) to increase the self-esteem and confidence of learners (Benmarrakchi et al., 2017b). Otherwise, feedback is given (shown in Figure 4.8).

The top of the screen displays a training activity number to show feedback on training progress to increase learners' self-awareness of progression (Al-Rubaian et al., 2014). It is possible for the

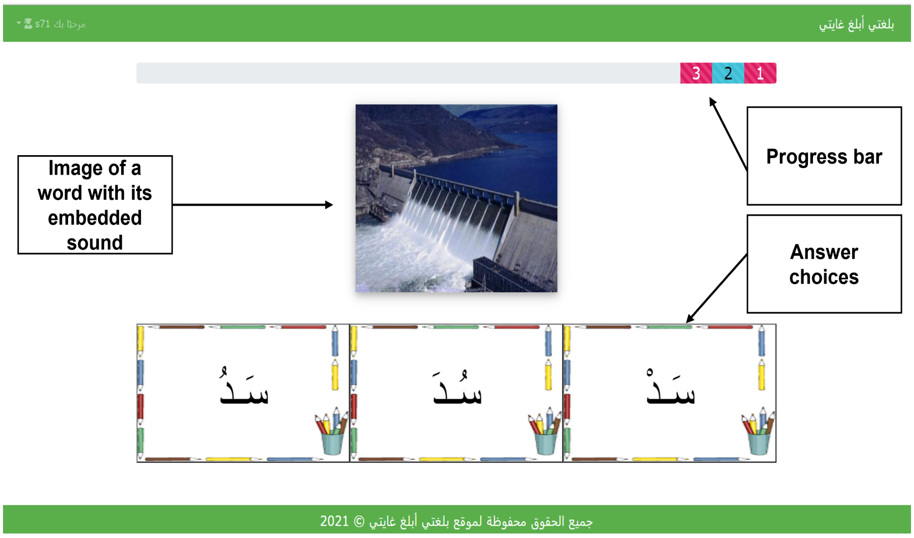

Figure 4.6: An example of a training activity displayed by the DTRSLT interface.

Figure 4.7: Feedback for a correct answer.

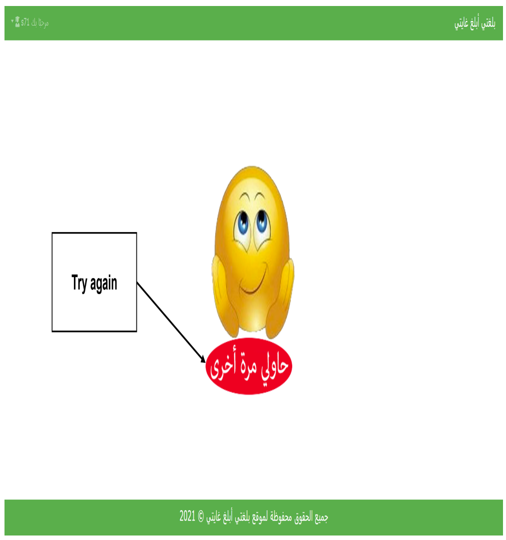

Figure 4.8: Feedback for an incorrect answer.

learner to re-play the target word as many times as they wish by clicking the image. Also, they can use the image as a hint. A motivational message (in both written and pictorial representation), shown in Figure 4.9, is presented in the middle of each training session after completion of some activities to motivate learners to continue (Benmarrakchi et al., 2017b). At the end of the session, a motivational message is displayed with the learner's overall score in this session to increase motivation and confidence (Benmarrakchi et al., 2017b) (see Figure 4.10).

Figure 4.9: A motivational message presented in the middle of a training session.

Figure 4.10: End of a training session with a motivational message and the overall score.

According to Guardiola (2001) and Benmarrakchi et al. (2017a), multimedia cognitive learning theories form the basis that must be considered when designing any e-learning system for people with dyslexia. One of these theories is the cognitive theory of multimedia learning (CTML), popularised by Mayer (1997), which identifies five principles of instructional design (Mayer and Moreno, 2002) (shown in Table 4.6). This theory has been used by many researchers (Sorden, 2013) as it considers the end user when designing and evaluating a learning environment.

Table 4.6: The cognitive theory of multimedia learning (CTML) principles of instructional design (Mayer and Moreno, 2002).

Principle	Description
The multimedia principle	Presenting information in multiple formats is better than presenting it in just one.
The contiguity principle	Presenting verbal and pictorial explanations simultaneously is better than presenting them successively.
The coherence principle	Eliminating unneeded sounds and words in an explanation makes it better understood.
The modality principle	Presenting auditory material is better than visual text on the screen.
The redundancy principle	Presenting information as auditory and animation is better than presenting auditory, printed text and animation (as redundant representation), which overloads working memory.

This research has followed CTML's instructional design principles (Mayer and Moreno, 2002) as well as classroom practice in designing the DTRSLT interface. Figure 4.6 shows that the training material in each activity was presented in spoken text and image (multimedia aids), spoken text instead of onscreen text (modality aids) simultaneously (contiguity aids), to accommodate learners' preferences for presenting information and help them discover their mistakes. No additional text was used to display the training material (redundancy aids), and no extraneous words or sounds unrelated to the training material were presented (coherence aids). Eliminating irrelevant words and sounds is useful because learners with dyslexia have limited working memory (Alsobhi et al., 2015a).

This research has also followed the web design accessibility guidelines for Arabic content for people with dyslexia published by Al-Wabil et al. (2006) and Alotaibi (2007). These guidelines include:

- Text size in the range of 16–20 points; bigger is better (Al-Wabil et al., 2006; Alotaibi, 2007) because it increases text readability (Chen et al., 2015).
- Font type (Times New Roman) as recommended for Arabic text for people with dyslexia (Alotaibi, 2007).
- Emphasising text (bold text instead of underline or italic) (Al-Wabil et al., 2006).
- Avoiding light text on dark backgrounds and using high contrast between background and font colours (Al-Wabil et al., 2006) to reduce any disturbance (Ohene-Djan and Gorle, 2003).
- Using diacritisation[6] (Al-Wabil et al., 2006) to improve reading accuracy for both skilled and poor readers.

4.5.2 Instruments

Data were collected using a variety of instruments presented in the following sections.

[6]Use of diacritics (short vowels).

4.5.2.1 Consent Form

The experiments were subject to ethical approval by the University of Birmingham, number (ERN_19–0528) (see Appendix A). Prior to conducting any experiments, written consent was obtained from the higher authority in the Ministry of Education (MoE) to conduct the experiments (see Appendix B). Written consent was also obtained from the participating schools (see Appendix C). After receiving schools' approval, consent forms were sent to participants' parents/guardians because participants were under 18 years old (see Appendix D). The consent form explained the objective of the experiment, the type of data that would be collected and what is expected from learners during the experiment. The consent form also clarified that nothing within the experiment could cause any harm to the participants and that all collected data will be recorded anonymously (using specific identifiers associated with each participant), encrypted and safely saved in a secure database. Data will not be disclosed to any third party. Only the researcher will be able to access the database. Finally, parents/guardians were told that participants could withdraw from the experiment at any time and could request permanent removal of their data.

4.5.2.2 Diagnostic Tests

The type of dyslexia was determined for each participant using dyslexia type diagnostic tests (see Appendix E) developed by special education teachers. Several special education experts validated the tests and refined the final versions. These tests are based on the reliable and standardised diagnostic tests approved by the Saudi MoE for special needs learners (Bukhari et al., 2016).

The LPD diagnostic test includes a list of 10 vowelised, migratable words to detect LPD. Migratable words happen when an error in letter position still creates a correct word. For example, the word *(تَمَهّل)*, which is pronounced *tmhl* and means *slowed down*, can be read as *(تُهمِل)*, which is pronounced *thml* and means *ignore*.

The VLD diagnostic test includes a list of 10 vowelised words to detect VLD. One example of VLD happens when the erroneously added vowel creates an existing word. For example, the word *(جَمَعَ)*, which is pronounced *jamaa* and means *collected*, can be read as *(جَمِيع)*, which is pronounced *jamie* and means *all*.

Participants were asked to read these words aloud in each test. Participants with other or multiple dyslexia types were not included in the experiments.

The reading skill level was determined for each participant using reading skill level tests developed by special education teachers. Several special education experts validated the tests and refined the final versions. The tests also fit the requirements of standardised tests approved by the Saudi MoE for special needs learners (Bukhari et al., 2016). Three primary tests were used to determine the reading skill level of participants: S1, S2 or S3 (see Appendix F).

Test S1 consists of 48 vowelised words. All words are from the curriculum and have the short vowels (fat-ha /a/, kasra /i/ and damma /u/) to allow presentation of the same letter in different positions with different short vowels within a word. For example, the letter *k (ك)* in the word *(كُتِبَ)*, which is pronounced *kutiba* and means *was written*, is also presented in a different position with a different short vowel in this word *(أُكِلَ)*, which is pronounced *okela* and means *was eaten*. This is one basic feature of Arabic that promotes the manifestation of dyslexia (Elbeheri and Everatt, 2007; Mahfoudhi et al., 2011).

Test S2 consists of 10 vowelised words. All words are from the curriculum and include the Sakin letter within two and three letter-words.

Test S3 consists of 10 vowelised words from the curriculum. Words differ in the number of letters and include Sakin letters and the combination of the three short vowels.

Participants were asked to read these words aloud in each test. Participants with other or multiple reading skill levels were not included in the experiments.

4.5.2.3 Pre-test, Immediate Post-test and Follow-up Test

This research followed the approach of pre- and post-test assessment, commonly used to examine the effects of a specific intervention in enhancing learning (Bao, 2006; Bonacina et al., 2015). Three types of tests were used to assess participants' learning gain: reading seen words, reading unseen words and understanding of seen words. *Seen words* are words included in the training material provided by the e-learning system. *Unseen words* are words not included in the training material to determine whether learners could generalise learned content to other new words (Nist and Joseph, 2008). Previous dyslexia research lacks measurement of knowledge generalisation, as mentioned in Chapter 3.

Special education experts were involved in developing and improving the seen and unseen word reading tests used in this research to ensure their validity and accuracy. Each test included 10 different vowelised words from the curriculum. An example of the test is shown in Appendix G.

In addition to assessing the learning gain of reading seen and unseen words, this research was interested in measuring whether learners can understand the meaning of words. The most common problems faced by children with dyslexia are inaccurate reading and not understanding written texts (Lyon et al., 2003; Shaywitz et al., 2008; Snowling and Hulme, 2012; Lerga et al., 2021). Learning to read requires both accuracy in reading words and understanding what is being read (Layes et al., 2020; Lerga et al., 2021). Reading words is a perceptual method of understanding the meaning of a word (McConaughy, 1978). However, previous dyslexia research lacks a measurement of word understanding.

Word understanding was assessed in this research by an adapted version of the *sentence comprehen-*

sion sub-test battery developed by Layes et al. (2015a) and the word-to-picture matching method developed by Friedmann and Haddad-Hanna (2014) for Arabic people with dyslexia. Rather than sentence comprehension as in (Layes et al., 2015a), this research measured word understanding (at the word level) by presenting 10 different words, each with four different images, where one image reflects the word's meaning (see Appendix H) and the other three do not. Participants were asked to read the target word and choose its appropriate image among a number of pictures. The seen word understanding test includes words included in the training material provided by the e-learning system. Special education experts were involved in developing and improving the word understanding test used in this research to ensure its validity and accuracy. This research did not measure word understanding for unseen words due to time constraints.

Before interacting with the system, each participant completed the pre-tests without time constraints (Layes et al., 2015a). The pre-test determined their level of reading skill and word understanding and was used to balance the experimental conditions.

After finishing the experiment, each participant completed the immediate post-tests to assess what they had learned (short-term effect). These tests reflect the immediate effects of matching learning material to a specific learner's characteristic on improving their reading and understanding. After two weeks, each participant completed the follow-up tests to assess if learning performance persists (long-term effect). Follow-up tests reflect the sustained learning of participants and any delayed effects on their learning gain of reading and understanding. The long-term effect was assessed two weeks after completion of the experiment for the following reasons: 1) this period was sufficient to assess whether participants' learning acquisition was persistent, 2) this duration appeared to be appropriate for the target age group of primary school participants as approved by special education teachers and was similar to that used by previous studies, such as (Knoop-van Campen et al., 2018), where they evaluated the long-term effect after one week and 3) a duration is greater than two weeks exceeded the length of the semester, and participants would not be available to complete the follow-up tests.

The same list of seen words, unseen words and word understanding tests was used in the pre-, immediate post- and follow-up tests for each experiment to allow for an accurate comparison of reading, as recommended in (Bonacina et al., 2015).

4.5.2.4 Learner Satisfaction

The learners' satisfaction was measured using the e-learner satisfaction (ELS) questionnaire (Wang, 2003). This research chose this tool for the following reasons: 1) it is validated and reliable, 2) it is a widely used tool, and 3) it covers different dimensions, such as learning content, system interface and personalisation, that are related to this research. These dimensions were assessed through 10 questions (see Appendix I). The questions about the learning community were not included because they require elements of collaboration that were not considered for this research.

Instead of using the 7-point Likert scale as in the original ELS, all items were adapted to a 5-point Likert scale using the Smileyometer (Alghabban and Hendley, 2020b; Alghabban et al., 2021; Alghabban and Hendley, 2022a). This was done to be consistent with other instruments, as argued by Betts and Hartley (2012).

As mentioned in Chapter 3, assessing satisfaction of learners with dyslexia in adaptive e-learning systems has received limited attention. In this research, it was necessary to determine whether learners with dyslexia were satisfied when interacting with the system for the following reasons: 1) Learner satisfaction is an essential aspect of learning (Sun et al., 2008), as it is a reliable indicator of a learning system's effectiveness and quality (Gatian, 1994; Kuo et al., 2013). 2) Previous literature reviews have found that learners' satisfaction is strongly linked with learners' motivation and engagement (Chen and Chih, 2011; Rodrigues et al., 2019). Consequently, a high level of satisfaction can contribute to high motivation and engagement as it reflects the quality of learners' experience (Alshammari et al., 2014). 3) It describes learners' beliefs regarding how the system they use meets their needs (Shee and Wang, 2008). A system that meets learner needs may result in them being more engaged, motivated and satisfied, all of which influence how effectively they learn (Alghabban and Hendley, 2020b).

Participants completed the ELS questionnaire after finishing the experiment.

4.5.2.5 Perceived Level of Usability

The perception of the usability of the system was measured using the system usability scale (SUS) questionnaire (Brooke, 1996). This research chose this tool for the following reasons: 1) it is a reliable and widely used tool, 2) it is a valid tool for comparing the usability of two or more systems (Peres et al., 2013), a point targeted in this research, and 3) it is used as a usability tool for Arabic users with a high degree of reliability (AlGhannam et al., 2018). Like the ELS tool, SUS's Likert scales were changed to use the Smileyometer (Alghabban and Hendley, 2020a; Putnam et al., 2020; Alghabban and Hendley, 2021, 2022b) (see Appendix J). Moreover, SUS's version with all positive items was used (Sauro and Lewis, 2011) for the following reasons. 1) According to Benson and Hocevar (1985), De Leeuw and Otter (1995) and Borgers et al. (2000), children have problems with negative voice statements and, therefore, it is advisable not to use negatively phrased statements for children. 2) To achieve consistency among questions (Bell, 2007; Read, 2008). 3) According to the recommendations by Sauro and Lewis (2011), SUS's version of all positive items can be used confidently by researchers because 1) scores will be the same as those in standard SUS, and 2) respondents are less likely to make errors when responding.

The usability score that reflects the overall usability is based on an easy-to-understand scale from 0 to 100: the higher the score, the better the usability of the proposed system. According to Bangor et al. (2008), scores between 70 and 80 indicate a satisfactory system, whereas scores higher than 90 indicates a system that is exceptionally usable.

As mentioned in Chapter 3, assessing the perceived level of usability in adaptive e-learning for learners with dyslexia has received limited attention. This is despite the fact that usability is one crucial factor that should be considered when evaluating adaptive e-learning systems. The usability aspect involves investigating the perceived level of usability when providing adaptation, which is a measure of the ease of use and learnability of a system that reflects how satisfied learners are with the system. Therefore, the effect of matching the material of the learning system in terms of perceived level of usability was examined in this research. In addition to being easy and quick to assess, the perceived level of usability provides an indirect measure of whether learners perceive the system as meeting their needs and this, in turn, is likely to affect their engagement and motivation (Alghabban and Hendley, 2022b). As such, usability can augment other metrics, such as learning gain and satisfaction, to judge whether adaptation based on learner needs has been successful (Alghabban and Hendley, 2022b).

Participants completed the SUS questionnaire after finishing the experiment.

The translation process of ELS and SUS questionnaires from the English version to Arabic includes forward translation and backward translation. The translation process aims to ensure an appropriate representation of meaning and was adapted from similar studies in the literature (Blaźica and Lewis, 2015; Tsang et al., 2017). Four independent, bilingual translators initially translated the questionnaires from the original English into Arabic. Two of the translators who had professional experience in the field and were knowledgeable about the concepts measured by the questionnaires provided a translation more similar to the original. The other two professionals, who were unaware of the questionnaire's objective, produced the second translation. In this way, subtle differences in the original questionnaire can be detected. Finally, a fifth unbiased, bilingual expert discussed these translations and resolved the discrepancies between the two versions.

In the backward translation, two independent translators independently translated the Arabic version from Arabic to English to make sure it was accurate. The translators were not aware of the intended components of the questionnaires to avoid bias. The back-translated versions were collected and compared to the original English version.

Next, an expert reviewed the translated versions and assessed whether the Arabic and English versions were conceptually equivalent. As a result, the final version was produced and pilot-tested with six children. Participants were asked to explain their thinking and response to each item in the questionnaires.

4.6 Participants

Arabic-speaking female learners from different primary schools in the KSA participated in the experiments. Due to the cultural constraints in the KSA, it was only possible for the researcher to work with female participants. However, this also has an advantage of reducing variances between participants.

All participants had officially been diagnosed with dyslexia. Primary school learners with dyslexia are chosen because access to learners in primary schools was more straightforward, convenient and practical than in intermediate and high schools, which helped to ensure that a reasonable number of participants were included.

All participants were familiar with electronic devices due to using them to play games and watch YouTube. They interacted with the e-learning system to practice reading.

4.7 Procedure

Approval was obtained from the Saudi MoE, schools, and parents/guardians, and the participants orally confirmed that they were happy to participate in the experiment and were aware that they could stop at any time. Each experiment was only conducted after getting full approval.

As shown in Figure 4.1, participants' demographic information, including age and grade, was collected in one session in each participant's school. Then, learners were welcomed and introduced to the experiment's objectives. After that, the dyslexia type for each participant was determined using dyslexia type diagnostic tests (in **Experiment 1**), their reading skill level was determined using reading skill level tests (in **Experiment 2**), and both dyslexia type and reading skill level were determined using dyslexia type and reading skill level tests (in **Experiment 3**). All participants were given the pre-tests to assess their level of reading skill and word understanding.

The preliminary testing was conducted using reliable, offline tools (described in Section 4.5.2). This is important to achieve a reliable assessment of dyslexia type and reading skill level, which is important for the experiments.

Subsequently, participants were divided equally into two independent groups: a control and an experimental group, and they were registered in the system. The experimental group used the matched version of the e-learning system, while the control group used the non-matched version. This structure allowed to examine the effectiveness of adaptation, as this research hypothesised that there would be a significant difference in learning gain of word reading, learning gain of word understanding, satisfaction and perceived level of usability of participants between these two groups. The two groups were balanced by the number of participants, age, grade, pre-test results and other characteristics (dyslexia type and/or reading skill level). The two groups were homogeneous in terms of native language and gender.

Participants in both groups interacted with training sessions that offered different reading activities. The difficulty of activities gradually increased in both versions. All data were encrypted and stored securely in a database, including usernames, passwords, dyslexia type, reading skill level, answer and score for each activity, time spent on that activity and overall score of each training session.

Both **Experiments 1 and 2** took place in a quiet room within the participant's school. **Experiment 3** was conducted remotely via Microsoft Teams due to school closures in response to the Covid-19 pandemic. All experiments were double-blind in that neither the participant nor the experimenter knew what condition was being used. The experimenter explained the layout of the system before the first session began. After that, every participant used the system individually (one participant at a time) under experimenter supervision to monitor the participant and solve any technical issues. The system tracked participants' progress as they used the system and stored user data in a database.

In **Experiment 1**, this research planned to have eight training sessions, each with 10 activities and training duration of approximately 30 minutes for each session. Participants used the system for two sessions each week for approximately a month. The duration of a training session (30 minutes) and frequency of the training sessions (two sessions each week) were approved by special education teachers and recommended in previous studies (Habib et al., 2002; Griffiths and Stuart, 2013; Wang et al., 2019; Layes et al., 2019; Aljojo, 2020). However, this research found that participants finished the session in an average of 15 minutes. Therefore, in **Experiments 2 and 3**, this research increased the number of activities per session to 20 and reduced the number of training sessions to six. Participants used the system in **Experiments 2 and 3** for two sessions each week for three weeks. Each training session lasted approximately 30 minutes.

Immediately after completing all training sessions, participants took immediate post-tests offline to derive short-term learning gain of reading and word understanding. The satisfaction and usability tools were then administered offline. Two weeks later, participants completed follow-up tests offline to derive long-term learning gain of reading and word understanding.

To validate the experimental design and instruments, a pilot study was conducted before running each experiment with six learners. The pilot study aimed to 1) test whether the proposed methodology and supporting material, in terms of diagnostic tests, pre-, immediate post- and follow-up tests, satisfaction and usability tools worked as expected, 2) identify any problems in the experimental design and any technical issues related to the system, 3) identify issues like confusion and participants questions, 4) test the duration of experiment and 5) collect participants' feedback and data.

4.8 Data Collection

A quantitative analysis approach was used to measure learning gain of reading and word understanding, learner satisfaction and perceived level of usability. The following sections introduce each of these metrics.

4.8.1 Learning Gain of Word Reading

Short-term and long-term learning gain of reading was measured using pre-tests, immediate post-tests and follow-up tests (presented in Section 4.5.2.3). The following formula was used to calculate the short-term learning gain (Alshammari et al., 2016; Pickering, 2017):

$$\text{Learning gain}_{\text{short-term}} = \text{immediate post-test score} - \text{pre-test score}$$

The following formula was used to calculate the long-term learning gain (Alshammari, 2016):

$$\text{Learning gain}_{\text{long-term}} = \text{follow-up test score} - \text{pre-test score}$$

In **Experiment 1**, short-term and long-term learning gain of reading seen words were assessed. However, learning gain of reading unseen words (both short and long term) was not assessed. However, it was considered in **Experiments 2 and 3**.

In **Experiment 2**, short-term learning gain of reading seen and unseen words was assessed. However, long-term learning gain of reading seen and unseen words was not assessed due to school closures in response to Covid-19, making access to participants impossible.

In **Experiment 3**, short-term and long-term learning gain of reading both seen and unseen words were assessed.

4.8.2 Learning Gain of Word Understanding

In this research, both short- and long-term learning gain of understanding seen words were measured using pre-tests, immediate post-tests and follow-up tests (presented in Section 4.5.2.3).

In **Experiment 1**, long-term learning gain of understanding seen words was assessed. However, short-term learning gain of understanding seen words was not assessed because the time of the last session was limited and included both completion of the last training session and the immediate post-test (to assess short-term learning gain of reading seen words), ELS and SUS. It was also difficult to reach participants in another scheduled session to conduct the immediate post-test of word understanding. This problem was considered in **Experiment 3**.

In **Experiment 2**, both short- and long-term learning gain of understanding seen words were not assessed due to practical constraints. These problems were taken into account in **Experiment 3**. In **Experiment 3**, both short- and long-term learning gain of understanding seen words were assessed.

4.8.3 Learner Satisfaction

The learners' satisfaction was measured using ELS (presented in Section 4.5.2.4) from different perspectives, including how satisfied they were with the learning content, learning interface and personalisation. ELS also measured the overall satisfaction with the e-learning system.

Learner satisfaction was assessed in all experiments.

4.8.4 Perceived Level of Usability

The perceived level of usability was measured using SUS (presented in Section 4.5.2.5). The perceived level of usability was assessed in all experiments.

4.8.5 Reading Speed

This research targeted measuring reading speed in this work, as learners with dyslexia experience a deficit in reading speed (Miller-Shaul, 2005; Suárez-Coalla and Cuetos, 2012; Martelli et al., 2014). Data to measure reading speed were collected in **Experiment 3** only because this research had not considered it as a metric in **Experiments 1 and 2**. However, the experiment was conducted remotely, and the data collected were not reliable.

4.9 Data Analysis

After each experiment was completed, the collected data were cleaned and analysed. Including incomplete data in the overall process of data analysis is not appropriate. Depending on the experimental variables, there may also be a need to process data. For example, some variables must be calculated using existing data from other variables, such as learning gain. After cleaning and processing data, this research used the IBM SPSS Statistical software package to analyse data. This research used statistical tests to explore significant differences between experimental groups in this research, such as the t-test and the Mann–Whitney U test (Pallant, 2011; Gray, 2014). Both tests are used when there are one independent and one dependent variable and two experimental groups, as in this research. The t-test is used when data are normally distributed, while the Mann–Whitney U test is used when data are not normally distributed. The Shapiro–Wilk test is used to determine whether data are normally distributed because it can be applied to data from small samples and large sample sizes (Pallant, 2011; Ghasemi and Zahediasl, 2012). The probability value is used to determine significance of the findings at the 5% level. A finding of $p > 0.05$, for instance, is not considered statistically significant and is attributed to chance rather than an effect of the treatment being tested in the experiment.

Likewise, effect size is used to evaluate the importance of findings. It is a primary measure used within research to measure change. It indicates how much the independent variable impacts the dependent variable or the strength of the difference between groups. Even though reporting effect sizes for research comparisons is important, previous studies regarding people with dyslexia and adaptive e-learning have not reported them (Alghabban et al., 2017; Al-Dawsari and Hendley, 2021). The most commonly used effect size measures are Cohen's d and r (Pallant, 2011; Nissen et al., 2018). Based on benchmarks suggested by Cohen (1988), a commonly used interpretation for d is to refer to effect sizes as small ($d = 0.2$), medium ($d = 0.5$) and large ($d = 0.8$). Additional findings in the literature indicate that it would be appropriate to redefine the rules of thumb for effect sizes as very small ($d = 0.01$), small ($d = 0.2$), medium ($d = 0.5$), large ($d = 0.8$), very large ($d = 1.2$) and huge ($d = 2.0$) (Sawilowsky, 2009).

In non-parametric tests, such as the Mann–Whitney U test, the effect size r is measured by dividing the absolute standardised test statistic (z) by the square root of the number of pairs, as shown in the following equation (4.1) (Fritz et al., 2012; Karadimitriou et al., 2018):

$$r = \frac{z}{\sqrt{N}} \tag{4.1}$$

The Cohen's classification of effect size (r) is that a small effect is 0.1, a medium effect is 0.3, and a large effect is 0.5 and above (Cohen, 1988; Fritz et al., 2012; Karadimitriou et al., 2018).

4.10 Summary

This chapter has covered the proposed framework to investigate the impact of adapting learning material based on the characteristics of learners with dyslexia by conducting three carefully designed and controlled experiments with an empirical evaluation in terms of learning gain of word reading, learning gain of word understanding, learner satisfaction and perceived level of usability.

Experiment 1 investigates the impact of adaptation based on dyslexia type. Experiment 2 investigates the impact of adaptation based on reading skill level. Experiment 3 investigates the impact of adaptation based on the combination of dyslexia type and reading skill level. Each experiment has its hypotheses and tools.

To support these experiments, a dynamic, web-based e-learning system called Dyslexia Type and Reading Skill Level Training (DTRSLT) was designed and implemented as an instantiation of the adaptive e-learning framework (explained in Section 4.5.1.1). DTRSLT trains Arabic learners with dyslexia by providing reading activities using a three-tier architecture with client, server and data storage.

The client tier allows learners to interact with learning material through the system's browser interface. The server tier including interaction data modeller and adaptation business logic. The interaction data modeller is responsible for monitoring learner actions with the system interface and updating both the learner-with-dyslexia model and the adaptation business logic with these actions. The adaptation business logic component is responsible for identifying the content items to be presented according to learner characteristics. The data storage tier includes both the learner-with-dyslexia model and the domain model. The learner-with-dyslexia model includes the types of dyslexia, the reading skill levels and some information about learners' behaviour while interacting with the system. The domain model stores learning material.

A between-subjects experimental design approach, which has a control and an experimental group, was used to achieve the purpose of each experiment. The experimental group used the matched version of DTRSLT that matches learning material to the targeted characteristic(s) of the learner, while the control group used the non-matched version of DTRSLT that provides generic learning material. All other aspects of both versions of DTRSLT were the same; the training content was the only difference between them. The next chapter will explain the results and discussion of each experiment in detail.

Chapter 5

Evaluation

5.1 Introduction

The previous chapter discussed the motivation behind this research and the methodology used to achieve its aim, including the general framework of experiments and the design of the Dyslexia Type and Reading Skill Level Training (DTRSLT) system to support the experiments, instruments, data collection and experimental procedure.

This chapter explains the results of the experimental evaluation of matching learning material to dyslexia type and reading skill level. It also discusses these results and how they relate to previous research.

This chapter is based on the content published in the following papers: Alghabban and Hendley (2020a,b, 2021); Alghabban et al. (2021); Alghabban and Hendley (2022a,b, 2023).

5.2 Experiment 1: Matching Learning Material to Dyslexia Type

5.2.1 Introduction

This section presents the results of the evaluation of matching learning material to dyslexia type (**letter position dyslexia (LPD)** and **vowel letter dyslexia (VLD)**). As mentioned in Chapter 4, these dyslexia types are the most common in Arabic. A controlled experiment was conducted to investigate whether matching learning material to the dyslexia type of learners with dyslexia enhances their learning experience. In particular, it investigated: 1) whether learners learn more, 2) whether this learning persists in the long term, 3) whether this matching affects their understanding of words, 4) whether this matching affects their satisfaction with the learning experience, and finally, 5) whether learners are aware of the matching of material to their needs and if that awareness indirectly affects their perception of the usability of the system.

This experiment investigated the following research question:

Research Question 1: Does matching e-learning material based on dyslexia type im-

prove learning gain compared to non-matched material, and does it achieve a high level of learner satisfaction and perceived level of usability?

5.2.2 Hypotheses

Five hypotheses were tested in this experiment:

H1.1: Matching learning material to the dyslexia type of learners with dyslexia achieves significantly better *short-term learning gain of reading seen words* compared to non-matched material.

H1.2: Matching learning material to the dyslexia type of learners with dyslexia achieves significantly better *long-term learning gain of reading seen words* compared to non-matched material.

H1.3: Matching learning material to the dyslexia type of learners with dyslexia achieves significantly better *long-term learning gain of understanding seen words* compared to non-matched material.

H1.4: Matching learning material to the dyslexia type of learners with dyslexia achieves significantly better *learner satisfaction* compared to non-matched material.

H1.5: Matching learning material to the dyslexia type of learners with dyslexia achieves significantly better *perceived level of usability* compared to non-matched material.

Two groups were used, a control group and an experimental group. The experimental group interacted with the matched version of DTRSLT that matches the learning material to the dyslexia type (either LPD or VLD), while the control group interacted with the non-matched version of the system that provides generic learning material (material that addresses a combination of both LPD and VLD). The system layout and interface were identical for both groups. The only difference is the provided learning material. Chapter 4 describes the design of the system interface and the provided activities.

In this experiment, this research measured short- and long-term learning gain of reading seen words, long-term learning gain of understanding seen words, learner satisfaction and perceived usability level.

5.2.3 Procedure

As mentioned in Chapter 4, participants were encouraged to participate in the experiment by providing different reading activities. The experiment was run physically in schools. Eight training sessions, each with 10 activities, were conducted, for a total of 80 activities. Table 5.1 shows the experimental procedure timetable. The learning material was selected from the primary school curriculum to target LPD and VLD (presented in Chapter 4).

5.2.4 Results

Forty participants with a mean age of 8.93 ($SD = 1.37$) were included in this experiment. They were chosen from five primary schools in the Kingdom of Saudi Arabia (KSA) (Jeddah). Figure

Table 5.1: Experiment 1: Procedure timetable.

Week#	Session	Activity
1	Pre-starting	Overview of the experiment, conducting dyslexia type diagnostic tests and pre-tests of word reading and word understanding.
2	Training sessions	First and second training sessions.
3		Third and fourth training sessions.
4		Fifth and sixth training sessions.
5		Seventh and eighth training sessions.
5	Immediate post-test, e-learner satisfaction (ELS) and system usability scale (SUS)	Conducting immediate post-test of word reading, ELS and SUS questionnaires.
7	Follow-up tests	Conducting follow-up tests of word reading and word understanding.

5.1 presents the characteristics of the participants.

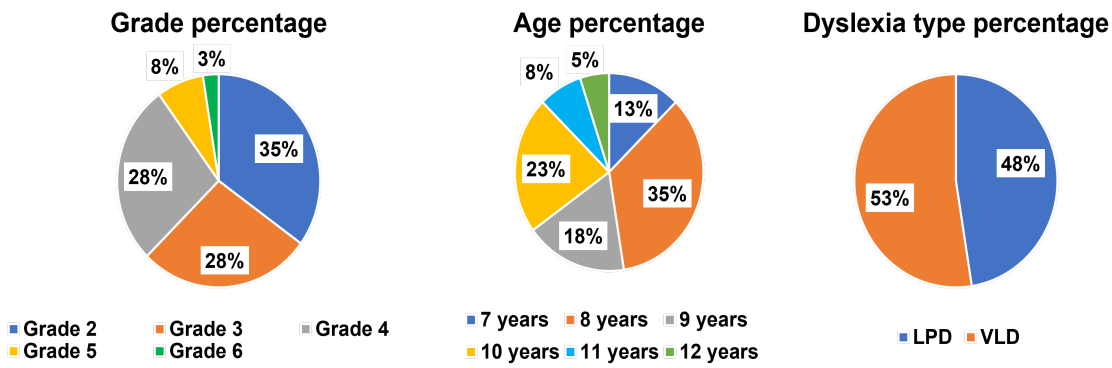

Figure 5.1: Experiment 1: Participant characteristics.

The participants were assigned either to the control group (n = 20, mean age = 8.95 years, SD = 1.39) or the experimental group (n = 20, mean age = 8.9 years, SD = 1.37), balanced by age, grade, dyslexia type and pre-test results of reading seen words and word understanding. There was no statistically significant difference between the means of each group in either age ($p = 0.947 > 0.05$), the pre-test result of reading seen words ($p = 0.904 > 0.05$) or the pre-test result of word understanding ($p = 0.718 > 0.05$).

All participants completed the experiment except two learners in the control group who were not available to complete the follow-up tests because they changed schools, and access to them was impossible.

The results of each hypothesis are described in the following sections.

5.2.4.1 Learning Gain of Reading Seen Words

Short-term Hypothesis (H1.1) about short-term learning gain of reading seen words was tested. Table 5.2 shows the experimental group had greater immediate post-test scores and short-term learning gains of reading than the control group. These findings reveal that matching learning material to dyslexia type had a positive effect on short-term learning gain of reading seen words.

The significance of the short-term learning gain of reading seen words was tested. As short-term

Table 5.2: Experiment 1: Control and experimental group results of pre-test, immediate post-test and short-term learning gain of reading seen words.

Group	N	Pre-test		Immediate post-test		Short-term learning gain of reading seen words	
		Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*
Control	20	4.05	3.22	4.65	3.27	0.60	1.43
Experimental	20	4.10	3.24	7.45	1.64	3.35	1.84

learning gain scores for both groups were normally distributed, as determined by Shapiro–Wilk's test ($p > 0.05$), an independent sample t-test with an alpha level of 0.05 was run to determine if there were differences in short-term learning gain scores between the experimental and control groups. Learning gain scores for both groups were homogeneous in variance, as determined by Levene's test for the equality of variances ($F = 2.936$, $p = 0.095$). Based on the means of short-term learning gain, the experimental group had larger short-term learning gain than the control group, with a statistically significant difference of 2.75, $t(38) = 5.27$, $p < 0.001$ (see Figure 5.2). The finding had a very large effect size (Cohen's $d = 1.67$). As a result, H1.1 is confirmed, and it can be concluded that matching learning material to dyslexia type yields significantly better short-term learning gain of reading seen words than not matching.

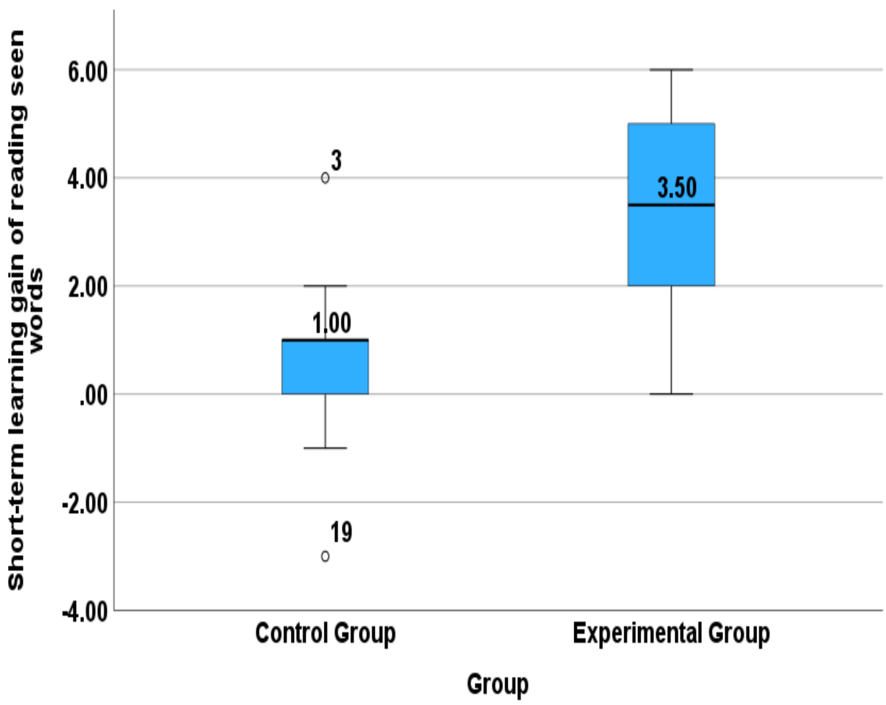

Figure 5.2: Experiment 1: Box plot for the results of short-term learning gain of reading seen words.

Long-term Hypothesis (H1.2) about long-term learning gain of reading seen words after two weeks have elapsed was tested. The sample size fell to 18 participants in the control group. After removing data related to participants who did not complete the follow-up test, there was no statistically significant difference between the means of each group in either age ($p = 0.675 > 0.05$), the pre-test result of reading seen words ($p = 0.851 > 0.05$) or the pre-test result of word understanding ($p = 0.702 > 0.05$).

Table 5.3 shows the experimental group had greater follow-up test scores and long-term learning gains of reading than the control group. These findings reveal that matching learning material to dyslexia type had a positive effect on long-term learning gain of reading seen words.

Table 5.3: Experiment 1: Control and experimental group results of pre-test, follow-up test and long-term learning gain of reading seen words.

Group	**N**	**Pre-test**		**Follow-up test**		**Long-term learning gain of reading seen words**	
		Mean	***SD***	***Mean***	***SD***	***Mean***	***SD***
Control	18	4.39	3.22	5.94	3.13	1.55	1.69
Experimental	20	4.10	3.24	8	1.95	3.90	2.13

The significance of the long-term learning gain of reading seen words was tested. As the long-term learning gain score distributions in the control group were not normally distributed (Shapiro–Wilk's test $p < 0.05$), an independent sample Mann–Whitney U test was run to determine if there were differences in long-term learning gain scores between the experimental and control groups. The results showed that the long-term learning gain scores for the experimental group ($median = 4$) were statistically significantly higher than the control group ($median = 1$), as shown in Figure 5.3, $U = 63.5$, $Z = 3.45$, $p < 0.001$. The finding had a large effect size ($r = 0.56$). As a result, H1.2 is confirmed, and it can be concluded that matching learning material to dyslexia type yields significantly better long-term learning gain of reading seen words than not matching.

5.2.4.2 Learning Gain of Understanding Seen Words

Hypothesis (H1.3), which is about long-term learning gain of understanding seen words, was tested. Table 5.4 shows the experimental group had greater follow-up test scores and long-term learning gains of understanding than the control group. These findings reveal that matching learning material to dyslexia type had a positive effect on long-term learning gain of understanding seen words.

Table 5.4: Experiment 1: Control and experimental group results of pre-test, follow-up test and long-term learning gain of understanding seen words.

Group	**N**	**Pre-test**		**Follow-up test**		**Long-term learning gain of understanding seen words**	
		Mean	***SD***	***Mean***	***SD***	***Mean***	***SD***
Control	18	3.67	2.79	4.94	2.53	1.27	1.64
Experimental	20	4.05	3.3	7.65	2.13	3.6	1.98

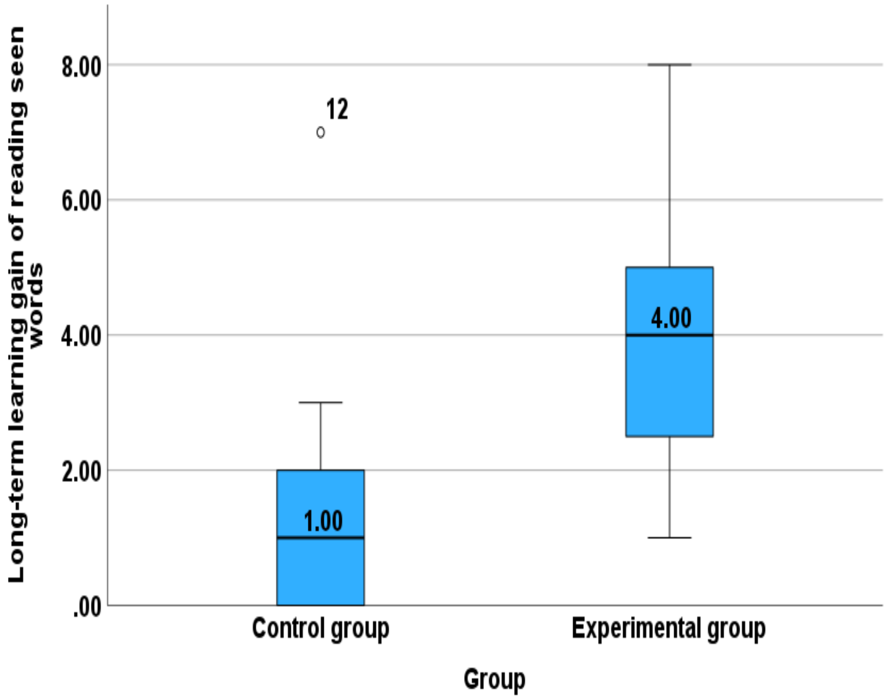

Figure 5.3: Experiment 1: Box plot for the results of long-term learning gain of reading seen words.

The significance of the long-term learning gain of understanding seen words was tested. As the long-term score distributions in the experimental group deviated from the normal distribution (Shapiro–Wilk's test $p < 0.05$), an independent sample Mann–Whitney U test was run to determine if there were differences in long-term learning gain scores between the two groups. The results showed that the long-term learning gain scores for the experimental group ($median = 3.5$) were statistically significantly higher than the control group ($median = 1$), as shown in Figure 5.4, $U = 63.5$, $Z = 3.33$, $p < 0.001$. The finding had a large effect size ($r = 0.54$). Therefore, H1.3 is confirmed, and it can be concluded that matching learning material to the dyslexia type yields significantly better long-term learning gain of understanding seen words than not matching.

5.2.4.3 Learner Satisfaction

The results of the fourth hypothesis (H1.4) on learner satisfaction are presented in this section. Satisfaction was calculated for each component, as shown in Table 5.5. The results indicated that the experimental group had higher mean learner satisfaction scores in terms of the learning content, the system personalisation and the system interface than the control group.

According to the analysis of the learners' satisfaction, the experimental group ($mean = 4.9$, $SD = 0.18$) had greater mean general satisfaction score than the control group ($mean = 4.68$, $SD = 0.38$), implying that matching learning material to dyslexia type positively affected learner satisfaction.

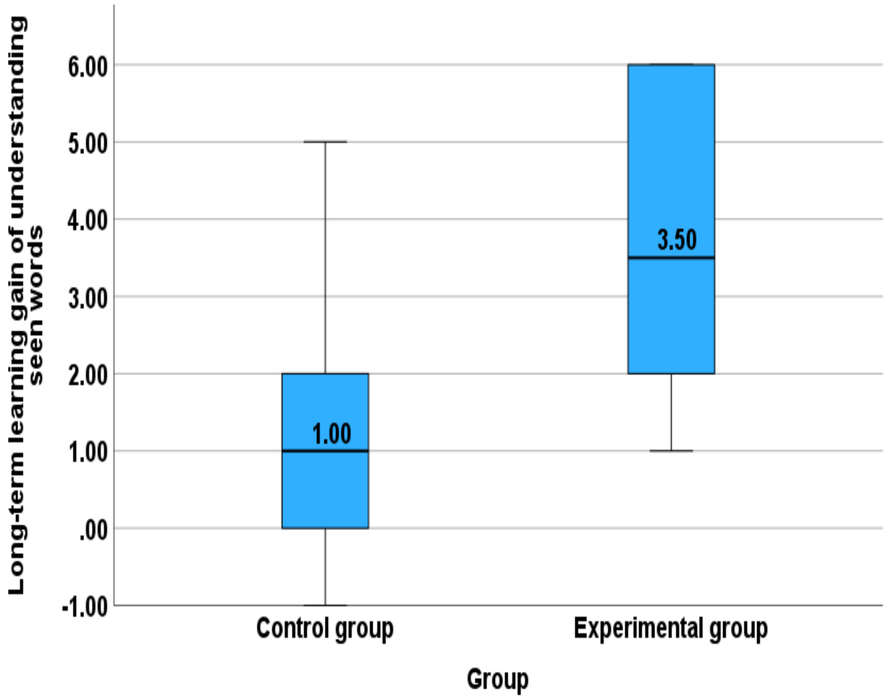

Figure 5.4: Experiment 1: Box plot for the results of long-term learning gain of understanding seen words.

Table 5.5: Experiment 1: Satisfaction scores of learners with dyslexia.

ELS components	Satisfaction of control group		Satisfaction of experimental group	
	Mean	*SD*	*Mean*	*SD*
Learning content	4.53	0.91	4.88	0.22
System personalisation	4.68	0.44	4.9	0.21
System interface	4.77	0.33	4.91	0.18
General satisfaction	4.68	0.38	4.9	0.18

The significance of the learner satisfaction score was tested. As the learner satisfaction score distributions in both groups were not normally distributed (Shapiro–Wilk's test $p < 0.05$), an independent sample Mann–Whitney U test was run to determine if there were differences in satisfaction scores between the experimental and control groups. The results showed that the general learner satisfaction score for the experimental group ($median = 5$) was statistically significantly higher than the control group ($median = 4.75$), as shown in Figure 5.5, $U = 122.5$, $Z = 2.27$, $p = 0.023$. The finding had a medium effect size ($r = 0.36$). As a result, H1.4 is confirmed, and it can be concluded that matching learning material to dyslexia type results in significantly better learner satisfaction than not matching.

5.2.4.4 Perceived Level of Usability

The results of the fifth hypothesis (H1.5) about perceived level of usability are presented in this section. The usability scores for the matched version of DTRSLT ($mean = 96$, $SD = 6.46$) and the non-matched version ($mean = 85.63$, $SD = 9.93$) were acceptable, as their average scores were

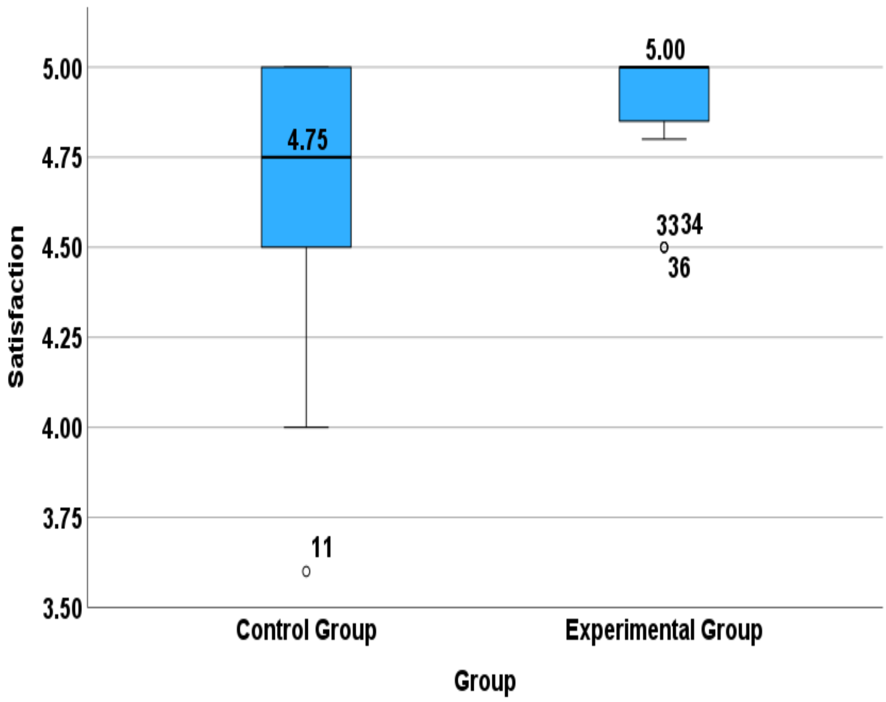

Figure 5.5: Experiment 1: Box plot for the results of learners' satisfaction.

greater than 70, implying that both versions were perceived as usable and valuable in learning (Bangor et al., 2008).

The two conditions were compared to obtain a deeper understanding of whether adaptivity significantly impacts the perceived usability level. As the data in the experimental group were not normally distributed (Shapiro–Wilk's test $p < 0.05$), an independent sample Mann–Whitney U test was run to compare the two conditions. The results indicated that the general usability score of the matched version ($median = 100$) was statistically significantly higher than the non-matched version ($median = 86.25$), as shown in Figure 5.6, $U = 71$, $Z = 3.56$, $p < 0.001$. The finding had a large effect size ($r = 0.56$). As a result, H1.5 is confirmed, and it can be concluded that matching learning material to dyslexia type results in significantly higher levels of perceived usability than not matching.

5.2.5 Discussion

This study aims to investigate whether adapting learning material based on a learner's dyslexia type improves their learning experience. The study assessed learning gain of reading seen material (both immediately at the end of the course and after a delay of two weeks), learning gain of understanding seen words, learner satisfaction and learner perception of the usability of the learning material.

This study contributes to current research on adaptivity by presenting evidence for the importance of using dyslexia type as a learner characteristic for adaptation (Alghabban and Hendley, 2020a,b).

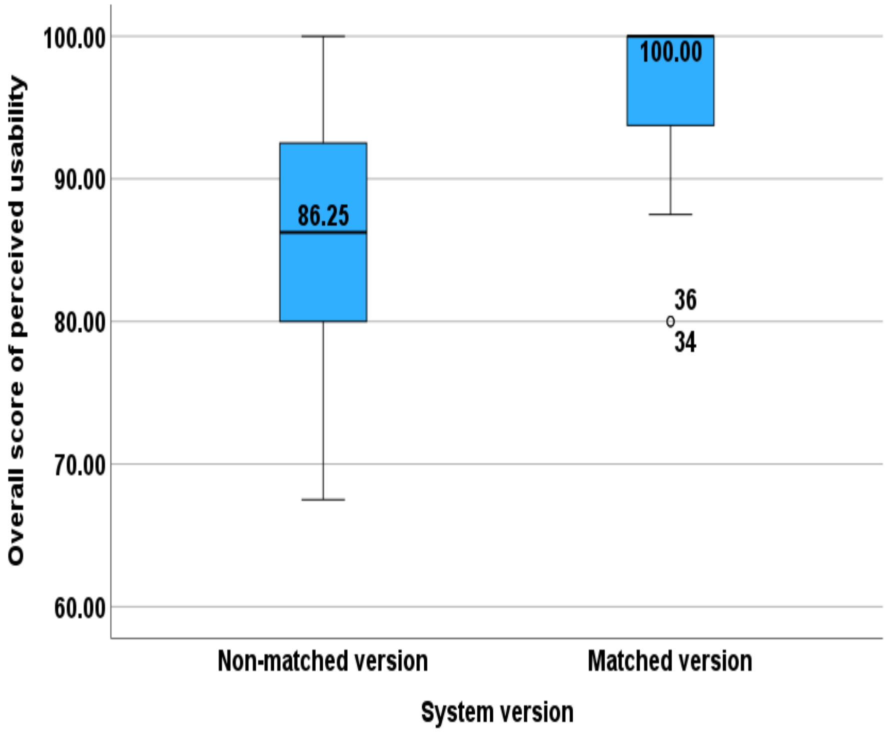

Figure 5.6: Experiment 1: Box plot for the results of perceived usability level.

The results are consistent with previous work, which has argued that learners with dyslexia differ in their dyslexia types, their reading problems and, therefore, their needs (Friedmann and Haddad-Hanna, 2014; Friedmann and Coltheart, 2016; Al-Dawsari and Hendley, 2021). Accordingly, considering these differences in the learning environment is important to enhance the learning experience of learners. Importantly, a distinctive aspect of this study was the investigation of the effectiveness of adaptation based on dyslexia type by conducting a carefully designed and controlled experiment with a reasonable number of participants (Alghabban and Hendley, 2020a). The effect of adaptation based on dyslexia type was one of the significant gaps that were not addressed and evaluated in the previous research targeting Arab people with dyslexia (Benmarrakchi et al., 2017a,b,c; Ouherrou et al., 2018; El Kah and Lakhouaja, 2018; Aldabaybah and Jusoh, 2018) and dyslexia in other languages, such as English (Broadhead et al., 2018; Sasupilli et al., 2019; Alsobhi and Alyoubi, 2019; Burac and Cruz, 2020; Srivastava and Haider, 2020; El Fazazi et al., 2021), Malay (Noor et al., 2017; Abdul Hamid et al., 2017; Pang and Jen, 2018) and Spanish (Rello et al., 2017; Arteaga et al., 2018). Even when more formal evaluation takes place, as in (Al-Dawsari and Hendley, 2021), they conducted a study with a small sample, which leads to an inability to derive a conclusion. These issues were addressed in this study.

Concerning the benefit to learning, the results showed that there is a short-term learning gain of word reading and that this benefit persists in the long term. Both are significantly higher in the condition where the system adapts to dyslexia type. These results are in line with previous research showing that considering characteristics of learners can enhance learning outcome (Liaw et al., 2007; Klašnja-Milićević et al., 2011; Ghaban and Hendley, 2018; Alshammari and Qtaish, 2019).

The current study also assessed learning gain of word understanding, which had not been reported and discussed in previous research (Lo et al., 2011; Bonacina et al., 2015; Benmarrakchi et al., 2017a,b,c; Ouherrou et al., 2018; El Kah and Lakhouaja, 2018; Aldabaybah and Jusoh, 2018; Al-Dawsari and Hendley, 2021). The results indicated that considering dyslexia type as an adaptive parameter is not only reflected in improved learning gain of word reading, but also in the learning gain of word understanding.

The study's results regarding learners' satisfaction follow Kangas et al. (2017)'s argument that there is a strong relationship between learners' motivation and satisfaction, where satisfaction is influenced by the learning content. This is in line with earlier literature (Lam and Wong, 1974; Kerwin, 1981; Alshammari et al., 2015b). The system displays the same interface layout in the two conditions; the only difference is that the content of training activities is matched to dyslexia type in the experimental group. The experimental condition rated the system interface component in ELS more highly than the control condition. This higher rating suggests that learners appear to be able to identify when a lesson is more appropriate to their needs, which may affect their perception of the course's quality. Also, the perception of suitability influences their attitude towards other aspects of the system, such as learning content and personalisation components. This reflects that learners are more satisfied when learning material is matched to their dyslexia type. This is in line with earlier research (Akbulut and Cardak, 2012; Alshammari et al., 2015b); when content was customised to the attributes of learners, those learners were more satisfied. In addition, the results indicated the importance of incorporating dyslexia type as an adaptive parameter to enhance learners' motivation and engagement and, thus, enhance their learning (Alghabban and Hendley, 2020b) as their motivation towards the content in adaptive e-learning is challenging (Abdul Hamid et al., 2018) and affects their learning achievement (Noor et al., 2017).

The assessment of satisfaction in this study can be used to learn how well the learning content meets the learners' needs. Even though learners may not be able to assess this match explicitly, they are at least subconsciously aware of it, and their awareness is reflected in their assessment of the system's aspects that are the same in the two conditions (Alghabban and Hendley, 2020b). This adds to the originality of this study as there is a lack of previous research that measured and discussed the learners' satisfaction.

Finally, although the two versions of the system were identical except for the content used in the training activities, learners' perceptions of the usability of the two versions differed significantly.

This means that adaptation in e-learning systems improves the perceived usability level. The high level of perceived usability in the matched version can be interpreted in line with earlier literature (Ardito et al., 2006; Zaharias and Poylymenakou, 2009; Alshammari et al., 2016), which reports that adaptation enhances learners' motivation, satisfaction and engagement to use the e-learning system. Adaptation has a direct effect by providing more appropriate learning material, and, because learners subconsciously perceive this support for their needs, adaptation influences their perception of the system they are using. This, in turn, may enhance their curiosity, satisfaction and motivation (Alghabban and Hendley, 2020a). In contrast, learners using the non-matched version may find it not supportive or responsive to their needs, making them less likely to engage, be motivated and use the non-matched version as a learning tool.

From this, learners' perceptions of the usability of an e-learning system can be an excellent metric to indirectly assess their attitudes towards their learning (Alghabban and Hendley, 2022b). It represents their assessment of the system's suitability to their needs, which is likely to influence their motivation and, in turn, increase the likelihood that an e-learning system will help them achieve their learning goals (Alshammari et al., 2016). As a result, it can augment other metrics, such as learning gain and satisfaction, to give additional insight into whether adaptation is beneficial (Alghabban and Hendley, 2021, 2022b). This adds to the originality of this study, as there is a lack of previous research that measured and discussed the perceived usability level.

To sum up, this study investigated the impact of adapting learning material based on the dyslexia type of learners. All hypotheses were confirmed by the results obtained. The results indicated that adapting learning material based on dyslexia type of learners with dyslexia leads to a significant improvement in both short-term and long-term learning gain of reading seen material, long-term learning gain of word understanding, learner satisfaction and perceived level of usability.

5.3 Experiment 2: Matching Learning Material to Reading Skill Level

5.3.1 Introduction

This section presents the results of the evaluation of matching learning material to reading skill level (**reading letters with short vowels (S1)**, **reading words with Sakin letter(s) (S2)** and **reading words with short vowels and Sakin letter(s) (S3)**). As mentioned in Chapter 4, these three reading skill levels were targeted in this research. A controlled experiment was conducted to investigate whether matching learning material to the reading skill level of learners with dyslexia enhances their learning experience. In particular, it investigated: 1) whether learners learn more, 2) whether this learning can be generalised to new material, 3) whether this matching affects their satisfaction with the learning experience, and finally, 4) whether learners are aware of the matching of material to their needs and if that awareness indirectly affects their perception of the usability of the system.

This experiment investigated the following research question:

Research Question 2: Does matching e-learning material based on reading skill level improve learning gain compared to non-matched material, and does it achieve a high level of learner satisfaction and perceived level of usability?

5.3.2 Hypotheses

Four hypotheses were tested in this experiment:

H2.1: Matching learning material to the reading skill level of learners with dyslexia achieves significantly better *short-term learning gain of reading seen words* compared to non-matched material.

H2.2: Matching learning material to the reading skill level of learners with dyslexia achieves significantly better *short-term learning gain of reading unseen words* compared to non-matched material.

H2.3: Matching learning material to the reading skill level of learners with dyslexia achieves significantly better *learner satisfaction* compared to non-matched material.

H2.4: Matching learning material to the reading skill level of learners with dyslexia achieves significantly better *perceived level of usability* compared to non-matched material.

Two groups were used, a control group and an experimental group. The experimental group interacted with the matched version of DTRSLT that matches the learning material to the reading skill level (either S1, S2 or S3), while the control group interacted with the non-matched version of the system that provides generic learning material (material that addresses a combination of all three skills). The system layout and interface were identical for both groups. The only difference is the provided learning material. Chapter 4 describes the design of the system interface and the provided activities.

In this experiment, this research measured short-term learning gain of reading seen and unseen words, learner satisfaction and perceived usability level.

5.3.3 Procedure

Participants were encouraged to participate in this experiment by providing different reading activities. The experiment was run physically in schools. Six training sessions, each with 20 activities, were conducted, for a total of 120 activities. Table 5.6 shows the experimental procedure timetable. The learning material was selected from the primary school curriculum to target the three reading skills (presented in Chapter 4).

Table 5.6: Experiment 2: Procedure timetable.

Week#	Session	Activity
1	Pre-starting	Overview of the experiment, conducting reading skill level diagnostic tests and pre-tests of word reading.
2	Training sessions	First and second training sessions.
3		Third and fourth training sessions.
4		Fifth and sixth training sessions.
4	Immediate post-tests, ELS and SUS	Conducting immediate post-tests of word reading, ELS and SUS questionnaires.

5.3.4 Results

Initially, 44 participants with a mean age of 8.5 ($SD = 1.05$) were included in this experiment. They were chosen from four primary schools in the KSA (Jeddah). The participants were assigned either to the control group ($n = 22$, mean $age = 8.5$ years, $SD = 1.01$) or the experimental group ($n = 22$, mean $age = 8.5$ years, $SD = 1.1$), balanced by age, grade, reading skill levels and pre-test results of reading seen and unseen words. There was no statistically significant difference between the means of each group in either age ($p = 1 > 0.05$), the pre-test result of reading seen words ($p = 0.875 > 0.05$) or the pre-test result of reading unseen words ($p = 0.888 > 0.05$).

The number of participants who finished the experiment was reduced to 41 because three learners (two in the experimental group and one in the control group) did not complete the last two training sessions due to school closures in response to Covid-19. The experimental group finished with 20 participants (mean $age = 8.4$ years, $SD = 1.09$) and the control group with 21 participants (mean $age = 8.48$ years, $SD = 1.03$). There was no statistically significant difference between the means of each group after removing data related to the participants who did not complete the experiment, in either age ($p = 0.808 > 0.05$), pre-test result of reading seen words ($p = 0.623 > 0.05$) or pre-test result of reading unseen words ($p = 0.589 > 0.05$). Figure 5.7 presents the characteristics of participants who finished the experiment.

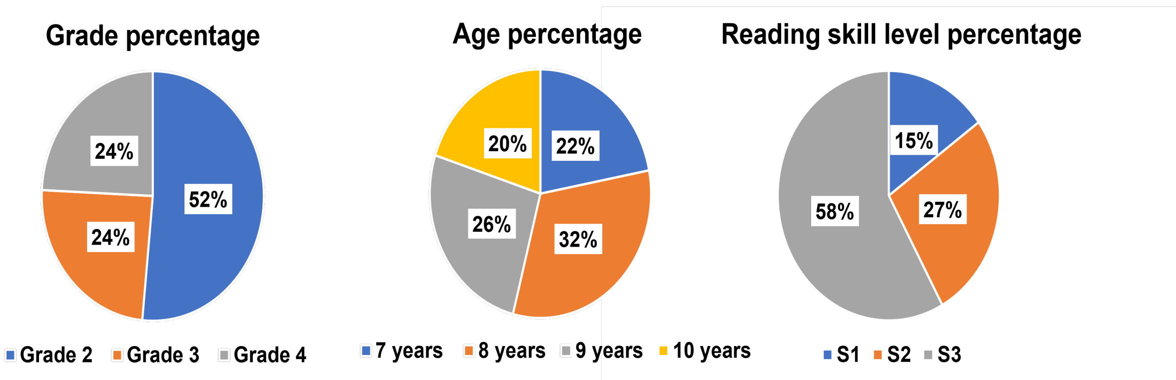

Figure 5.7: Experiment 2: Participant characteristics.

The results of each hypothesis are described in the following sections.

5.3.4.1 Learning Gain of Reading Seen Words

Hypothesis (H2.1) about short-term learning gain of reading seen words was tested. Table 5.7 shows the experimental group had greater immediate post-test scores and short-term learning gains of reading than the control group. These findings reveal that matching learning material to reading skill level had a positive effect on short-term learning gain of reading seen words.

Table 5.7: Experiment 2: Control and experimental group results of pre-test, immediate post-test and short-term learning gain of reading seen words.

Group	**N**	**Pre-test**		**Immediate post-test**		**Short-term learning gain of reading seen words**	
		Mean	***SD***	***Mean***	***SD***	***Mean***	***SD***
Control	21	4.19	1.99	5.76	1.87	1.57	1.8
Experimental	20	3.9	1.74	8.5	0.83	4.6	1.67

The significance of the short-term learning gain of reading seen words was tested. As the short-term learning gain score distributions in the control group were not normally distributed (Shapiro–Wilk's test $p < 0.05$), an independent sample Mann–Whitney U test was run to determine if there were differences in short-term learning gain scores between the experimental and control groups. The results showed that the short-term learning gain scores for the experimental group ($median = 4.5$) were statistically significantly higher than the control group ($median = 1$), as shown in Figure 5.8, $U = 46.5$, $Z = 4.31$, $p < 0.001$. The finding had a large effect size ($r = 0.67$). As a result, H2.1 is confirmed, and it can be concluded that matching learning material to reading skill level yields significantly better short-term learning gain of reading seen words than not matching.

5.3.4.2 Learning Gain of Reading Unseen Words

Hypothesis (H2.2) about short-term learning gain of reading unseen words was tested. Table 5.8 shows the experimental group had greater immediate post-test scores and short-term learning gains of reading than the control group. These findings reveal that matching learning material to reading skill level had a positive effect on short-term learning gain of reading unseen words.

Table 5.8: Experiment 2: Control and experimental group results of pre-test, immediate post-test and short-term learning gain of reading unseen words.

Group	**N**	**Pre-test**		**Immediate post-test**		**Short-term learning gain of reading unseen words**	
		Mean	***SD***	***Mean***	***SD***	***Mean***	***SD***
Control	21	0.67	0.86	1.05	1.07	0.38	0.74
Experimental	20	0.85	1.04	3.5	1.24	2.65	1.5

The significance of the short-term learning gain of reading unseen words was tested. As the short-term learning gain score distributions of both groups were not normally distributed (Shapiro–Wilk's test $p < 0.05$), an independent sample Mann–Whitney U test was run to determine if there were

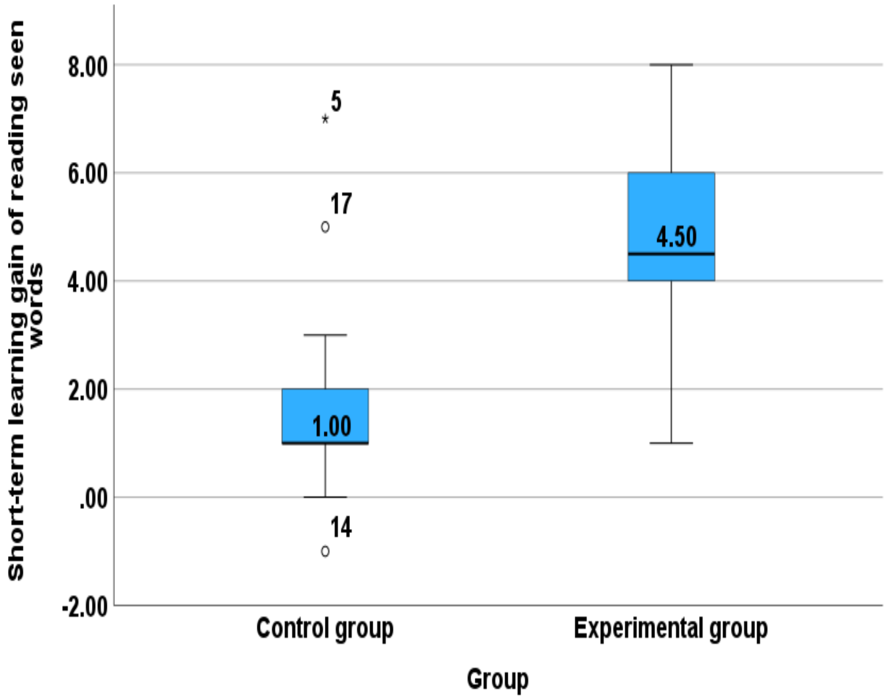

Figure 5.8: Experiment 2: Box plot for the results of short-term learning gain of reading seen words.

differences in short-term learning gain scores between the experimental and control groups. The results showed that the short-term learning gain scores for the experimental group ($median = 2$) were statistically significantly higher than those of the control group ($median = 0$), as shown in Figure 5.9, $U = 35$, $Z = 4.71$, $p < 0.001$. The finding had a large effect size ($r = 0.74$). As a result, H2.2 is confirmed, and it can be concluded that matching learning material to reading skill level yields significantly better short-term learning gain of reading unseen words than not matching.

5.3.4.3 Learner Satisfaction

The results of the third hypothesis (H2.3) on learner satisfaction are presented in this section. Satisfaction was calculated for each component, as shown in Table 5.9. The results indicated that the experimental group had higher mean learner satisfaction scores in terms of the learning content, the system personalisation and the system interface than the control group.

Table 5.9: Experiment 2: Satisfaction scores of learners with dyslexia.

ELS components	Satisfaction of control group		Satisfaction of experimental group	
	Mean	*SD*	*Mean*	*SD*
Learning content	4.21	0.48	4.63	0.34
System personalisation	3.93	1.004	5	0.0
System interface	4.36	0.61	4.76	0.21
General satisfaction	4.23	0.44	4.77	0.13

According to the analysis of the learners' satisfaction, the experimental group ($mean = 4.77$,

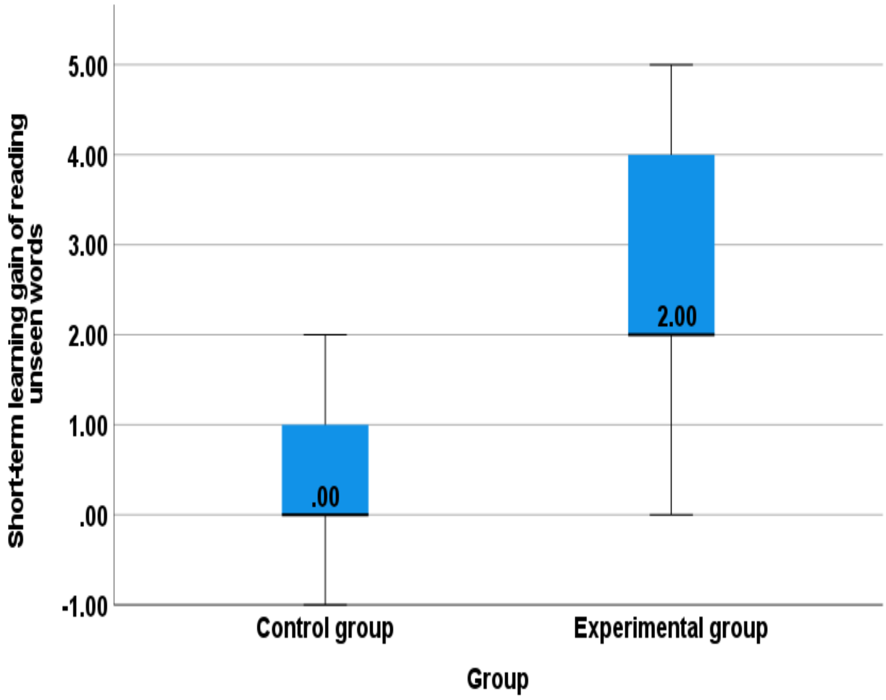

Figure 5.9: Experiment 2: Box plot for the results of short-term learning gain of reading unseen words.

$SD = 0.13$) had greater mean general satisfaction scores than the control group ($mean = 4.23$, $SD = 0.44$), implying that matching learning material to reading skill level positively affected learner satisfaction.

The significance of the learner satisfaction score was tested. As the learner satisfaction scores for each group were normally distributed, as assessed by Shapiro–Wilk's test ($p > 0.05$), an independent sample t-test with an alpha level of 0.05 was run to determine if there were differences in learner satisfaction scores between the experimental and control groups. Based on the means of general satisfaction score, the experimental group had a larger general satisfaction score than the control group, with a statistically significant difference of 0.54, $t(23.37) = 5.38$, $p < 0.001$ (see Figure 5.10). The finding had a very large effect size (Cohen's $d = 1.65$). As a result, H2.3 is confirmed, and it can be concluded that matching learning material to reading skill level results in significantly better learner satisfaction than not matching.

5.3.4.4 Perceived Level of Usability

The results of the fourth hypothesis (H2.4) about perceived level of usability are presented in this section. The usability scores for the matched version of DTRSLT ($mean = 96.25$, $SD = 3.39$) and the non-matched version ($mean = 84.76$, $SD = 12.09$) were acceptable, as their average scores were greater than 70, implying that both versions were perceived as usable and valuable in learning (Bangor et al., 2008).

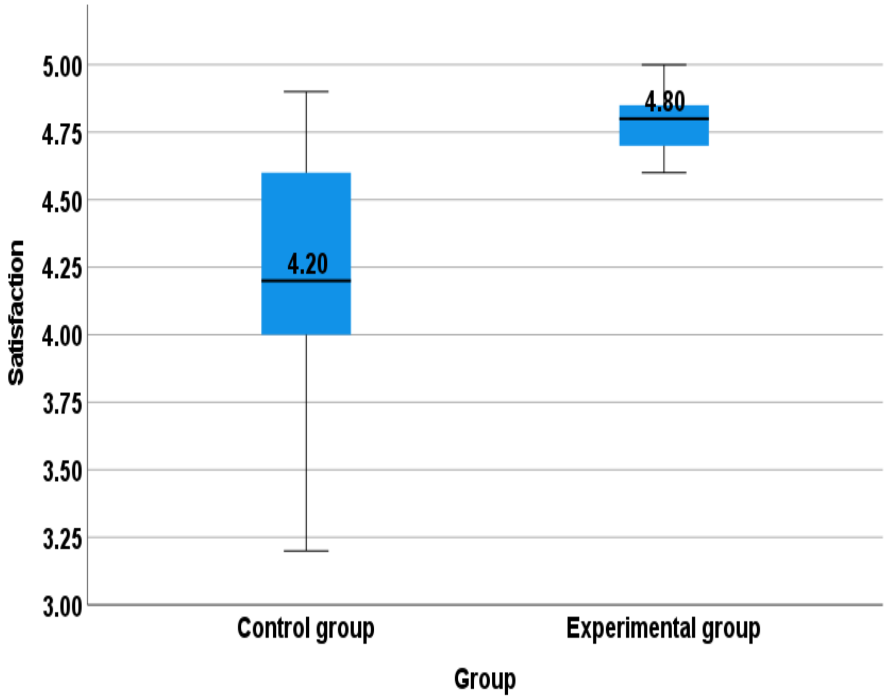

Figure 5.10: Experiment 2: Box plot for the results of learners' satisfaction.

The two conditions were compared to obtain a deeper understanding of whether adaptivity significantly impacts the perceived usability level. As the data in both groups were not normally distributed (Shapiro–Wilk's test $p < 0.05$), an independent sample Mann–Whitney U test was run to compare the two conditions. The results indicated that the general usability score of the matched version ($median = 97.5$) was statistically significantly higher than that of the non-matched version ($median = 85$), as shown in Figure 5.11, $U = 62$, $Z = 3.9$, $p < 0.001$. The finding had a large effect size ($r = 0.61$). As a result, H2.4 is confirmed, and it can be concluded that matching learning material to reading skill level results in significantly higher levels of perceived usability than not matching.

5.3.5 Discussion

This study aims to investigate whether adapting learning material based on a learner's reading skill level improves their learning experience. The study assessed learning gain of reading seen and unseen materials (immediately after completion of the course), learner satisfaction and learner perception of the usability of the learning material.

This study was affected by Covid-19, which decreased the number of participants. This research could not assess long-term learning gain of word reading due to school closures that made access to participants impossible.

This study contributes to current research on adaptive e-learning by highlighting the importance of including reading skill level of learners with dyslexia as a learner characteristic for adaptation (Al-

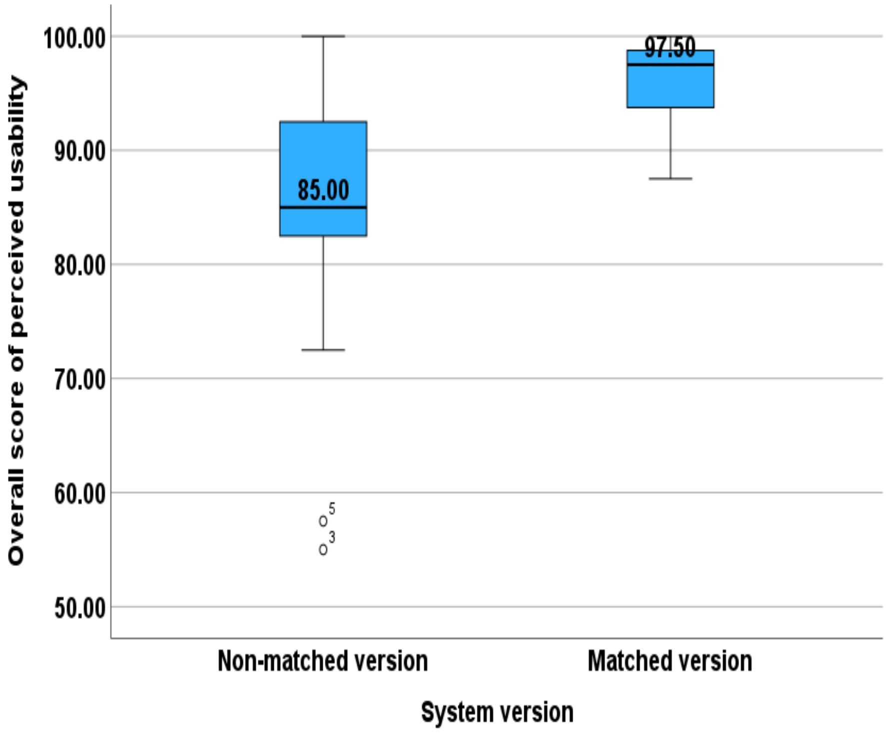

Figure 5.11: Experiment 2: Box plot for the results of perceived usability level.

ghabban and Hendley, 2021; Alghabban et al., 2021; Alghabban and Hendley, 2022b). It is in line with previous research, which has argued that the knowledge level of learners should be considered in education (Felder and Silverman, 1988; Essalmi et al., 2010; Klašnja-Milićević et al., 2011), and that adapting learning material to the knowledge level of learners enhances their learning (Melis et al., 2001; Mitrovic, 2003; Chorfi and Jemni, 2004; Weber and Brusilovsky, 2016). As in classroom practice, once the teachers determine a learner's reading level, they select the appropriate learning material for each learner, allowing for more successful learning (Dolgin, 1975).

This study differs from existing works targeting knowledge level of learners with dyslexia, which lack formal evaluation (Benmarrakchi et al., 2017c; Alsobhi and Alyoubi, 2019; El Fazazi et al., 2021). As with Study 1, this study investigated the effectiveness of adaptation based on reading skill level of learners with dyslexia by conducting a carefully designed and controlled experiment with a reasonable number of participants (Alghabban and Hendley, 2021; Alghabban et al., 2021; Alghabban and Hendley, 2022b).

Based on the researcher's knowledge, previous research has not assessed whether learners with dyslexia can apply learned content to new content (Alghabban and Hendley, 2022b). The current study is distinctive in assessing learning gain of reading new material as a metric for evaluating the effectiveness of adaptive e-learning systems. Results indicated that learners achieved better learning gain in reading new words when the material was matched to their reading skill level (Alghabban et al., 2021). This reflects that the benefit of adaptation based on this characteristic can be generalised to new material. The results of this study are in line with previous research that has argued that adapting materials to learners' skill levels will improve their learning and, therefore, there is a greater likelihood of generalisation (Daly III et al., 1996).

This study's results are in line with Study 1 regarding learners' satisfaction. The interface layout was the same between the two conditions, and they only differ in the learning content of training activities that are matched to reading skill level in the experimental group. Learners in the experimental condition rated the components of ELS more highly than did learners in the control condition. This reflects that adaptation based on reading skill level of learners with dyslexia can enhance the motivation and engagement of learners (Alghabban et al., 2021).

Finally, as with Study 1, this study also showed that learners perceived the usability of the two versions differently. As the two versions were identical in layout and interface except for the words used in the training activities, the difference between the two conditions in perceived usability cannot be attributed to the user interface. Rather, it can be attributed to adapting material to the learner's reading skill level.

To sum up, this study investigated the impact of adapting learning material based on the reading skill level of learners. The results confirmed all hypotheses. Adapting learning material based on reading skill level of learners with dyslexia leads to a significant improvement in short-term learning gain of reading seen and unseen materials, learner satisfaction and perceived level of usability.

5.4 Experiment 3: Matching Learning Material to Dyslexia Type and Reading Skill Level

5.4.1 Introduction

This section presents the results of the evaluation of matching learning material to both dyslexia type (**LPD** or **VLD**) and reading skill level (**S1**, **S2** or **S3**). A controlled experiment was conducted to investigate whether matching learning material to both dyslexia type and reading skill level of learners with dyslexia enhances their learning experience. In particular, it investigated: 1) whether learners learn more, 2) whether this learning persists in the long term, 3) whether their learning benefit can be generalised to new material, 4) whether this generalisation persists in the long term, 5) whether this matching affects their understanding of words, 6) whether this understanding persists in the long term, 7) whether this matching affects their satisfaction with the learning experience, and finally, 8) whether learners are aware of the matching of material to their needs and if that awareness indirectly affects their perception of the usability of the system.

This experiment investigated the following research question:

Research Question 3: Does matching e-learning material based on a combination of

dyslexia type and reading skill level improve learning gain compared to non-matched material, and does it achieve a high level of learner satisfaction and perceived level of usability?

5.4.2 Hypotheses

Eight hypotheses were tested in this experiment:

H3.1: Matching learning material to the dyslexia type and reading skill level of learners with dyslexia achieves significantly better *short-term learning gain of reading seen words* compared to non-matched material.

H3.2: Matching learning material to the dyslexia type and reading skill level of learners with dyslexia achieves significantly better *long-term learning gain of reading seen words* compared to non-matched material.

H3.3: Matching learning material to the dyslexia type and reading skill level of learners with dyslexia achieves significantly better *short-term learning gain of reading unseen words* compared to non-matched material.

H3.4: Matching learning material to the dyslexia type and reading skill level of learners with dyslexia achieves significantly better *long-term learning gain of reading unseen words* compared to non-matched material.

H3.5: Matching learning material to the dyslexia type and reading skill level of learners with dyslexia achieves significantly better *short-term learning gain of understanding seen words* compared to non-matched material.

H3.6: Matching learning material to the dyslexia type and reading skill level of learners with dyslexia achieves significantly better *long-term learning gain of understanding seen words* compared to non-matched material.

H3.7: Matching learning material to the dyslexia type and reading skill level of learners with dyslexia achieves significantly better *learner satisfaction* compared to non-matched material.

H3.8: Matching learning material to the dyslexia type and reading skill level of learners with dyslexia achieves significantly better *perceived level of usability* compared to non-matched material.

Two groups were used, a control group and an experimental group. The experimental group interacted with the matched version of DTRSLT that matches the learning material to dyslexia type (LPD or VLD) and reading skill level (S1, S2 or S3), while the control group interacted with the non-matched version of the system that provides generic learning material (a combination of learning materials for all dyslexia types and reading skills). The system layout and interface were identical for both groups. The only difference is the provided learning material. Chapter 4 describes the design of the system interface and the provided activities.

In this experiment, this research measured short- and long-term learning gain of reading seen and unseen words, short- and long-term learning gain of understanding seen words, learner satisfaction and perceived usability level.

5.4.3 Procedure

Participants were encouraged to participate in this experiment by providing different reading activities. The experiment was run remotely via Microsoft Teams due to school closures in response to Covid-19. There were six training sessions, each with 20 activities (a total of 120 activities). Table 5.10 shows the experimental procedure timetable. The learning material was the same as in Experiments 1 and 2 (presented in Chapter 4).

Table 5.10: Experiment 3: Procedure timetable.

Week#	Session	Activity
1	Pre-starting	Overview of the experiment, conducting dyslexia type and reading skill level diagnostic tests.
	Pre-tests	Conducting pre-tests of word reading and word understanding.
2	Training sessions	First and second training sessions.
3		Third and fourth training sessions.
4		Fifth and sixth training sessions.
4	Immediate post-tests, ELS and SUS	Conducting immediate post-tests of word reading and word understanding, ELS and SUS questionnaires.
6	Follow-up tests	Conducting follow-up tests of word reading and word understanding.

5.4.4 Results

Forty-seven participants with a mean age of 10.09 ($SD = 1.3$) were included in this experiment. They were chosen from 21 primary schools in the KSA (Jeddah, Tabuk and Alwajh). Figure 5.12 presents the characteristics of participants.

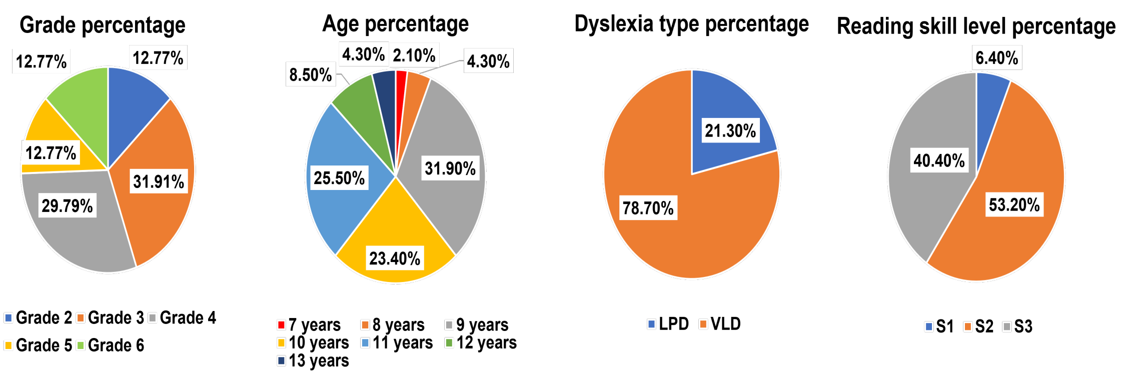

Figure 5.12: Experiment 3: Participant characteristics.

The participants were assigned to the control group ($n = 24$, mean $age = 10.04$ years, $SD = 1.27$) or the experimental group ($n = 23$, mean $age = 10.13$ years, $SD = 1.36$), balanced by age, grade, dyslexia type, reading skill level and pre-test results of reading seen and unseen words, and word understanding. There was no statistically significant difference between the means of each group in either age ($p = 0.878 > 0.05$), the pre-test result of reading seen words ($p = 0.754 > 0.05$), the pre-test result of reading unseen words ($p = 0.698 > 0.05$) or the pre-test result of word understanding ($p = 0.439 > 0.05$).

All participants completed the experiment.

The results of each hypothesis are described in the following sections.

5.4.4.1 Learning Gain of Reading Seen Words

Short-term Hypothesis (H3.1) about short-term learning gain of reading seen words was tested. Table 5.11 shows the experimental group had greater immediate post-test scores and short-term learning gains of reading than the control group. These findings reveal that matching learning material to both dyslexia type and reading skill level had a positive effect on short-term learning gain of reading seen words.

Table 5.11: Experiment 3: Control and experimental group results of pre-test, immediate post-test, follow-up test, short- and long-term learning gain of reading seen words.

Group	N	Pre-test		Immediate post-test		Follow-up test		Short-term learning gain of reading seen words		Long-term learning gain of reading seen words	
		Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Control	24	4.54	2.11	5.83	1.74	5.88	1.75	1.29	1.16	1.34	2.01
Experimental	23	4.78	2.15	8.39	1.62	8.74	1.25	3.61	1.23	3.96	1.64

The significance of the short-term learning gain of reading seen words was tested. As the short-term learning gain score distributions in the control group were not normally distributed (Shapiro–Wilk's test $p < 0.05$), an independent sample Mann–Whitney U test was run to determine if there were differences in short-term learning gain scores between the experimental and control groups. The results showed that the short-term learning gain scores for the experimental group ($median = 4$) were statistically significantly higher than the control group ($median = 1$), as shown in Figure 5.13, $U = 52$, $Z = 4.85$, $p < 0.001$. The finding had a large effect size ($r = 0.71$). As a result, H3.1 is confirmed, and it can be concluded that matching learning material to dyslexia type and reading skill level yields significantly better short-term learning gain of reading seen words than not matching.

Long-term Hypothesis (H3.2) about long-term learning gain of reading seen words after two weeks have elapsed was tested. Table 5.11 shows the experimental group had greater follow-up test scores and long-term learning gains of reading than the control group. These findings reveal that matching learning material to both dyslexia type and reading skill level had a positive effect on long-term learning gain of reading seen words.

The significance of the long-term learning gain of reading seen words was tested. As long-term

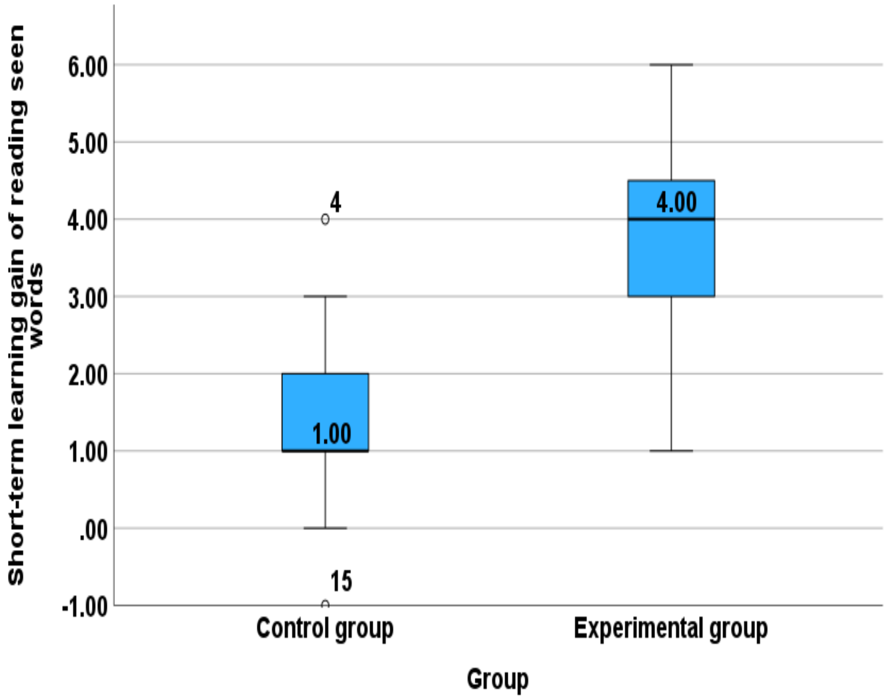

Figure 5.13: Experiment 3: Box plot for the results of short-term learning gain of reading seen words.

learning gain scores for both groups were normally distributed, as determined by Shapiro–Wilk's test ($p > 0.05$), an independent sample t-test with an alpha level of 0.05 was run to determine if there were differences in long-term learning gain scores between the experimental and control groups. Learning gain scores for both groups were homogeneous in variance, as determined by Levene's test for the equality of variances ($F = 0.574$, $p = 0.452$). Based on the means of long-term learning gain, the experimental group had larger long-term learning gains than the control group, with a statistically significant difference of 2.63, $t(45) = 4.89$, $p < 0.001$ (see Figure 5.14). The finding had a very large effect size (Cohen's $d = 1.43$). As a result, H3.2 is confirmed, and it can be concluded that matching learning material to dyslexia type and reading skill level yields significantly better long-term learning gain of reading seen words than not matching.

5.4.4.2 Learning Gain of Reading Unseen Words

Short-term Hypothesis (H3.3) about short-term learning gain of reading unseen words was tested. Table 5.12 shows the experimental group had greater immediate post-test scores and short-term learning gains of reading than the control group. These findings reveal that matching learning material to both dyslexia type and reading skill level had a positive effect on short-term learning gain of reading unseen words.

The significance of the short-term learning gain of reading unseen words was tested. As the short-term learning gain score distributions in the control group were not normally distributed (Shapiro–

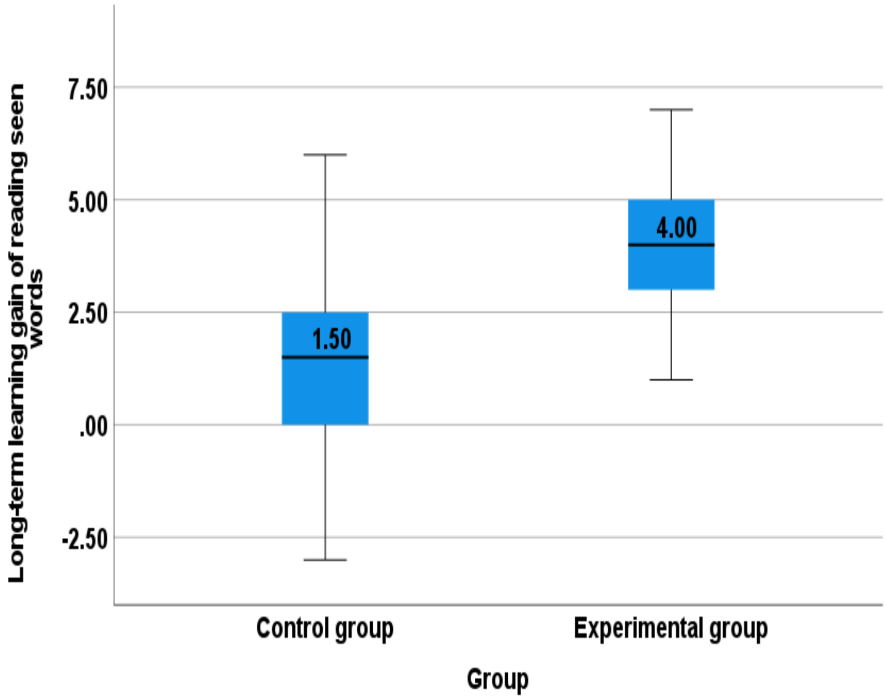

Figure 5.14: Experiment 3: Box plot for the results of long-term learning gain of reading seen words.

Table 5.12: Experiment 3: Control and experimental group results of pre-test, immediate post-test, follow-up test, short- and long-term learning gain of reading unseen words.

Group	N	Pre-test		Immediate post-test		Follow-up test		Short-term learning gain of reading unseen words		Long-term learning gain of reading unseen words	
		Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Control	24	2.96	2.05	3.5	2.02	3.58	2.15	0.54	1.02	0.62	1.09
Experimental	23	3.17	2.17	6.13	1.77	6.78	1.35	2.96	1.39	3.61	1.64

Wilk's test $p < 0.05$), an independent sample Mann–Whitney U test was run to determine if there were differences in short-term learning gain scores between the experimental and control groups. The results showed that the short-term learning gain scores for the experimental group ($median = 3$) were statistically significantly higher than those for the control group ($median = 0.5$), as shown in Figure 5.15, $U = 43$, $Z = 5.06$, $p < 0.001$. The finding had a large effect size ($r = 0.74$). As a result, H3.3 is confirmed, and it can be concluded that matching learning material to dyslexia type and reading skill level yields significantly better short-term learning gain of reading unseen words than not matching.

Long-term Hypothesis (H3.4) about long-term learning gain of reading unseen words after two weeks have elapsed was tested. Table 5.12 shows the experimental group had greater follow-up test scores and long-term learning gains of reading than the control group. These findings reveal that matching learning material to both dyslexia type and reading skill level had a positive effect on

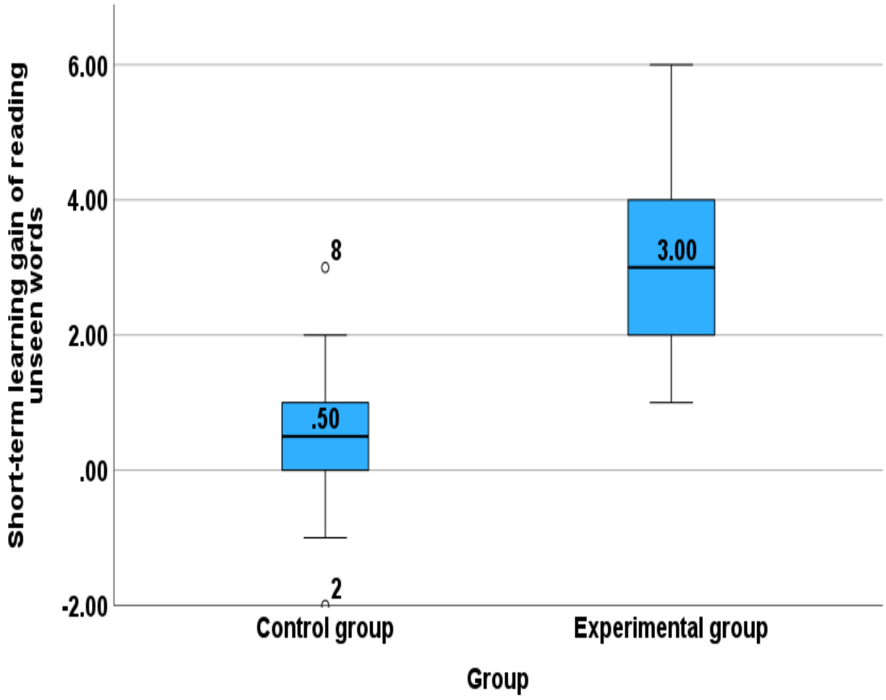

Figure 5.15: Experiment 3: Box plot for the results of short-term learning gain of reading unseen words.

long-term learning gain of reading unseen words.

The significance of the long-term learning gain of reading unseen words was tested. As the long-term learning gain score distributions in the control group were not normally distributed (Shapiro–Wilk's test $p < 0.05$), an independent sample Mann–Whitney U test was run to determine if there were differences in long-term learning gain scores between the experimental and control groups. The results showed that the long-term learning gain scores for the experimental group ($median = 4$) were statistically significantly higher than the control group ($median = 0$), as shown in Figure 5.16, $U = 38.5$, $Z = 5.12$, $p < 0.001$. The finding had a large effect size ($r = 0.75$). As a result, H3.4 is confirmed, and it can be concluded that matching learning material to dyslexia type and reading skill level yields significantly better long-term learning gain of reading unseen words than not matching.

5.4.4.3 Learning Gain of Understanding Seen Words

Short-term Hypothesis (H3.5) about the short-term learning gain of understanding seen words was tested. Table 5.13 shows the experimental group had greater immediate post-test scores and short-term learning gains of understanding than the control group. These findings reveal that matching learning material to both dyslexia type and reading skill level had a positive effect on short-term learning gain of understanding seen words.

The significance of the short-term learning gain of understanding seen words was tested. As short-

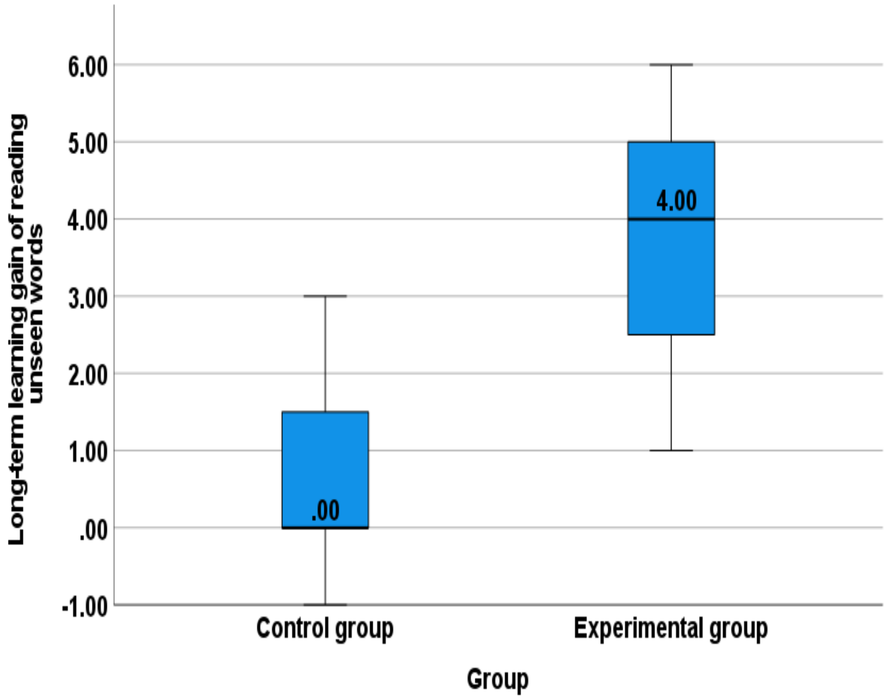

Figure 5.16: Experiment 3: Box plot for the results of long-term learning gain of reading unseen words.

Table 5.13: Experiment 3: Control and experimental group results of pre-test, immediate post-test, follow-up test, short- and long-term learning gain of understanding seen words.

Group	N	Pre-test		Immediate post-test		Follow-up test		Short-term learning gain of understanding seen words		Long-term learning gain of understanding seen words	
		Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Control	24	4.5	2.5	6.13	2.17	6.25	1.8	1.63	1.5	1.75	2.07
Experimental	23	4	2.17	7.65	1.75	8.17	1.19	3.65	1.8	4.17	2.06

term scores for both groups were normally distributed, as determined by Shapiro–Wilk's test ($p > 0.05$), an independent sample t-test with an alpha level of 0.05 was run to determine if there were differences in short-term learning gain scores between the experimental and control groups. Learning gain scores for both groups were homogeneous in variance, as determined by Levene's test for the equality of variances ($F = 0.145$, $p = 0.705$). Based on the means of short-term learning gain, the experimental group had larger short-term learning gains than the control group, with a statistically significant difference of 2.02, $t(45) = 4.205$, $p < 0.001$ (see Figure 5.17). The finding had a very large effect size (Cohen's $d = 1.22$). As a result, H3.5 is confirmed, and it can be concluded that matching learning material to dyslexia type and reading skill level yields significantly better short-term learning gain of understanding seen words than not matching.

Long-term Hypothesis (H3.6) about long-term learning gain of understanding seen words after two weeks have elapsed was tested. Table 5.13 shows the experimental group had greater follow-up test scores and long-term learning gains of understanding than the control group. These findings

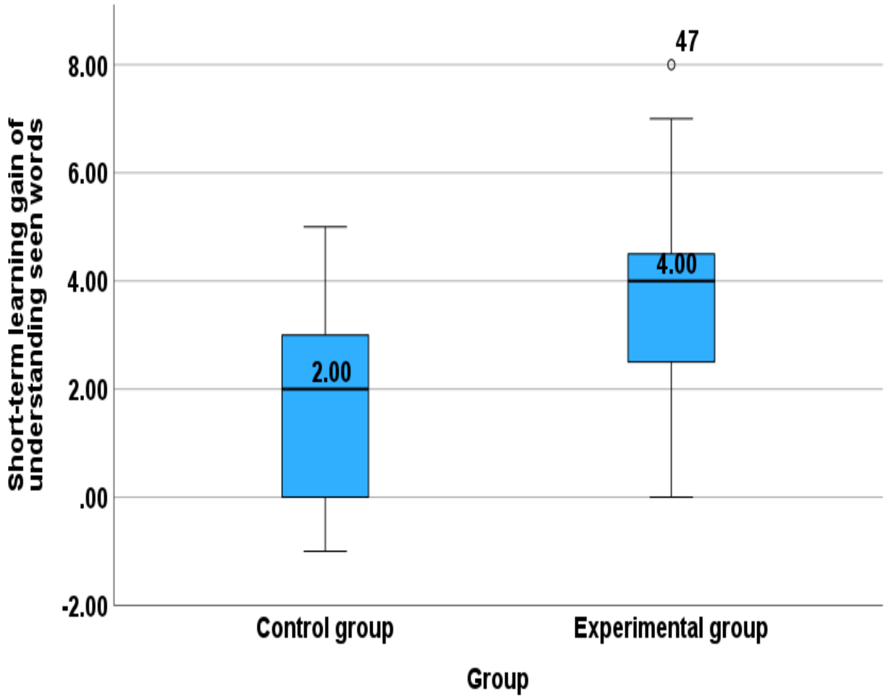

Figure 5.17: Experiment 3: Box plot for the results of short-term learning gain of understanding seen words.

reveal that matching learning material to both dyslexia type and reading skill level had a positive effect on long-term learning gain of understanding seen words.

The significance of the long-term learning gain of understanding seen words was tested. As long-term scores for both groups were normally distributed, as determined by Shapiro–Wilk's test ($p > 0.05$), an independent sample t-test with an alpha level of 0.05 was run to determine if there were differences in long-term learning gain scores between the experimental and control groups. Learning gain scores for both groups were homogeneous in variance, as determined by Levene's test for the equality of variances ($F = 0.120$, $p = 0.730$). Based on the means of long-term learning gain, the experimental group had larger long-term learning gains than the control group, with a statistically significant difference of 2.42, $t(45) = 4.024$, $p < 0.001$ (see Figure 5.18). The finding had a very large effect size (Cohen's $d = 1.17$). As a result, H3.6 is confirmed, and it can be concluded that matching learning material to dyslexia type and reading skill level yields significantly better long-term learning gain of understanding seen words than not matching.

5.4.4.4 Learner Satisfaction

The results of the seventh hypothesis (H3.7) about learner satisfaction are presented in this section. Satisfaction was calculated for each component, as shown in Table 5.14. The results indicated that the experimental group had higher mean learner satisfaction scores in terms of the learning content, the system personalisation and the system interface than the control group.

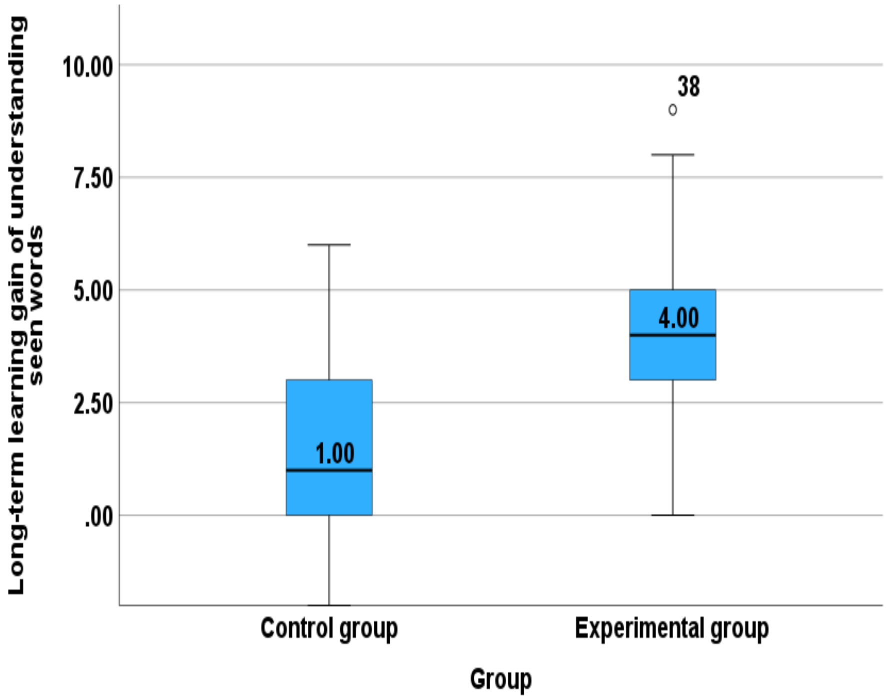

Figure 5.18: Experiment 3: Box plot for the results of long-term learning gain of understanding seen words.

Table 5.14: Experiment 3: Satisfaction scores of learners with dyslexia.

ELS components	**Satisfaction of control group**		**Satisfaction of experimental group**	
	Mean	***SD***	***Mean***	***SD***
Learning content	3.83	0.63	4.74	0.44
System personalisation	3.96	0.83	4.72	0.47
System interface	4.32	0.5	4.68	0.29
General satisfaction	4.1	0.45	4.7	0.33

According to the analysis of the learners' satisfaction, the experimental group ($mean = 4.7$, $SD = 0.33$) had greater mean general satisfaction scores than the control group ($mean = 4.1$, $SD = 0.45$), implying that matching learning material to dyslexia type and reading skill level positively affected learner satisfaction.

The significance of the learner satisfaction scores was tested. As the learner satisfaction scores in the experimental group were not normally distributed (Shapiro–Wilk's test $p < 0.05$), an independent sample Mann–Whitney U test was run to determine if there were differences in satisfaction scores between the experimental and control groups. The results showed that the general learner satisfaction score for the experimental group ($median = 4.8$) was statistically significantly higher than the control group ($median = 4.15$), as shown in Figure 5.19, $U = 68$, $Z = 4.44$, $p < 0.001$. The finding had a large effect size ($r = 0.65$). As a result, H3.7 is confirmed, and it can be concluded that matching learning material to dyslexia type and reading skill level yields significantly better learner satisfaction than not matching.

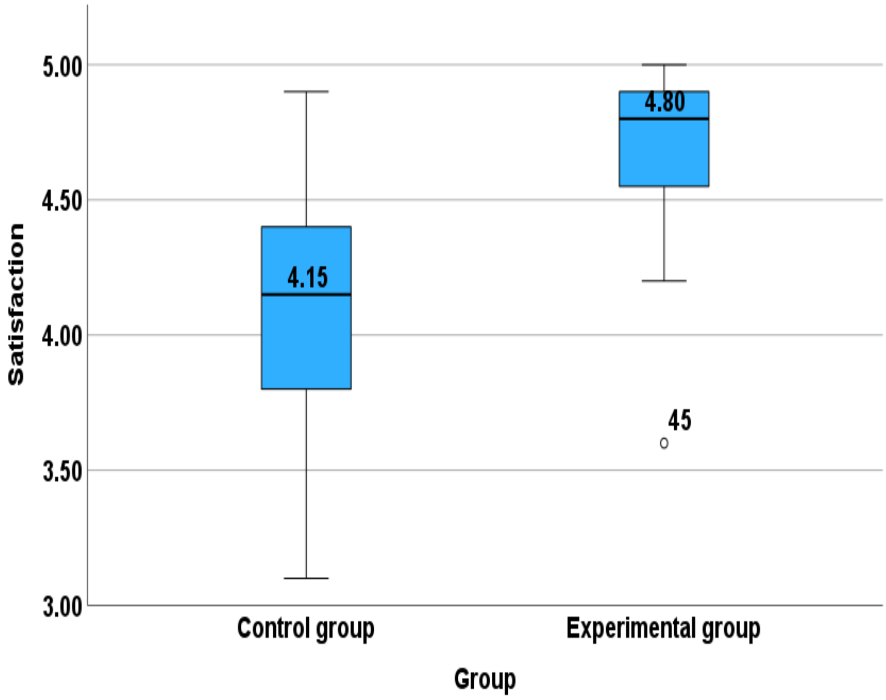

Figure 5.19: Experiment 3: Box plot for the results of learners' satisfaction.

5.4.4.5 Perceived Level of Usability

The results of the eighth hypothesis (H3.8) about perceived level of usability are presented in this section. The usability scores for the matched version of DTRSLT ($mean = 93.04$, $SD = 7.38$) and the non-matched version ($mean = 82.4$, $SD = 11.88$) were acceptable, as both average scores were greater than 70, implying that both versions were perceived as usable and valuable in learning (Bangor et al., 2008).

To obtain a deeper understanding of whether adaptation significantly impacts the perceived level of usability, the two conditions were compared. As the data in both groups were not normally distributed (Shapiro–Wilk's test $p < 0.05$), an independent sample Mann–Whitney U test was run to compare the two conditions. The results indicated that the general usability score of the matched version ($median = 95$) was statistically significantly higher than the non-matched version ($median = 85$), as shown in Figure 5.20, $U = 107.5$, $Z = 3.61$, $p < 0.001$. The finding had a large effect size ($r = 0.53$). As a result, H3.8 is confirmed, and it can be concluded that matching learning material to dyslexia type and reading skill level results in significantly higher levels of perceived usability than not matching.

5.4.5 Discussion

This study differs from earlier research on dyslexia in that it investigates the benefit of adaptation based on a combination of two distinct characteristics of learners with dyslexia: dyslexia type and

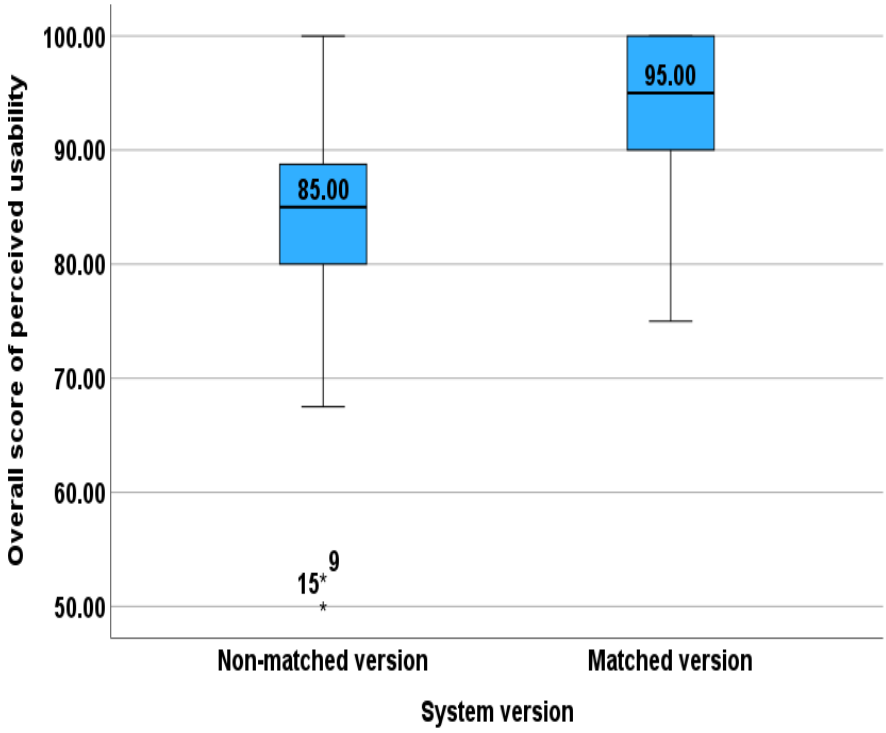

Figure 5.20: Experiment 3: Box plot for the results of perceived usability level.

reading skill level. The study assessed learning gain of reading seen and unseen materials and learning gain of word understanding (immediately at the end of the course and after a two-week delay), learner satisfaction and learner perception of the usability of the learning material.

This study was affected by Covid-19 and was conducted remotely via Microsoft Teams due to school closures.

This study contributes to current research by confirming that the combination of both dyslexia type and reading skill level of learners with dyslexia in adaptive e-learning is a significant factor in enhancing their learning (Alghabban and Hendley, 2022a, 2023). As with Studies 1 and 2, a distinctive aspect of this study was the investigation of the effectiveness of adaptation by conducting a carefully designed and controlled experiment with a reasonable number of participants (Alghabban and Hendley, 2022a, 2023). The effect of adaptation based on a combination of two or more characteristics of learners with dyslexia was a significant gap that was unaddressed in the previous research, leading to difficulty in interpreting the effectiveness of the proposed systems (Benmarrakchi et al., 2017c; Alsobhi and Alyoubi, 2019, 2020; El Fazazi et al., 2021). Even so, Benmarrakchi et al. (2017c), Alsobhi and Alyoubi (2020) and El Fazazi et al. (2021) pointed to the need to consider the various characteristics of learners with dyslexia to improve their learning process. This issue was considered in this study (Alghabban and Hendley, 2022a, 2023).

The results of the significant learning gain for both reading (Alghabban and Hendley, 2023) and understanding obtained in the condition where the system adapts to both dyslexia type and reading skill level are consistent with Study 1 that considers dyslexia type (Alghabban and Hendley, 2020a,b) and with Study 2 that considers reading skill level (Alghabban and Hendley, 2021; Alghabban et al., 2021; Alghabban and Hendley, 2022b). The learning gains achieved in this study are clear in the short term, and the benefit persists over the long term, as seen in Study 1.

This study also found that this adaptation, based on the combination of dyslexia type and reading skill level, significantly improved learning gain for reading new words (Alghabban and Hendley, 2023), as seen in Study 2, and that this effect persists rather than being only a short-term effect. This suggests that adaptation based on two characteristics of learners with dyslexia leads to an improvement in generalisation (Alghabban and Hendley, 2022a, 2023).

This study's results are consistent with the results of Studies 1 and 2 regarding learners' satisfaction. Learners with dyslexia were more likely to be satisfied and motivated when learning material was matched to both dyslexia type and reading skill level (Alghabban and Hendley, 2022a, 2023).

Finally, the high level of perceived usability in the matched version can be interpreted in line with Studies 1 and 2, where learners perceived the usability of the two versions differently. Because the two versions were identical in layout and interface except for the words used in the activities, the difference between the two conditions in perceived usability cannot be attributed to the user interface. Rather, it can be attributed to adapting the material to dyslexia type and reading skill level. This suggests that learners are aware of when a lesson is more suited to their needs and that this affects their perception of the quality of the course.

To sum up, this study investigated the impact of adapting learning material based on the combination of dyslexia type and reading skill level of learners. The results confirmed all hypotheses. The results indicated that adapting learning material based on these two characteristics of learners with dyslexia leads to a significant improvement in both short- and long-term learning gain of reading seen and unseen materials and both short- and long-term learning gain of word understanding. Adaptation also enhances learner satisfaction and perceived level of usability.

5.5 Overall Discussion

This research contributes to recent research on adaptive e-learning and dyslexia by presenting evidence for the importance of adapting learning material to meet the different needs of learners with dyslexia in e-learning environments. The work sheds light on the benefit of adaptation based on two characteristics of learners with dyslexia: dyslexia type and reading skill level. The effect of adaptation based on characteristics of learners with dyslexia is a significant gap that was not addressed and evaluated in previous research.

This work shows that adaptation based on each characteristic alone (dyslexia type in Experiment 1 and reading skill level in Experiment 2) and combining them (in Experiment 3) enhances learners' learning gain of word reading and word understanding and that this effect persists rather than being only a short-term effect. It also shows an enhancement in learning gain for reading new words (both for short- and long-term effects), which shows an improvement in generalisation.

This work shows that learners are more satisfied and engaged when material is matched to their characteristics than when they must work with non-matched material. It also shows that the perceived level of usability when learning material is matched to learner characteristics is greater than when it is not matched. This suggests that learners are aware of when a lesson is more suited to their needs and that this affects their perception of the quality of the course.

This research planned to measure reading speed in Experiment 3; however, the data collected were not reliable.

A summary of the outcomes of all experiments is presented in Table 5.15.

Table 5.15: A summary of the outcomes of experiments.

Outcomes	**Group**	**Experiment 1**		**Experiment 2**		**Experiment 3**	
		Mean	***SD***	***Mean***	***SD***	***Mean***	***SD***
Short-term learning gain of reading seen words	Control	0.60	1.43	1.57	1.8	1.29	1.16
	Experimental	3.35	1.84	4.6	1.67	3.61	1.23
Long-term learning gain of reading seen words	Control	1.55	1.69	N/A	N/A	1.34	2.01
	Experimental	3.90	2.13	N/A	N/A	3.96	1.64
Short-term learning gain of reading unseen words	Control	N/A	N/A	0.38	0.74	0.54	1.02
	Experimental	N/A	N/A	2.65	1.5	2.96	1.39
Long-term learning gain of reading unseen words	Control	N/A	N/A	N/A	N/A	0.62	1.09
	Experimental	N/A	N/A	N/A	N/A	3.61	1.64
Short-term learning gain of understanding seen words	Control	N/A	N/A	N/A	N/A	1.63	1.5
	Experimental	N/A	N/A	N/A	N/A	3.65	1.8
Long-term learning gain of understanding seen words	Control	1.27	1.64	N/A	N/A	1.75	2.07
	Experimental	3.6	1.98	N/A	N/A	4.17	2.06
Learner satisfaction	Control	4.68	0.38	4.23	0.44	4.1	0.45
	Experimental	4.9	0.18	4.77	0.13	4.7	0.33
Perceived level of usability	Control	85.63	9.93	84.76	12.09	82.4	11.88
	Experimental	96	6.46	96.25	3.39	93.04	7.38

Within this research, the researcher did not seek to investigate whether the two dyslexia types (LPD and VLD) each benefitted. Rather, the researcher aggregated the effect across both types. However, out of curiosity, the researcher repeated the analysis for each of the two dyslexia types separately. This is summarised in Table 5.16. Whilst caution should be applied to drawing strong conclusions, it appears that learners with each dyslexia type benefit from the matching of learning material to their dyslexia type.

Table 5.16: A comparison of the effect between learners with LPD and VLD.

Outcomes	Dyslexia type	Group	Experiment 1				Experiment 3			
			N	*Mean*	*SD*	*Comparison*	*N*	*Mean*	*SD*	*Comparison*
Short-term learning gain of reading seen words	LPD	Control	8	0.88	2.03	t(17) = 2.51 p = 0.011	3	1.33	0.58	U =2.5 Z = 1.86 p = 0.062
		Experimental	11	3.18	1.94		7	3.14	1.35	
	VLD	Control	12	0.42	0.9	t(19) = 5.23 p <0.001	21	1.29	1.23	t(35) = 6.33 p <0.001
		Experimental	9	3.56	1.81		16	3.81	1.17	
Long-term learning gain of reading seen words	LPD	Control	7	2	2.45	t(15) = 1.49 p = 0.079	3	1.33	1.53	t(8) = 1.78 p = 0.056
		Experimental	10	3.9	2.69		7	3	1.29	
	VLD	Control	11	1.27	1.009	t(19) = 4.7 p <0.001	21	1.33	2.11	t(35) = 4.79 p <0.001
		Experimental	10	3.9	1.52		16	4.38	1.63	
Short-term learning gain of reading unseen words	LPD	Control	N/A	N/A	N/A	N/A	3	0.33	0.58	U =1 Z= 2.27 p = 0.023
		Experimental	N/A	N/A	N/A		7	2	1	
	VLD	Control	N/A	N/A	N/A	N/A	21	0.75	1.08	t(35) = 7.01 p <0.001
		Experimental	N/A	N/A	N/A		16	3.38	1.36	
Long-term learning gain of reading unseen words	LPD	Control	N/A	N/A	N/A	N/A	3	0.67	1.15	U = 2.5 Z = 1.89 p = 0.059
		Experimental	N/A	N/A	N/A		7	2.71	1.38	
	VLD	Control	N/A	N/A	N/A	N/A	21	0.62	1.12	t(35) = 7.48 p <0.001
		Experimental	N/A	N/A	N/A		16	4	1.63	
Short-term learning gain of understanding seen words	LPD	Control	N/A	N/A	N/A	N/A	3	0.33	1.15	U = 3 Z = 1.73 p = 0.084
		Experimental	N/A	N/A	N/A		7	3.14	2.41	
	VLD	Control	N/A	N/A	N/A	N/A	21	1.81	1.47	U = 54 Z = 3.56 p <0.001
		Experimental	N/A	N/A	N/A		16	3.88	1.5	
Long-term learning gain of understanding seen words	LPD	Control	7	1.43	2.3	t(15) = 1.89 p = 0.039	3	1.33	0.58	U = 4 Z = 1.5 p = 0.123
		Experimental	10	3.5	2.17		7	3.57	2.88	
	VLD	Control	11	1.18	1.17	U = 15 Z = 2.94 p = 0.003	21	1.81	2.2	t(35) = 4 p <0.001
		Experimental	10	3.7	1.89		16	4.44	1.63	
Learner satisfaction	LPD	Control	8	4.68	0.34	U = 17.5 Z = 2.44 p = 0.015	3	4.5	0.36	t(8) = 0.18 p = 0.43
		Experimental	11	4.95	0.15		7	4.44	0.48	
	VLD	Control	12	4.68	0.42	U = 43.5 Z = 0.79 p = 0.43	21	4.04	0.44	t(35) = 6.8 p <0.001
		Experimental	9	4.84	0.21		16	4.82	0.15	
Perceived level of usability	LPD	Control	8	86.88	9.3	U = 8.5 Z = 3.05 p = 0.002	3	85	2.5	t(8) = 1.002 p = 0.173
		Experimental	11	97.5	6.02		7	90.7	9.4	
	VLD	Control	12	84.79	10.6	t(19) = 2.3 p = 0.016	21	82.02	12.67	U = 6 Z = 1.04 p = 0.29
		Experimental	9	94.17	6.8		16	94.06	6.38	

5.6 Conclusion

This chapter has presented the results of the evaluation of matching learning material to dyslexia type and reading skill level of learners with dyslexia in terms of learning gain of word reading, learning gain of word understanding, learner satisfaction and perceived level of usability. This evaluation employed the experimental evaluation approach and conducted a carefully designed and controlled experiment with participants engaged in a realistic learning environment. This approach has been considered an appropriate method for evaluating adaptive e-learning systems (Brown et al., 2009;

Paramythis et al., 2010; Akbulut and Cardak, 2012; Truong, 2016). All of the experiments emphasised careful investigation, sound experimental design and precise reporting of findings. Previous related works lack carefully designed experiments or use small sample sizes (Benmarrakchi et al., 2017a,b,c; Ouherrou et al., 2018; El Kah and Lakhouaja, 2018; Aldabaybah and Jusoh, 2018; Al-Dawsari and Hendley, 2021).

In this research, three experiments were conducted, each having specific objectives and hypotheses. Experiment 1 investigated the impact of adaptation based on dyslexia type. Every learner in the experimental group received customised learning material according to their dyslexia type. In contrast, learners in the control group received generic material. According to the findings, matching learning material to dyslexia type results in significantly better short-term learning gain of reading and shows the persistence of this gain and word understanding in the long term compared to non-matched material. In addition, matching learning material based on dyslexia type achieves significantly better learner satisfaction and perceived level of usability.

Experiment 2 investigated the impact of adaptation based on reading skill level. Every learner in the experimental group received customised learning material according to their reading skill levels. Learners in the control group received generic material. According to the findings, matching learning material to the reading skill level of learners with dyslexia results in significantly better short-term learning gain of reading, learner satisfaction and perceived level of usability compared to non-matched material. In addition, matching learning material based on reading skill level showed the most significant generalisation for reading new words in the short term.

Experiment 3 investigated the impact of adaptation based on combining dyslexia type and reading skill level. Every learner in the experimental group received customised learning material according to their dyslexia type and reading skill level. In contrast, learners in the control group received generic material. Matching learning material to both dyslexia type and reading skill level of learners with dyslexia yields significantly better short-term learning gain of reading, persistence of this gain in the long term, learner satisfaction and perceived level of usability compared to non-matched material. In addition, matching learning material based on the combination of these two characteristics of learners with dyslexia showed a greater generalisation for reading new words in both the short and the long term compared to the non-matched material. Short-term learning gain of word understanding and persistence of this understanding in the long term were also greater when learning material was matched to these two characteristics than when it was not matched.

Although the types of dyslexia targeted in this work are the most common in Arabic, and the selected reading skills are basic skills, other dyslexia types and reading skills could also be incorporated to investigate their impact on the learning experience. The experiments were conducted with female Arabic learners with dyslexia in primary schools. It is probable that these results can be generalised to other languages, to male learners and to other age groups or to other learning domains, but that generalisation is not answered by this work and will require further investigation. The next chapter will offer more details about the limitations of this work and recommendations for future research.

Chapter 6

Conclusion

6.1 Introduction

This chapter first summarises the work done in this research and then discusses the main questions. It also discusses the main contributions of this research to the literature. Lastly, this chapter reviews the limitations of this work and how these limitations can be addressed in future research.

This chapter is based on the content published in the following papers: Alghabban and Hendley (2020a,b, 2021); Alghabban et al. (2021); Alghabban and Hendley (2022a,b, 2023).

6.2 Summary of the Work

From the literature presented in Chapters 2 and 3, this research concluded that each individual with dyslexia has different characteristics, such as preferences, knowledge level and dyslexia type. Therefore, it is essential to consider these different needs and characteristics of learners with dyslexia to provide an effective learning environment and enhance their learning. This can be achieved through adaptive e-learning.

The literature has proposed several adaptive e-learning systems for learners with dyslexia by considering different aspects, such as knowledge level, learning style, preferences and type of dyslexia. However, the conclusions lack a well-designed and implemented experimental evaluation, making it difficult to assess the effectiveness of the proposed systems. For this reason, this work aimed to investigate the impact of matching learning material based on two basic characteristics of learners with dyslexia (dyslexia type and reading skill level) on the learning experience of learners by conducting several carefully designed and controlled experiments with an empirical evaluation in terms of learning gain of word reading, learning gain of word understanding, learner satisfaction and perceived level of usability.

To achieve this research aim, Chapter 4 presented the proposed framework for evaluating the impact of matching learning material based on the characteristics of learners with dyslexia. To support the experiments, this research designed and built a dynamic, web-based e-learning system called Dyslexia Type and Reading Skill Level Training (DTRSLT) as an instantiation of the adaptive e-learning framework. This adaptive e-learning framework includes three main components to produce the adaptation: the learner model, the domain model and the adaptation model. It also includes two auxiliary components: the interaction module and the interaction data modeller. The DTRSLT system utilises a simple, three-tier architecture, which includes client, server and data storage. The details of each tier are covered in Chapter 4. DTRSLT was built to support controlled experiments. The DTRSLT system provides different reading activities. There are two versions of DTRSLT to support the experimental conditions: one for the experimental group and another for the control group. The experimental group used the matched version of the e-learning system that matches learning material to the learner's targeted characteristic(s), while the control group used the non-matched version that provides generic learning material. The system layout and interface were identical for both groups. The only difference was the provided learning material.

Chapter 5 presented the results of the evaluation of matching learning material to dyslexia type and reading skill level. Experiment 1 investigated the impact of matching learning material based on dyslexia type in terms of short- and long-term learning gain of reading seen words, long-term learning gain of understanding seen words, learner satisfaction and perceived level of usability. Experiment 2 investigated the impact of matching learning material based on reading skill level in terms of short-term learning gain of reading seen and unseen words, learner satisfaction and perceived level of usability. Finally, Experiment 3 investigated the impact of matching learning material based on both dyslexia type and reading skill level in terms of short- and long-term learning gain of reading seen and unseen words, short- and long-term learning gain of understanding seen words, learner satisfaction and perceived level of usability. The results of these experiments are summarised in the following section.

6.3 Research Questions Re-visited

This work aimed to investigate the impact of matching learning material (based on the different characteristics of learners with dyslexia) on their learning experience. Therefore, it attempted to address the following key research question:

Does matching e-learning material based on the characteristics of learners with dyslexia improve those learners' experience of learning?

Different characteristics can be considered, such as learning style, personality, knowledge level and dyslexia type. However, including all these characteristics to answer this broad question was difficult due to practical and time constraints. Therefore, this research made this question more specific by focusing on two characteristics of learners with dyslexia, dyslexia type and reading skill level, as they are significant in education (Felder and Silverman, 1988; Essalmi et al., 2010; Klašnja-Milićević et al., 2011; Friedmann and Haddad-Hanna, 2014; Friedmann and Coltheart, 2016). Hence, the key research question can be broken down into three specific sub-questions as follows:

Research Question 1: Does matching e-learning material based on dyslexia type improve learning gain compared to non-matched material, and does it achieve a high level of learner satisfaction and perceived level of usability?

To answer this question, Experiment 1 was conducted with 40 participants to investigate the impact of matching learning material based on the dyslexia type (see Section 5.2). The findings indicated that matching learning material to dyslexia type yields significantly better short- and long-term learning gain of reading seen words, long-term learning gain of understanding seen words, learner satisfaction and perceived level of usability than non-matched material with a medium-to-very-large effect size.

Research Question 2: Does matching e-learning material based on reading skill level improve learning gain compared to non-matched material, and does it achieve a high level of learner satisfaction and perceived level of usability?

To answer this question, Experiment 2 was conducted with 41 participants to investigate the impact of matching learning material based on the reading skill level (see Section 5.3). The findings indicated that matching learning material to reading skill level yields significantly better short-term learning gain of reading seen and unseen words, learner satisfaction and perceived level of usability than non-matched material with a large-to-very-large effect size.

Research Question 3: Does matching e-learning material based on a combination of dyslexia type and reading skill level improve learning gain compared to non-matched material, and does it achieve a high level of learner satisfaction and perceived level of usability?

To answer this question, Experiment 3 was conducted with 47 participants to investigate the impact of matching learning material based on the combination of both dyslexia type and reading skill level (see Section 5.4). The findings indicated that matching learning material to dyslexia type and reading skill level yields significantly better short- and long-term learning gain of reading seen and unseen words, short- and long-term learning gain of understanding seen words, learner satisfaction and perceived level of usability than non-matched material with a large-to-very-large effect size.

In conclusion, the work done in this thesis highlights the value of matching learning material to meet the different characteristics of learners with dyslexia in e-learning systems. Specifically, two characteristics were targeted: the dyslexia type and the reading skill level. Matching the learning materials to each characteristic (separately and to both) significantly improves the learning experience of the learners, in particular, their learning gain of word reading and understanding, satisfaction and perceived level of usability, compared to the non-matched materials. This work is also seen as a foundation in adaptive e-learning for people with dyslexia and the beginning of further research on this topic, with more characteristics of people with dyslexia to be addressed in future research.

6.4 Summary of Research Contributions

According to Section 1.5, this research has made several significant contributions in the field of dyslexia and adaptive e-learning systems, and several papers have already been presented and published at refereed international conferences. Two peer-reviewed journal articles have also been published (see Section 1.6).

This work contributes to the recent research by highlighting the significance of adapting learning material to different characteristics of learners with dyslexia, specifically, dyslexia type and reading skill level. Prior works lack experimental evaluations to assess the impact of adaptation on learners' achievement, which leads to difficulty in understanding the effectiveness of the proposed systems. When there was an evaluation, most studies relied on collecting informal feedback, which leads again to difficulty in evaluating the effectiveness of the systems. Where more formal evaluation did take place, systems were evaluated with a small number of participants, which led to an inability to draw reliable conclusions. These are significant gaps in current research targeted at dyslexia in Arabic (Alghabban et al., 2017; Benmarrakchi et al., 2017a,b,c; El Kah and Lakhouaja, 2018; Ouherrou et al., 2018; Aldabaybah and Jusoh, 2018; Al-Dawsari and Hendley, 2021) and other languages, such as English (Broadhead et al., 2018; Sasupilli et al., 2019; Srivastava and Haider, 2020; Burac and Cruz, 2020; El Fazazi et al., 2021), Malay (Noor et al., 2017; Abdul Hamid et al., 2017; Pang and Jen, 2018) and Spanish (Rello et al., 2017; Arteaga et al., 2018). They have not been investigated or appropriately evaluated in an adaptive e-learning system for learners with dyslexia.

The major contribution of this work comes from carefully investigating and understanding the effectiveness of adaptation based on dyslexia type (Alghabban and Hendley, 2020a,b), reading skill level (Alghabban et al., 2021; Alghabban and Hendley, 2021, 2022b) and the combination of both dyslexia type and reading skill level (Alghabban and Hendley, 2022a, 2023). This research is unique in that it is based on theory and practice and used a carefully designed and controlled experimental evaluation approach that involved a reasonable number of subjects. It analyses and reports the quantitative findings of three experiments in terms of learning gain, learner satisfaction and perceived level of usability. This work is also distinctive in assessing the persistence of learning gain in the long term and whether the learned content can be generalised to new material (in both the short and long term). This work also assesses learners' ability to understand words in the short term and whether this understanding persisted. This adds originality and novelty by providing further evidence for the significance of adapting learning material to meet the different characteristics of learners with dyslexia in e-learning systems.

6.5 Limitations and Future Work

This research has some limitations that should be considered when interpretting the results and which should be explored in future studies. We describe these below.

In studies like these, there are many possible biases that can affect the outcomes. One example is the selection of the population of participants in the studies, which may not be representative of the target population. This affects the extent to which the results can be generalised. In this research, the researcher sought to minimise this by using multiple sources for participant identification, such as collaborating with schools and special education experts, to reach a diverse and representative sample.

The experimental protocol specified that both parents and the child must give consent and that this can be withdrawn at any time. This could introduce some bias: Parents who consent to their child participating in a study may have specific characteristics, such as educational level or greater involvement in their child's education. Participants were divided into the two experimental conditions, balanced by age, grade, pre-test results, and other characteristics (dyslexia type and/or reading skill level). The two groups were homogeneous in terms of native language and gender. There was no significant difference between the means of each group in either age or the pre-test results. There was not an attempt to balance by socio-economic characteristics and so it is possible that one condition was biased in this way.

There is a risk that knowledge of which experimental condition the participant is in can influence the behaviour of both the participants and the experimenter. For this reason, the experiment was double-blind – neither the participant or experimenter were aware of the condition to which a participant was allocated.

For cultural reasons within KSA, only female subjects were used in these studies. Any conclusions drawn from the sample may not be generalisable to males and so further work should be done to repeat the studies with male participants.

In each experiment, this research assessed the impact of adaptation on the learning experience of learners with dyslexia by measuring learning gain of word reading, learning gain of word understanding, learner satisfaction and perceived level of usability. This research measured learning gain of reading and understanding immediately after completion of the experiment to document how much the learners had gained. This research measured them again two weeks after the completion of the experiment to assess whether the learning gains of reading and understanding were persistent. Two weeks was a sufficient period to assess the persistence of learning gain. It might be interesting to assess the persistence of learning gain in the longer term (beyond one academic semester or a year).

This research targeted measuring reading speed in this work, as learners with dyslexia experience a deficit in reading speed (Miller-Shaul, 2005; Suárez-Coalla and Cuetos, 2012; Martelli et al., 2014). Reading speed can be considered a trustworthy measure of word decoding fluency for learners with dyslexia (Layes et al., 2015b). However, the data collected were not reliable because the experiment was conducted remotely, and the Internet connections were not always stable. Therefore, it is possible to extend this work by measuring reading speed as another metric. This work can also be extended by measuring learners' motivation, as little attention has been paid to this metric in adaptive e-learning systems for learners with dyslexia. Learners' motivation can be measured using the dropout rate as an indirect proxy for engagement (Ghaban and Hendley, 2018). This means that learners who are more engaged will use the e-learning system for longer and that this, in turn, leads to improved learning outcomes.

This work did not aim to consider, separately, how participants with the two different dyslexia types (LPD and VLD) responded to the matching of learning material. The researcher did perform a post hoc analysis (presented in Table 5.16), but it would be necessary to undertake further studies in order to be able to draw any reliable conclusions.

The findings of this work were reported using a quantitative methodological approach that was appropriate to the research questions and measurements. Qualitative methods, such as interviewing subjects and observing their behaviour while they interact with an e-learning system, are also helpful. Observing how learners interact with the system could reveal pertinent information to support this research conclusion, such as whether they are engaged and their preferences for presenting material in different modes. The data can be analysed using thematic content analysis (Braun and Clarke, 2006). Observation work should be planned carefully and piloted. Using a mixed methods (quantitative and qualitative) approach will make the conclusion more reliable and could also provide different insights.

This work aimed to investigate and understand whether adaptation based on characteristics of learners with dyslexia, in particular, dyslexia type and reading skill level, is beneficial. This research concluded that adaptation based on each characteristic alone and combining them achieved significant improvement in the learning experience of learners. This work did not target whether comparing the benefits of combining two characteristics would be greater or less than the benefits of each characteristic alone. Each experiment had its aim, and circumstances, and was conducted at different times, with different participant profiles. This research believes that the benefits of adaptation based on the two characteristics will be greater than the benefits of adaptation based on each characteristic alone. More studies are needed to evaluate that.

Another important point is that the amount of training through the e-learning system was limited. All sessions were short term, lasting about half an hour for each training session, with two sessions per a week, distributed over approximately one month. This is true in the case of the training examined in this work, as approved by special education teachers and as recommended in previous studies, rather than teaching learners new skills that require long-term sessions. Thus, one possible suggestion for future work is to repeat the experiments for longer periods of time, such as one semester, with more learning objects, to determine if learners benefit from a longer learning experience.

To conduct this research, this research asked primary school learners aged 7–13 years to participate in experiments due to their ease of access. All experiments were conducted with young girls only because of the cultural constraints in the Kingdom of Saudi Arabia (KSA) that separate male and female children in educational institutions. Therefore, only female subjects could be accessed. This circumstance cannot be avoided and has the advantage of reducing variances between subjects. The age group and gender restrictions make it difficult to draw conclusions about same-age boys or older learners. More research is required.

This work targeted dyslexia in Arabic as there is a paucity of studies targeting dyslexia in this language (Alsswey et al., 2021), despite the fact that this language is widely spoken and has a considerable rate of dyslexia (El Kah and Lakhouaja, 2015; Benmarrakchi et al., 2017b; Alghabban and Hendley, 2020a; Al-Dawsari and Hendley, 2022). The orthography and the structure of the Arabic language differ from those of many other languages. As a result, dyslexia in Arabic is manifested differently from dyslexia in English (AlRowais et al., 2013). This limits the generalisability of this research across other languages with transparent orthographies (such as Turkish and Spanish), with non-transparent orthographies (such as English and French), or with both transparent and non-transparent orthographies (such as Hebrew). In general, this research believes the findings can be generalised across other languages, but more studies are needed.

Another limitation of this work is that this research did not consider the severity of dyslexia (mild, moderate and severe), which differs from person to person. People with mild dyslexia may make fewer spelling and reading mistakes than those with moderate and severe dyslexia but, nevertheless, not be comparable to peers without dyslexia. People with moderate dyslexia may show more anxiety and be less engaged and shy when reading. People with severe dyslexia may resist spelling and reading and feel uncomfortable doing either activity. They make more mistakes when spelling and reading than people with mild and moderate dyslexia. Therefore, how the method and extent of learning depend on the severity of dyslexia is an interesting question that requires further investigation.

This work primarily focused on the two most common types of dyslexia in Arabic: letter position dyslexia (LPD) and vowel letter dyslexia (VLD). Other types of dyslexia have been identified and reported for Arabic: attentional dyslexia, neglect dyslexia, visual dyslexia, surface dyslexia and deep dyslexia (Friedmann and Haddad-Hanna, 2014). These types may overlap, resulting in learners with more than one type of dyslexia. In order to control the experiments, this research focused on LPD and VLD, and we did not include learners with other types of dyslexia or learners with more than one type of dyslexia. This decision limits this research's generalisability to other types of dyslexia. In general, this research believes the findings can be generalised across other types of dyslexia, but more studies are needed.

This work primarily focused on a limited number of reading skill levels: reading letters with short vowels (S1), reading words with Sakin letter(s) (S2) and reading words with short vowels and Sakin letter(s) (S3). This was an appropriate decision due to practical constraints. The findings are expected to be generalisable to other reading skills in Arabic, such as reading words with long vowels, reading and comprehension of sentences and paragraphs, but further research is required.

Other characteristics need to be considered as input into the adaptation process. Dyslexia type and reading skill level are only two characteristic of learners with dyslexia. The importance of learning styles, cognitive styles, personality, and behaviour cannot be ignored (Abdul Hamid et al., 2017; Benmarrakchi et al., 2017c; El Fazazi et al., 2021). Future studies incorporating these different characteristics of learners with dyslexia are needed to investigate their impact on the learning process. As Brown (2007) states, *'the nature of learning is obviously very complex, with a large interplay of factors'* (p. 116) (Brown, 2007). Therefore, adaptive e-learning research based on other characteristics of learners with dyslexia using carefully designed experiments would be useful.

The comorbidities of dyslexia with other developmental disorders, such as attention-deficit/hyperactivity disorder (ADHD) and dyscalculia, cannot be ignored (Gooch et al., 2014). Another possible direction of research is to consider the adaptation of learning based on the co-occurrence of dyslexia with other disorders. It would be interesting to understand whether adaptation based on the comorbidities of dyslexia with other developmental disorders would be beneficial to learners.

Adaptive e-learning systems can adapt different aspects, such as gamification elements, learning content or the presentation of learning content, according to learner characteristics. This research focused on adapting learning content to the characteristics of learners with dyslexia. Therefore, another important area of future research could be to investigate adapting the presentation of content. Adapting gamification elements to the needs of individuals with dyslexia is important, as their motivation in e-learning is challenging (Gooch et al., 2016; Abdul Hamid et al., 2018). The gamification elements could include badges, point scoring, avatars and peer competition (Domínguez et al., 2013). Another direction involves incorporating and investigating collaborative and social learning features, such as chatting, sharing with others and question-and-answer forums. Social features and gamification elements can be incorporated into adaptive e-learning systems. However, it is necessary to evaluate each aspect independently before integrating all aspects into the system. As a whole, the final system must also be carefully evaluated to understand the value.

This research targeted reading skill as it is a language-related skill that has been intensively investigated in previous research. However, other domains could be addressed, such as spelling and writing.

Compared with previous research, the sample size of the three experiments was reasonable, especially as each experiment included 40–47 participants, compared to previous research that included fewer learners. It was difficult to recruit more participants due to practical constraints. However, this work can be extended by repeating the experiments with a larger sample size and see if the same findings will be obtained.

In this work, a dynamic, web-based e-learning system was designed and implemented, as an instantiation of the adaptive e-learning framework, to support the experiments. To make this system more practical for use by teachers in the classroom in the future, the points described in the following paragraphs should be considered.

In the design of the e-learning system, the content of the course in the domain model remained fixed throughout each experiment. The content in the domain model cannot be updated because the e-learning system does not provide this functionality. This research did not focus on the domain model. The content of the domain model was built to illustrate a particular aspect of the system relevant to the reading course. To make this system more practical in the classroom, this research suggests including the ability to update content in the domain model to comply with course objectives. Also, extra material could be added to increase the number of training sessions.

The learner model in the system was augmented to include a diagnosis of dyslexia type and reading skill level. This model is instantiated using reliable, offline diagnostic tools. This is important to be able to build a sound evaluation of the effectiveness of the adaptation and to control the experiments in this research. Future enhancements of the system could automate these tests, but this is challenging.

The adaptation business logic component was built to match training material based on the characteristics of the learners. This is done to fit this research's aim and maintain controlled experiments. The content was presented to all learners in the same way and in the same order (the difficulty level gradually increased from easy to advanced). However, some learners may have prior knowledge of some content; they might become bored with the basic content. Therefore, the system can be improved to dynamically assess the learner's current level of knowledge by conducting a test and then presenting material that suits their knowledge level. Also, learners' interactions and behaviours can be monitored and updated continuously, allowing for more accurate and dynamic learner models to be created.

Another possible direction to increase the practicality of the system would be to incorporate the concept of open learner modelling. Open learner modelling involves facilitating the process by which learners can inspect their levels of domain knowledge, preferences, learning progress and preferred materials to learn.

When using the system, participants had limited control over the learning process in each experiment. They were required to complete the assigned tasks and follow the system's recommendations due to the nature of controlled experiments. However, this restriction is inconsistent with constructivism, which emphasises learner control as an important aspect of learning (Ertmer and Newby, 1993). Therefore, the system can be improved by allowing learners to control the learning process by deciding how and in what order they will approach learning.

6.6 Summary

Individuals with dyslexia have different needs, characteristics and interests. Previous studies have addressed some characteristics of learners with dyslexia in adaptive e-learning systems. However, evaluation of these systems has weaknesses which leads to difficulty in understanding the effectiveness of these systems. From this perspective, this research aimed through this thesis to investigate and explore the effectiveness of adapting learning material to two characteristics of learners with dyslexia: dyslexia type and reading skill level. This research did this by conducting three carefully designed and controlled experiments with the empirical evaluation in terms of learning gain of word reading, learning gain of word understanding, learner satisfaction and perceived level of usability. This research has shown that adaptation based on the characteristics of learners with dyslexia has a significant benefit in enhancing the learning experience of Arabic learners with dyslexia.

This thesis demonstrated the effectiveness of adapting learning material to the characteristics of learners with dyslexia. In addition, this research may be used as a basis for further investigation that includes other aspects of learners with dyslexia to build a dynamic adaptive e-learning system that ensures learners have the best learning experience.

References

Abdul Hamid, S. S., Admodisastro, N., Kamaruddin, A., Manshor, N., and Ghani, A. A. A. (2017). Informing design of an adaptive learning model for student with dyslexia: A preliminary study. In *Proceedings of the 3rd International Conference on Human-Computer Interaction and User Experience in Indonesia*, CHIuXiD'17, pages 67–75, New York, NY, USA. Association for Computing Machinery.

Abdul Hamid, S. S., Admodisastro, N., Manshor, N., Ghani, A. A. A., and Kamaruddin, A. (2018). Engagement prediction in the adaptive learning model for students with dyslexia. In *Proceedings of the 4th International Conference on Human-Computer Interaction and User Experience in Indonesia*, CHIuXiD '18, pages 66–73, New York, NY, USA. Association for Computing Machinery.

Abdullah, M. H. L., Hisham, S., and Parumo, S. (2009). Mylexics: An assistive courseware for dyslexic children to learn basic Malay language. *ACM SIGACCESS Accessibility and Computing*, (95):3–9.

Abu-Rabia, S. (1997). Reading in Arabic orthography: The effect of vowels and context on reading accuracy of poor and skilled native Arabic readers. *Reading and Writing*, 9:65–78.

Abu-Rabia, S. (2012). The role of morphology and short vowelization in reading morphological complex words in Arabic: Evidence for the domination of the morpheme/root-based theory in reading Arabic. *Creative Education*, 3(4):486–494.

Abu-Rabia, S. (2019). The role of short vowels in reading Arabic: A critical literature review. *Journal of Psycholinguistic Research*, 48(4):785–795.

Abu-Rabia, S. and Sammour, R. (2013). Spelling errors' analysis of regular and dyslexic bilingual Arabic-English students. *Open Journal of Modern Linguistics*, 3:58–68.

Abu-Rabia, S., Share, D., and Mansour, M. S. (2003). Word recognition and basic cognitive processes among reading-disabled and normal readers in Arabic. *Reading and Writing*, 16:423–442.

Abu-Rabia, S. and Siegel, L. S. (1995). Different orthographies different context effects: The effects of Arabic sentence context in skilled and poor readers. *Reading Psychology*, 16(1):1–19.

Abu-Rabia, S. and Taha, H. (2005). Reading in Arabic orthography: Characteristics, research findings, and assessment. In Joshi, R. M. and Aaron, P., editors, *Handbook of orthography and literacy*, pages 321–338. Routledge.

Abu-Rabia, S. and Taha, H. (2006). Phonological errors predominate in Arabic spelling across grades 1–9. *Journal of Psycholinguistic Research*, 35(2):167–188.

Ahmad, S. Z., Ludin, N. N. A. A. N., Ekhsan, H. M., Rosmani, A. F., and Ismail, M. H. (2012). Bijak membaca - applying phonic reading technique and multisensory approach with interactive multimedia for dyslexia children. In *2012 IEEE Colloquium on Humanities, Science and Engineering (CHUSER)*, pages 554–559.

Akbulut, Y. and Cardak, C. S. (2012). Adaptive educational hypermedia accommodating learning styles: A content analysis of publications from 2000 to 2011. *Computers & Education*, 58(2):835–842.

Al-Dawsari, H. and Hendley, R. (2021). The effect of matching learning material to learners' dyslexia type on reading performance. In Arabnia, H. R., Deligiannidis, L., Tinetti, F. G., and Tran, Q. N., editors, *Advances in software engineering, education, and e-learning. Transactions on computational science and computational intelligence*, pages 837–845. Springer.

Al-Dawsari, H. M. and Hendley, R. (2022). Understanding the needs of Arab learners with dyslexia for adaptive system. In *Proceedings of the 35th International BCS Human-Computer Interaction*, pages 1–10.

Al-Ghurair, N. and Alnaqi, G. (2019). Adaptive Arabic application for enhancing short-term memory of dyslexic children. *Journal of Engineering Research*, 7(1):1–11.

Al-Rubaian, A., Alssum, L., Alharbi, R., Alrajhi, W., Aldayel, H., Alangari, N., Al-Negheimish, H., Alfayez, A., Alwaalan, S., and Aljindan, R. (2014). The design and development of empathetic serious games for dyslexia: BCI Arabic phonological processing training systems. In Marcus, A., editor, *Design, user experience, and usability. User experience design practice. Lecture notes in computer science*, pages 105–112. Springer.

Al-Sartawi, Z., Khashan, A., Al-Sartawi, A., and Abujouda, W. (2001). *Madkhal ela souobat attallam [Introduction to specific learning difficulties]*. Special Education Academy Publications, Riyadh, Saudi Arabia.

Al-Wabil, A., Zaphiris, P., and Wilson, S. (2006). Web design for dyslexics: Accessibility of Arabic content. In Miesenberger, K., Klaus, J., Zagler, W. L., and Karshmer, A. I., editors, *Computers helping people with special needs*, pages 817–822. Springer Berlin Heidelberg.

Aldabaybah, B. and Jusoh, S. (2018). Usability features for Arabic assistive technology for dyslexia. In *2018 9th IEEE Control and System Graduate Research Colloquium (ICSGRC)*, pages 223–228.

Alexander, P. A., Schallert, D. L., and Reynolds, R. E. (2009). What is learning anyway? A topographical perspective considered. *Educational Psychologist*, 44(3):176–192.

Alghabban, W. G., Al-Dawsari, H. M., and Hendley, R. (2021). Understanding the impact on learners' reading performance and behaviour of matching e-learning material to dyslexia type and reading skill level. In Fang, X., editor, *HCI in games: Serious and immersive games*, pages 135–154, Cham. Springer International Publishing.

Alghabban, W. G. and Hendley, R. (2020a). Adapting e-learning to dyslexia type: An experimental study to evaluate learning gain and perceived usability. In Stephanidis, C., Harris, D., Li, W.-C., Schmorrow, D. D., Fidopiastis, C. M., Zaphiris, P., Ioannou, A., Fang, X., Sottilare, R. A., and Schwarz, J., editors, *HCI international 2020 – Late breaking papers: Cognition, learning and games*, pages 519–537, Cham. Springer International Publishing.

Alghabban, W. G. and Hendley, R. (2020b). The impact of adaptation based on students' dyslexia type: An empirical evaluation of students' satisfaction. In Kuflik, T., Torre, I., Burke, R., and Gena, C., editors, *Adjunct Publication of the 28th ACM Conference on User Modeling, Adaptation and Personalization*, UMAP '20 Adjunct, pages 41–46, New York, NY, USA. Association for Computing Machinery.

Alghabban, W. G. and Hendley, R. (2021). Student perception of usability: A metric for evaluating the benefit when adapting e-learning to the needs of students with dyslexia. In *Proceedings of the 13th International Conference on Computer Supported Education – Volume 1: CSEDU*, pages 207–219. INSTICC, SciTePress.

Alghabban, W. G. and Hendley, R. (2022a). Exploring the effectiveness of adaptation based on dyslexia type and reading skill level to support learners with dyslexia. In *Proceedings of the 35th International BCS Human-Computer Interaction*, pages 1–10.

Alghabban, W. G. and Hendley, R. (2022b). Perceived level of usability as an evaluation metric in adaptive e-learning: A case study with dyslexic children. *SN Computer Science*, 3:1–11.

Alghabban, W. G. and Hendley, R. (2023). Adaptive e-learning and dyslexia: An empirical evaluation and recommendations for future work. *Interacting with Computers*, pages 1–10.

Alghabban, W. G., Salama, R. M., and Altalhi, A. H. (2017). Mobile cloud computing: An effective multimodal interface tool for students with dyslexia. *Computers in Human Behavior*, 75:160–166.

AlGhannam, B. A., Albustan, S. A., Al-Hassan, A. A., and Albustan, L. A. (2018). Towards a standard Arabic system usability scale: Psychometric evaluation using communication disorder app. *International Journal of Human-Computer Interaction*, 34(9):799–804.

Aljojo, N. (2020). Understanding the sequence of learning in Arabic text – Saudi Arabian dyslexics and learning aid software. *Educational Technology & Society*, 23(2):47–60.

Aljojo, N., Munshi, A., Almukadi, W., Hossain, A., Omar, N., Aqel, B., Almhuemli, S., Asirri, F., and Alshamasi, A. (2018). Arabic alphabetic puzzle game using eye tracking and chatbot for dyslexia. *International Journal of Interactive Mobile Technologies (iJIM)*, 12(5):58–80.

Ally, M. (2004). Foundations of educational theory for online learning. In Anderson, T., editor, *The theory and practice of online learning*, pages 15–44. AU press, Athabasca University.

Alotaibi, A. Z. (2007). The effect of font size and type on reading performance with Arabic words in normally sighted and simulated cataract subjects. *Clinical and Experimental Optometry*, 90(3):203–206.

AlRowais, F., Wald, M., and Wills, G. (2013). An Arabic framework for dyslexia training tools. In *1^{st} International Conference on Technology for Helping People with Special Needs (ICTHP-2013) (19/02/13 - 20/02/13)*, pages 63–68.

Alshammari, M. (2016). *Adaptation based on learning style and knowledge level in e-learning systems*. Doctoral dissertation, University of Birmingham.

Alshammari, M., Anane, R., and Hendley, R. J. (2014). Adaptivity in e-learning systems. In *2014 8^{th} International Conference on Complex, Intelligent and Software Intensive Systems*, pages 79–86.

Alshammari, M., Anane, R., and Hendley, R. J. (2015). An e-learning investigation into learning style adaptivity. In Bui, T. X. and Sprague, R. H., editors, *2015 48^{th} Hawaii International Conference on System Sciences*, pages 11–20.

Alshammari, M., Anane, R., and Hendley, R. J. (2015a). The impact of learning style adaptivity in teaching computer security. In *Proceedings of the 2015 ACM Conference on Innovation and Technology in Computer Science Education*, ITiCSE '15, pages 135–140, New York, NY, USA. Association for Computing Machinery.

Alshammari, M., Anane, R., and Hendley, R. J. (2015b). Students' satisfaction in learning style-based adaptation. In Sampson, D. G., Huang, R., Hwang, G., Liu, T., Chen, N., and Tsai, C., editors, *2015 IEEE 15^{th} International Conference on Advanced Learning Technologies*, pages 55–57.

Alshammari, M., Anane, R., and Hendley, R. J. (2016). Usability and effectiveness evaluation of adaptivity in e-learning systems. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*, CHI EA '16, pages 2984–2991, New York, NY, USA. Association for Computing Machinery.

Alshammari, M. T. (2019). Design and learning effectiveness evaluation of gamification in e-learning systems. *International Journal of Advanced Computer Science and Applications*, 10(9):204–208.

Alshammari, M. T. and Qtaish, A. (2019). Effective adaptive e-learning systems according to learning style and knowledge level. *Journal of Information Technology Education*, 18:529–547.

Alsobhi, A. and Alyoubi, K. (2020). Learning styles and dyslexia types - understanding their relationship and its benefits in adaptive e-learning systems. *International Journal of Interactive Mobile Technologies (iJIM)*, 14(15):25–43.

Alsobhi, A. Y. and Alyoubi, K. H. (2019). Adaptation algorithms for selecting personalised learning experience based on learning style and dyslexia type. *Data Technologies and Applications*, 53(2):189–200.

Alsobhi, A. Y., Khan, N., and Rahanu, H. (2014). Toward linking dyslexia types and symptoms to the available assistive technologies. In *2014 IEEE 14th International Conference on Advanced Learning Technologies*, pages 597–598. IEEE.

Alsobhi, A. Y., Khan, N., and Rahanu, H. (2015a). DAEL framework: A new adaptive e-learning framework for students with dyslexia. *Procedia Computer Science*, 51:1947–1956.

Alsobhi, A. Y., Khan, N., and Rahanu, H. (2015b). Personalised learning materials based on dyslexia types: Ontological approach. *Procedia Computer Science*, 60:113–121.

Alsswey, A., El-Qirem, F. A., and Al Tarawneh, M. H. (2021). Dyslexic Arabic students in the Arab countries: A systematic review of assistive technology progress and recommendations. *International Journal of Early Childhood Special Education*, 13(1):114–120.

Amesbury, L. (2007). Dyslexia: A holistic review of the strengths and difficulties. University of Wolverhampton, Learning and Teaching projects, UK, Wolverhampton.

Anderson, J. R. (2000). *Learning and memory: An integrated approach.* John Wiley & Sons Inc.

Anderson, T. (2004). Towards a theory of online learning. In Anderson, T., editor, *The theory and practice of online learning*, volume 2, pages 109–119.

Anderson, T. (2008). *The theory and practice of online learning.* Athabasca University Press, 2nd edition.

Anjaneyulu, K., Singer, R., and Harding, R. (1998). Usability studies of a remedial multimedia system. *Journal of Educational Multimedia and Hypermedia*, 7(2):207–236.

Annett, M. (1996). Laterality and types of dyslexia. *Neuroscience & Biobehavioral Reviews*, 20(4):631–636.

Araújo, R. D., Brant-Ribeiro, T., Ferreira, H. N., Dorça, F. A., and Cattelan, R. G. (2020). Using learning styles for creating and personalizing educational content in ubiquitous learning environments. *Brazilian Journal of Computers in Education*, 28:133–149.

Ardito, C., Costabile, M. F., Marsico, M. D., Lanzilotti, R., Levialdi, S., Roselli, T., and Rossano, V. (2006). An approach to usability evaluation of e-learning applications. *Universal Access in the Information Society*, 4(3):270–283.

Aroyo, L., Dolog, P., Houben, G., Kravcik, M., Naeve, A., Nilsson, M., and Wild, F. (2006). Interoperability in personalized adaptive learning. *Journal of Educational Technology & Society*, 9(2):4–18.

Arteaga, J. M., , and Pinedo Rivera, D. I. (2018). A process model to develop educational applications for children with dyslexia. In Juárez-Ramírez, R., y Fernández, C. F., García, C. G., Reyes, S. V., Cisneros, J. A., Ríos, B. F., González, H. P., and Jiménez, S., editors, *2018 6th International Conference in Software Engineering Research and Innovation (CONISOFT)*, pages 79–87.

Åsberg, J. and Dahlgren Sandberg, A. (2012). Dyslexic, delayed, precocious or just normal? Word reading skills of children with autism spectrum disorders. *Journal of Research in Reading*, 35(1):20–31.

August, G. J. and Garfinkel, B. D. (1990). Comorbidity of ADHD and reading disability among clinic-referred children. *Journal of Abnormal Child Psychology*, 18(1):29–45.

Ayari, S. (1996). Diglossia and illiteracy in the Arab world. *Language, Culture and Curriculum*, 9(3):243–253.

Bailey, J. E. and Pearson, S. W. (1983). Development of a tool for measuring and analyzing computer user satisfaction. *Management Science*, 29(5):530–545.

Bangor, A., Kortum, P. T., and Miller, J. T. (2008). An empirical evaluation of the system usability scale. *International Journal of Human-Computer Interaction*, 24(6):574–594.

Bao, L. (2006). Theoretical comparisons of average normalized gain calculations. *American Journal of Physics*, 74(10):917–922.

Barańczuk, U. (2019). The five factor model of personality and emotion regulation: A meta-analysis. *Personality and Individual Differences*, 139:217–227.

Bastug, M. (2014). The structural relationship of reading attitude, reading comprehension and academic achievement. *International Journal of Social Sciences and Education*, 4(4):931–946.

Bechtel, W. and Graham, G. (1999). *A companion to cognitive science*. Wiley.

Béland, R. and Mimouni, Z. (2001). Deep dyslexia in the two languages of an Arabic/French bilingual patient. *Cognition*, 82(2):77–126.

Bell, A. (2007). Designing and testing questionnaires for children. *Journal of Research in Nursing*, 12(5):461–469.

Benmarrakchi, F., Kafi, J. E., Elhore, A., and Haie, S. (2017a). Exploring the use of the ICT in supporting dyslexic students' preferred learning styles: A preliminary evaluation. *Education and Information Technologies*, 22:2939–2957.

Benmarrakchi, F. E., Kafi, J. E., and Elhore, A. (2017b). Communication technology for users with specific learning disabilities. *Procedia Computer Science*, 110:258–265.

Benmarrakchi, F. E., Kafi, J. E., and Elhore, A. (2017c). User modeling approach for dyslexic students in virtual learning environments. *International Journal of Cloud Applications and Computing (IJCAC)*, 7(2):1–9.

Benson, A. D. (2002). Using online learning to meet workforce demand: A case study of stakeholder influence. *Quarterly Review of Distance Education*, 3(4):443–452.

Benson, J. and Hocevar, D. (1985). The impact of item phrasing on the validity of attitude scales for elementary school children. *Journal of Educational Measurement*, 22(3):231–240.

Berninger, V. W., Nielsen, K. H., Abbott, R. D., Wijsman, E., and Raskind, W. (2008). Writing problems in developmental dyslexia: Under-recognized and under-treated. *Journal of School Psychology*, 46(1):1–21.

Betts, L. and Hartley, J. (2012). The effects of changes in the order of verbal labels and numerical values on children's scores on attitude and rating scales. *British Educational Research Journal*, 38(2):319–331.

Beynon, M. (2007). Computing technology for learning -in need of a radical new conception. *Journal of Educational Technology & Society*, 10(1):94–106.

Bhatia, T. K. (1983). Literacy in monolingual societies. *Annual Review of Applied Linguistics*, 4:23–38.

Blaźica, B. and Lewis, J. R. (2015). A slovene translation of the system usability scale: The SUS-SI. *International Journal of Human-Computer Interaction*, 31(2):112–117.

Blom, J. (2000). Personalization: A taxonomy. In *Extended Abstracts on Human Factors in Computing Systems*, CHI EA '00, pages 313–314, New York, NY, USA. Association for Computing Machinery.

Boder, E. (1973). Developmental dyslexia: A diagnostic approach based on three atypical reading-spelling patterns. *Developmental Medicine & Child Neurology*, 15(5):663–687.

Bonacina, S., Cancer, A., Lanzi, P. L., Lorusso, M. L., and Antonietti, A. (2015). Improving reading skills in students with dyslexia: The efficacy of a sublexical training with rhythmic background. *Frontiers in Psychology*, 6:1–8.

Bonavita, V. and De Simone, R. (2008). Towards a definition of comorbidity in the light of clinical complexity. *Neurological Sciences*, 29(1):99–102.

Bontcheva, K. (2002). Adaptivity, adaptability, and reading behaviour: Some results from the evaluation of a dynamic hypertext system. In De Bra, P., Brusilovsky, P., and Conejo, R., editors, *Adaptive hypermedia and adaptive web-based systems*, pages 69–78. Springer Berlin Heidelberg.

Borgers, N., de Leeuw, E., and Hox, J. (2000). Children as respondents in survey research: Cognitive development and response quality 1. *Bulletin of Sociological Methodology/Bulletin de Méthodologie Sociologique*, 66(1):60–75.

Boumaraf, A. and Macoir, J. (2016). The influence of visual word form in reading: Single case study of an Arabic patient with deep dyslexia. *Reading and Writing*, 29(1):137–158.

Bransford, J. D., Brown, A. L., and Cocking, R. R. (2000). *How people learn: Brain, mind, experience, and school.* Washington, DC: National Academy Press.

Braun, V. and Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2):77–101.

Brazier, Y. (2020). What to know about dyslexia. *Medical News Today.* Available at `https://www.medicalnewstoday.com/articles/186787`.

Brimo, K., Dinkler, L., Gillberg, C., Lichtenstein, P., Lundstrom, S., and Åsberg Johnels, J. (2021). The co-occurrence of neurodevelopmental problems in dyslexia. *Dyslexia*, 27(3):277–293.

British Dyslexia Association (2010). What is dyslexia? `https://www.bdadyslexia.org.uk/dyslexia/about-dyslexia/what-is-dyslexia`. Accessed October 16, 2021.

Broadhead, M., Daylamani-Zad, D., Mackinnon, L., and Bacon, L. (2018). A multisensory 3D environment as intervention to aid reading in dyslexia: A proposed framework. In *2018 10th International Conference on Virtual Worlds and Games for Serious Applications (VS-Games)*, pages 1–4.

Brooke, J. (1996). SUS-A quick and dirty usability scale. In Jordan, P. W., Thomas, B., McClelland, I. L., and Weerdmeester, B., editors, *Usability evaluation in industry*, pages 189–194.

Brown, E. (2007). *The use of learning styles in adaptive hypermedia.* Doctoral dissertation, University of Nottingham.

Brown, E. J., Brailsford, T. J., Fisher, T., and Moore, A. (2009). Evaluating learning style personalization in adaptive systems: Quantitative methods and approaches. *IEEE Transactions on Learning Technologies*, 2(1):10–22.

Brown, J. S., Collins, A., and Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher*, 18(1):32–42.

Brown, W. E., Eliez, S., Menon, V., Rumsey, J. M., White, C. D., and Reiss, A. L. (2001). Preliminary evidence of widespread morphological variations of the brain in dyslexia. *Neurology*, 56(6):781–783.

Bruner, J. S. (1966). *Toward a theory of instruction.* Harvard University Press.

Brusilovsky, P. (1998). Methods and techniques of adaptive hypermedia. In Brusilovsky, P., Kobsa, A., and Vassileva, J., editors, *Adaptive hypertext and hypermedia*, pages 1–43. Springer Netherlands, Dordrecht.

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

Brusilovsky, P. (2007). Adaptive navigation support. In Brusilovsky, P., Kobsa, A., and Nejdl, W., editors, *The adaptive web: Methods and strategies of web personalization*, pages 263–290. Springer Berlin Heidelberg.

Brusilovsky, P. (2012). Adaptive hypermedia for education and training. In Durlach, P. J. and Lesgold, A. M., editors, *Adaptive technologies for training and education*, volume 46, pages 46–68. Cambridge University Press.

Brusilovsky, P., Eklund, J., and Schwarz, E. (1998). Web-based education for all: A tool for development adaptive courseware. *Computer Networks and ISDN Systems*, 30(1):291–300.

Brusilovsky, P. and Millán, E. (2007). User models for adaptive hypermedia and adaptive educational systems. In Brusilovsky, P., Kobsa, A., and Nejdl, W., editors, *The adaptive web: Methods and strategies of web personalization*, pages 3–53. Springer Berlin Heidelberg.

Bukhari, Y. A., AlOud, A. S., Abughanem, T. A., AlMayah, S. A., Al-Shabib, M. S., and Al-Jaber, S. A. (2016). *Alaikhtibarat altashkhisiat lidhuyi sueubat altaalum fi madatay allughat alarabia wa alriyadiat fi almarhalat alebtidaeiia [Diagnostic tests for people with learning difficulties in the subjects of Arabic language and mathematics at the primary stage].* General Administration for Special Education, The General Administration for Evaluation and Quality of Education, Ministry of Education, Saudi Arabia.

Bunt, A., Carenini, G., and Conati, C. (2007). Adaptive content presentation for the web. In Brusilovsky, P., Kobsa, A., and Nejdl, W., editors, *The adaptive web: Methods and strategies of web personalization*, pages 409–432. Springer Berlin Heidelberg.

Burac, M. and Cruz, J. D. (2020). Development and usability evaluation on individualized reading enhancing application for dyslexia (IREAD): A mobile assistive application. In *IOP Conference Series: Materials Science and Engineering*, volume 803, page 012015. IOP Publishing.

Burke, M. D., Crowder, W., Hagan-Burke, S., and Zou, Y. (2009). A comparison of two path models for predicting reading fluency. *Remedial and Special Education*, 30(2):84–95.

Butterworth, B. and Tang, J. (2004). Dyslexia has a language barrier. `https://www.theguardian.com/education/2004/sep/23/research.highereducation2`. Accessed January 23, 2019.

Cantillon, P., Wood, D. F., and Yardley, S. (2017). *ABC of learning and teaching in medicine.* John Wiley & Sons, 3rd edition.

Carliner, S. (2004). *An overview of online learning.* Human Resource Development Press, 2nd edition.

Carver, C., Howard, R., and Lane, W. (1999). Enhancing student learning through hypermedia courseware and incorporation of student learning styles. *IEEE Transactions on Education*, 42(1):33–38.

Cassidy, S. (2004). Learning styles: An overview of theories, models, and measures. *Educational Psychology*, 24(4):419–444.

Cavender, A., Trewin, S., and Hanson, V. (2008). General writing guidelines for technology and people with disabilities. *ACM SIGACCESS Accessibility and Computing*, (92):17–22.

Cercone, K. (2008). Characteristics of adult learners with implications for online learning design. *Association for the Advancement of Computing in Education (AACE)*, 16(2):137–159.

Chen, C., Keong, M., Teh, C., and Chuah, K. (2015). Learners with dyslexia: Exploring their experiences with different online reading affordances. *Themes in Science and Technology Education*, 8(1):63–79.

Chen, P. and Chih, J. (2011). The relations between learner motivation and satisfaction with management training: An empirical study in Taiwan. *International Journal of Management*, 28(1):77–90.

Chorfi, H. and Jemni, M. (2004). PERSO: Towards an adaptive e-learning system. *Journal of Interactive Learning Research*, 15(4):433–447.

Chrysafiadi, K. and Virvou, M. (2013). Student modeling approaches: A literature review for the last decade. *Expert Systems with Applications*, 40(11):4715–4729.

Clark, R. E. (2001). A summary of disagreements with the "mere vehicles" argument. In Clark, R. E., editor, *Learning from media: Arguments, analysis, and evidence*, pages 125–136. Information Age Publishing.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences.* Lawrence Erlbaum Associates, 2nd edition.

Conrad, D. (2002). Deep in the hearts of learners: Insights into the nature of online community. *Journal of Distance Education*, 17(1):1–19.

Cook, V. (1997). L2 users and English spelling. *Journal of Multilingual and Multicultural Development*, 18(6):474–488.

Cook, V. and Bassetti, B. (2005). Chapter 1: An introduction to researching second language writing systems. In Cook, V. and Bassetti, B., editors, *Second language writing systems*, pages 1–68. Multilingual Matters.

Cope, N., Harold, D., Hill, G., Moskvina, V., Stevenson, J., Holmans, P., Owen, M. J., O'Donovan, M. C., and Williams, J. (2005). Strong evidence that KIAA0319 on chromosome 6p is a susceptibility gene for developmental dyslexia. *The American Journal of Human Genetics*, 76(4):581–591.

Critchley, M. (1968). Developmental dyslexia. *Pediatric Clinics of North America*, 15(3):669–676.

Curry, L. (1983). An organization of learning styles theory and constructs.

Daly III, E. J., Martens, B. K., Kilmer, A., and Massie, D. R. (1996). The effects of instructional match and content overlap on generalized reading performance. *Journal of Applied Behavior Analysis*, 29(4):507–518.

Davis, R. D. and Braun, E. M. (2011). *The gift of dyslexia: Why some of the brightest people can't read and how they can learn.* Souvenir Press.

De Bra, P. (2008). Adaptive hypermedia. In Adelsberger, H. H., Kinshuk, Pawlowski, J. M., and Sampson, D. G., editors, *Handbook on information technologies for education and training*, pages 29–46. Springer.

De Bra, P. and Ruiter, J. (2001). AHA! adaptive hypermedia for all. In *WebNet*, pages 262–268. Citeseer.

De Leeuw, E. and Otter, M. E. (1995). The reliability of children's responses to questionnaire items; question effects in children's questionnaire data. In Hox, J., van der Meulen, B., Janssens, J., ter Laak, J., and Tavecchio, L., editors, *Advances in family research*, pages 251–258. Amsterdam: Thesis Publishers.

de Quirós, J. B. and Schrager, O. L. (1978). *Neuropsychological fundamentals in learning disabilities.* Academic Therapy Publications.

Delone, W. H. and McLean, E. R. (2003). The DeLone and McLean model of information systems success: A ten-year update. *Journal of Management Information Systems*, 19(4):9–30.

Dix, A., Finlay, J., Abowd, G. D., and Beale, R. (2003). *Human-computer interaction.* Pearson Education, 3rd edition.

Dolgin, A. B. (1975). How to match reading materials to student reading levels. *The Social Studies*, 66(6):249–252.

Domínguez, A., Saenz-de-Navarrete, J., de Marcos, L., Fernández-Sanz, L., Pagés, C., and Martínez-Herráiz, J. (2013). Gamifying learning experiences: Practical implications and outcomes. *Computers & Education*, 63:380–392.

Downes, S. (2008). Places to go: Connectivism & connective knowledge. *Innovate: Journal of Online Education*, 5(1):1–6.

Draffan, E. (2002). Dyslexia and technology. In Lawrie Phipps, A. S. and Seale, J., editors, *Access all areas: Disability, technology and learning*, pages 24–48. TechDis with the Association for Learning Technology.

Driscoll, M. (2002). Blended learning: Let's get beyond the hype. *E-Learning*, 1(4):1–4.

Duffy, T. M. and Cunningham, D. J. (1996). Constructivism: Implications for the design and delivery of instruction. In Jonassen, D. H., editor, *Handbook of research for educational communications and technology*, pages 170–198. Citeseer.

Dulude, L. (2012). Writing systems, phonemic awareness, and bilingualism: Cross-linguistic issues in dyslexia. *Indiana University Undergraduate Journal of Cognitive Science*, 7:22–30.

Eden, G. F. (2016). Early identification and treatment of dyslexia a brain-based perspective. *Perspectives on Language and Literacy*, 42(1):7–9.

Edwards, H. and Benedyk, R. (2007). A comparison of usability evaluation methods for child participants in a school setting. In *Proceedings of the 6th International Conference on Interaction Design and Children*, IDC '07, pages 9–16, New York, NY, USA. Association for Computing Machinery.

Ehri, L. C. (2005). Learning to read words: Theory, findings, and issues. *Scientific Studies of Reading*, 9(2):167–188.

El Bachari, E., Abelwahed, E. H., and El Adnani, M. (2011). E-learning personalization based on dynamic learners' preference. *International Journal of Computer Science & Information Technology*, 3(3):200–216.

El Fazazi, H., Elgarej, M., Qbadou, M., and Mansouri, K. (2021). Design of an adaptive e-learning system based on multi-agent approach and reinforcement learning. *Engineering, Technology & Applied Science Research*, 11(1):6637–6644.

El Kah, A. and Lakhouaja, A. (2015). Arabic learning disabilities in public primary schools: The case of east side of Morocco. In *2015 5th International Conference on Information Communication Technology and Accessibility (ICTA)*, pages 1–5.

El Kah, A. and Lakhouaja, A. (2018). Developing effective educative games for Arabic children primarily dyslexics. *Education and Information Technologies*, 23(6):2911–2930.

Elbeheri, G. (2004). Dyslexia in Egypt. In Smythe, I., Everatt, J., and Salter, R., editors, *The International book of dyslexia: A guide to practice and resources*, pages 79–85. Wileys.

Elbeheri, G. (2005). Dyslexia in Egypt. In Smythe, I., editor, *Provision and use of information technology with dyslexic students in university in Europe*, pages 136–144.

Elbeheri, G. and Everatt, J. (2007). Literacy ability and phonological processing skills amongst dyslexic and non-dyslexic speakers of Arabic. *Reading and Writing*, 20:273–294.

Elbeheri, G., Everatt, J., Mahfoudhi, A., Abu Al-Diyar, M., and Taibah, N. (2011). Orthographic processing and reading comprehension among Arabic speaking mainstream and LD children. *Dyslexia*, 17(2):123–142.

Elbeheri, G., Everatt, J., Reid, G., and Mannai, H. a. (2006). Dyslexia assessment in Arabic. *Journal of Research in Special Educational Needs*, 6(3):143–152.

EL_Rahman, S. A. (2021). A game-based learning for teaching Arabic letters to dyslexic and deaf children. In Al-Emran, M., Shaalan, K., and Hassanien, A. E., editors, *Recent advances in intelligent systems and smart applications*, pages 337–361. Springer International Publishing, Cham.

Ertmer, P. A. and Newby, T. J. (1993). Behaviorism, cognitivism, constructivism: Comparing critical features from an instructional design perspective. *Performance Improvement Quarterly*, 6(4):50–72.

Essalmi, F., Ayed, L. J. B., Jemni, M., Kinshuk, and Graf, S. (2010). A fully personalization strategy of e-learning scenarios. *Computers in Human Behavior*, 26(4):581–591.

Everatt, J., Weeks, S., and Brooks, P. (2008). Profiles of strengths and weaknesses in dyslexia and other learning difficulties. *Dyslexia*, 14(1):16–41.

Evers, V., Cramer, H., van Someren, M., and Wielinga, B. (2010). Interacting with adaptive systems. In Babuška, R. and Groen, F. C. A., editors, *Interactive collaborative information systems*, pages 299–325. Springer.

Exley, S. (2003). The effectiveness of teaching strategies for students with dyslexia based on their preferred learning styles. *British Journal of Special Education*, 30(4):213–220.

Feigh, K. M., Dorneich, M. C., and Hayes, C. C. (2012). Toward a characterization of adaptive systems: A framework for researchers and system designers. *Human Factors*, 54(6):1008–1024.

Felder, R. M. and Silverman, L. K. (1988). Learning and teaching styles in engineering education. *Engineering Education*, 78(7):674–681.

Fiez, J. A. and Petersen, S. E. (1998). Neuroimaging studies of word reading. *Proceedings of the National Academy of Sciences*, 95(3):914–921.

Finstad, K. (2010). The usability metric for user experience. *Interacting with Computers*, 22(5):323–327.

Fitzpatrick, J., Sanders, J., and Worthen, B. (2015). *Program evaluation: Alternative approaches and practical guidelines*. Vital Source (for Pearson), 4th edition.

Fostick, L., Eshcoly, R., Shtibelman, H., Nehemia, R., and Levi, H. (2014). Efficacy of temporal processing training to improve phonological awareness among dyslexic and normal reading students. *Journal of Experimental Psychology: Human Perception and Performance*, 40(5):1799–1807.

Fredricks, J. A., Blumenfeld, P. C., and Paris, A. H. (2004). School engagement: Potential of the concept, state of the evidence. *Review of Educational Research*, 74(1):59–109.

Friedmann, N. and Coltheart, M. (2016). Types of developmental dyslexia. In Bar-On, A. and Ravid, D., editors, *Handbook of communication disorders: Theoretical, empirical, and applied linguistics perspectives*, pages 1–37. De Gruyter Mouton, Berlin, Boston.

Friedmann, N. and Haddad-Hanna, M. (2014). Types of developmental dyslexia in Arabic. In Saiegh-Haddad, E. and Joshi, R. M., editors, *Handbook of Arabic literacy: Insights and perspectives*, pages 119–151. Springer Netherlands, Dordrecht.

Fritz, C. O., Morris, P. E., and Richler, J. J. (2012). Effect size estimates: Current use, calculations, and interpretation. *Journal of Experimental Psychology: General*, 141(1):2–18.

Gaggi, O., Palazzi, C. E., Ciman, M., Galiazzo, G., Franceschini, S., Ruffino, M., Gori, S., and Facoetti, A. (2017). Serious games for early identification of developmental dyslexia. *Computers in Entertainment*, 15(2).

Gal, Y. (2002). An HMM approach to vowel restoration in Arabic and Hebrew. In *Proceedings of the ACL-02 Workshop on Computational Approaches to Semitic Languages*, pages 1–7.

Gatian, A. W. (1994). Is user satisfaction a valid measure of system effectiveness? *Information & Management*, 26(3):119–131.

Gauch, S., Speretta, M., Chandramouli, A., and Micarelli, A. (2007). User profiles for personalized information access. In Brusilovsky, P., Kobsa, A., and Nejdl, W., editors, *The adaptive web: Methods and strategies of web personalization*, pages 54–89. Springer Berlin Heidelberg.

Gena, C. (2005). Methods and techniques for the evaluation of user-adaptive systems. *The Knowledge Engineering Review*, 20(1):1–37.

Gena, C. and Ardissono, L. (2004). Intelligent support to the retrieval of information about hydric resources. In De Bra, P. and Nejdl, W., editors, *Adaptive hypermedia and adaptive web-based systems*, pages 126–135. Springer Berlin Heidelberg.

Gena, C. and Weibelzahl, S. (2007). Usability engineering for the adaptive web. In Brusilovsky, P., Kobsa, A., and Nejdl, W., editors, *The adaptive web: Methods and strategies of web personalization*, pages 720–762. Springer Berlin Heidelberg.

Ghaban, W. (2021). Can games and gamification improve online learners' outcomes and satisfaction on the Madrasati platform in Saudi Arabia? In Fang, X., editor, *HCI in games: Serious and immersive games*, pages 189–200, Cham. Springer International Publishing.

Ghaban, W. and Hendley, R. (2018). Investigating the interaction between personalities and the benefit of gamification. In *Proceedings of the 32nd International BCS Human-Computer Interaction Conference 32*, pages 1–13.

Ghaban, W. and Hendley, R. (2020). Can we predict the best gamification elements for a user based on their personal attributes? In Fang, X., editor, *HCI in games*, pages 58–75, Cham. Springer International Publishing.

Ghaban, W. H. (2019). *Adapting gamification elements to learners' personalities.* Doctoral dissertation, University of Birmingham.

Ghasemi, A. and Zahediasl, S. (2012). Normality tests for statistical analysis: A guide for non-statisticians. *International Journal of Endocrinology and Metabolism*, 10(2):486–489.

Gholamain, M. and Geva, E. (1999). Orthographic and cognitive factors in the concurrent development of basic reading skills in English and Persian. *Language Learning*, 49(2):183–217.

Gillberg, C. (2010). The essence in child psychiatry: Early symptomatic syndromes eliciting neurodevelopmental clinical examinations. *Research in Developmental Disabilities*, 31(6):1543–1551.

Glazzard, J. (2010). The impact of dyslexia on pupils' self-esteem. *Support for Learning*, 25(2):63–69.

Goldie, J. G. S. (2016). Connectivism: A knowledge learning theory for the digital age? *Medical Teacher*, 38(10):1064–1069.

Gooch, D., Hulme, C., Nash, H. M., and Snowling, M. J. (2014). Comorbidities in preschool children at family risk of dyslexia. *Journal of Child Psychology and Psychiatry*, 55(3):237–246.

Gooch, D., Vasalou, A., Benton, L., and Khaled, R. (2016). Using gamification to motivate students with dyslexia. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*, CHI '16, pages 969–980, New York, NY, USA. Association for Computing Machinery.

Goswami, U. (2002). Phonology, reading development, and dyslexia: A cross-linguistic perspective. *Annals of Dyslexia*, 52(1):139–163.

Gray, D. E. (2014). *Doing research in the real world*. Sage Publications Limited, 3rd edition.

Griffiths, Y. and Stuart, M. (2013). Reviewing evidence-based practice for pupils with dyslexia and literacy difficulties. *Journal of Research in Reading*, 36(1):96–116.

Guardiola, J. G. (2001). The evolution of research on dyslexia. *Anuario de psicologia*, 32(1):3–30.

Habib, M., Rey, V., Daffaure, V., Camps, R., Espesser, R., Joly-Pottuz, B., and Demonet, J. (2002). Phonological training in children with dyslexia using temporally modified speech: A three-step pilot investigation. *International Journal of Language & Communication Disorders*, 37(3):289–308.

Hamidi, H. and Chavoshi, A. (2018). Analysis of the essential factors for the adoption of mobile learning in higher education: A case study of students of the University of Technology. *Telematics and Informatics*, 35(4):1053–1070.

Hannula-Jouppi, K., Kaminen-Ahola, N., Taipale, M., Eklund, R., Nopola-Hemmi, J., Kääriäinen, H., and Kere, J. (2005). The axon guidance receptor gene ROBO1 is a candidate gene for developmental dyslexia. *PLoS Genetics*, 1(4):467–474.

Hariyanto, D. and Köhler, T. (2020). A web-based adaptive e-learning application for engineering students: An expert-based evaluation. *International Journal of Engineering Pedagogy*, 10(2):60–71.

Harrati, N., Bouchrika, I., Tari, A., and Ladjailia, A. (2016). Exploring user satisfaction for e-learning systems via usage-based metrics and system usability scale analysis. *Computers in Human Behavior*, 61:463–471.

Hauger, D. and Köck, M. (2007). State of the art of adaptivity in e-learning platforms. In *LWA 2007 Lernen - Wissen - Adaption: Workshop at Adaptivity and User Modeling in Interactive Systems*, pages 355–360.

Helland, T. and Kaasa, R. (2005). Dyslexia in English as a second language. *Dyslexia*, 11(1):41–60.

Holmes, B. and Gardner, J. (2006). *E-Learning: Concepts and practice*. SAGE.

Hung, S., Yu, W., Liou, K., and Hsu, S. (2009). Exploring e-learning effectiveness based on activity theory: An example of asynchronous distance learning. *MIS Review: An International Journal*, 15(1):63–87.

International Organization for Standardization (1998). *ISO 9241-11: Ergonomic requirements for office work with visual display terminals (VDTs): Part 11: Guidance on usability*. 1st edition.

Isaksen, S. G., Lauer, K. J., and Wilson, G. V. (2003). An examination of the relationship between personality type and cognitive style. *Creativity Research Journal*, 15(4):343–354.

Jameson, A. (2007). Adaptive interfaces and agents. In Sears, A. and Jacko, J. A., editors, *The human-computer interaction handbook: Fundamentals, evolving technologies and emerging applications*, pages 433–458. CRC Press, 2nd edition.

Johansson, B. B. (2006). Cultural and linguistic influence on brain organization for language and possible consequences for dyslexia: A review. *Annals of Dyslexia*, 13:13–50.

Johnels, J. Å., Gillberg, C., and Kopp, S. (2019). A hyperlexic-like reading style is associated with increased autistic features in girls with ADHD. *Journal of Attention Disorders*, 23(8):767–776.

Jonassen, D. H. (1991). Objectivism versus constructivism: Do we need a new philosophical paradigm? *Educational Technology Research and Development*, 39:5–14.

Jones, M. (2015). *Dyslexia explained.* Nessy Learning UK.

Jung, H. (2014). Ubiquitous learning: Determinants impacting learners' satisfaction and performance with smartphones. *Language learning & technology*, 18(3):97–119.

Kamala, R. (2014). Multisensory approach to reading skills of dyslexic students. *IOSR Journal Of Humanities and Social Science*, 19(5):32–34.

Kangas, M., Siklander, P., Randolph, J., and Ruokamo, H. (2017). Teachers' engagement and students' satisfaction with a playful learning environment. *Teaching and Teacher Education*, 63:274–284.

Karadimitriou, S. M., Marshall, E., and Knox, C. (2018). Mann-Whitney U test. *Sheffield: Sheffield Hallam University.*

Karolyi, C., Winner, E., Gray, W., and Sherman, G. F. (2003). Dyslexia linked to talent: Global visual-spatial ability. *Brain and Language*, 85(3):427–431.

Katzir, T., Shaul, S., Breznitz, Z., and Wolf, M. (2004). The universal and the unique in dyslexia: A cross-linguistic investigation of reading and reading fluency in Hebrew-and English-speaking children with reading disorders. *Reading and Writing*, 17:739–768.

Keller, J. M. (1987). Development and use of the ARCS model of instructional design. *Journal of Instructional Development*, 10(2):2–10.

Kerwin, M. A. (1981). Student involvement as a dimension of the student-perceived teaching behavior of post secondary educators. *Adult Education*, 31(2):85–92.

Klašnja-Milićević, A., Vesin, B., Ivanović, M., and Budimac, Z. (2011). E-learning personalization based on hybrid recommendation strategy and learning style identification. *Computers & Education*, 56(3):885–899.

Knoop-van Campen, C. A. N., Segers, E., and Verhoeven, L. (2018). The modality and redundancy effects in multimedia learning in children with dyslexia. *Dyslexia*, 24(2):140–155.

Knowles, E. and Kerkman, D. (2007). An investigation of students attitude and motivation toward online learning. *InSight: A Collection of Faculty Scholarship*, 2:70–80.

Knutov, E. (2012). *Generic adaptation framework for unifying adaptive web-based systems.* Doctoral dissertation, Eindhoven University of Technology.

Kobsa, A., Koenemann, J., and Pohl, W. (2001). Personalised hypermedia presentation techniques for improving online customer relationships. *The Knowledge Engineering Review*, 16(2):111–155.

Kop, R. and Hill, A. (2008). Connectivism: Learning theory of the future or vestige of the past? *International Review of Research in Open and Distributed Learning*, 9(3):1–13.

Kozlowski, S. W., Gully, S. M., Brown, K. G., Salas, E., Smith, E. M., and Nason, E. R. (2001). Effects of training goals and goal orientation traits on multidimensional training outcomes and performance adaptability. *Organizational Behavior and Human Decision Processes*, 85(1):1–31.

Krupska, M. and Klein, C. (1995). *Demystifying dyslexia raising awareness and developing support for dyslexic people and adults.* London Language & Literacy Unit.

Kuo, Y., Walker, A. E., Belland, B. R., and Schroder, K. E. E. (2013). A predictive study of student satisfaction in online education programs. *International Review of Research in Open and Distributed Learning*, 14(1):16–39.

LaFrance, E. D. B. (1997). The gifted/dyslexic child: Characterizing and addressing strengths and weaknesses. *Annals of Dyslexia*, 47(1):163–182.

Lam, Y. J. and Wong, A. (1974). Attendance regularity of adult learners: An examination of content and structural factors. *Adult Education*, 24(2):130–142.

Landerl, K. and Moll, K. (2010). Comorbidity of learning disorders: Prevalence and familial transmission. *Journal of Child Psychology and Psychiatry*, 51(3):287–294.

Larsen, J. P., Høien, T., Lundberg, I., and Ødegaard, H. (1990). MRI evaluation of the size and symmetry of the planum temporale in adolescents with developmental dyslexia. *Brain and Language*, 39(2):289–301.

Layes, S., Guendouz, M., Lalonde, R., and Rebaï, M. (2020). Combined phonological awareness and print knowledge training improves reading accuracy and comprehension in children with reading disabilities. *International Journal of Disability, Development and Education*, 69(4):1185–1199.

Layes, S., Lalonde, R., Mecheri, S., and Rebaï, M. (2015a). Phonological and cognitive reading related skills as predictors of word reading and reading comprehension among Arabic dyslexic children. *Psychology*, 6(1):20–38.

Layes, S., Lalonde, R., and Rebaï, M. (2015b). Reading speed and phonological awareness deficits among Arabic-speaking children with dyslexia. *Dyslexia*, 21(1):80–95.

Layes, S., Lalonde, R., and Rebaï, M. (2019). Effects of an adaptive phonological training program on reading and phonological processing skills in Arabic-speaking children with dyslexia. *Reading & Writing Quarterly*, 35(2):103–117.

Lerga, R., Candrlic, S., and Jakupovic, A. (2021). A review on assistive technologies for students with dyslexia. In *Proceedings of the 13th International Conference on Computer Supported Education (CSEDU 2021)*, volume 2, pages 64–72.

Lerner, J. W. (1989). Educational interventions in learning disabilities. *Journal of the American Academy of Child & Adolescent Psychiatry*, 28(3):326–331.

Lexercise (2016). Dyslexia test - online from Lexercise. `https://www.lexercise.com/tests/dyslexia-test`. Accessed August 02, 2022.

Liaw, S., Huang, H., and Chen, G. (2007). An activity-theoretical approach to investigate learners' factors toward e-learning systems. *Computers in Human Behavior*, 23(4):1906–1920.

Lin, B. and Hsieh, C. (2001). Web-based teaching and learner control: A research review. *Computers & Education*, 37(3):377–386.

Linn, M. C. (1996). Cognition and distance learning. *Journal of the American Society for Information Science*, 47(11):826–842.

Lipka, O., Siegel, L. S., and Vukovic, R. (2005). The literacy skills of English language learners in Canada. *Learning Disabilities Research & Practice*, 20(1):39–49.

Lo, Y., Cooke, N. L., and Starling, A. L. P. (2011). Using a repeated reading program to improve generalization of oral reading fluency. *Education and Treatment of Children*, 34(1):115–140.

Lyon, G. R., Shaywitz, S. E., and Shaywitz, B. A. (2003). A definition of dyslexia. *Annals of Dyslexia*, 53(1):1–14.

MacFarlane, S., Sim, G., and Horton, M. (2005). Assessing usability and fun in educational software. In *Proceedings of the 2005 Conference on Interaction Design and Children*, IDC '05, pages 103–109, New York, NY, USA. Association for Computing Machinery.

Magnisalis, I., Demetriadis, S., and Karakostas, A. (2011). Adaptive and intelligent systems for collaborative learning support: A review of the field. *IEEE Transactions on Learning Technologies*, 4(1):5–20.

Mahdavi, I., Fazlollaht, H., Heidarzade, A., Mahdavi-Am, N., and Rooshan, Y. (2008). A heuristic methodology for multi-criteria evaluation of web-based e-learning systems based on user satisfaction. *Journal of Applied Sciences*, 8(24):4603–4609.

Mahfoudhi, A., Everatt, J., and Elbeheri, G. (2011). Introduction to the special issue on literacy in Arabic. *Reading and Writing*, 24:1011–1018.

Makhoul, B. (2017). Moving beyond phonological awareness: The role of phonological awareness skills in Arabic reading development. *Journal of Psycholinguistic Research*, 46:469–480.

Maravanyika, M., Dlodlo, N., and Jere, N. (2017). An adaptive recommender-system based framework for personalised teaching and learning on e-learning platforms. In *2017 IST-Africa Week Conference*, pages 1–9.

Martelli, M., De Luca, M., Lami, L., Pizzoli, C., Pontillo, M., Spinelli, D., and Zoccolotti, P. (2014). Bridging the gap between different measures of the reading speed deficit in developmental dyslexia. *Experimental Brain Research*, 232(1):237–252.

Martins, A. C., Faria, L., De Carvalho, C. V., and Carrapatoso, E. (2008). User modeling in adaptive hypermedia educational systems. *Journal of Educational Technology & Society*, 11(1):194–207.

Mastropavlou, M. and Zakopoulou, V. (2013). Integrated intelligent LEARNing environment for reading and writing D3. 2- learning strategies specification report. *Work*, 4:1–40.

Mayer, R. E. (1997). Multimedia learning: Are we asking the right questions? *Educational Psychologist*, 32(1):1–19.

Mayer, R. E. (1999). Designing instruction for constructivist learning. In Reigeluth, C. M. and Carr-Chellman, A. A., editors, *Instructional-design theories and models: A new paradigm of instructional theory*, volume 2, pages 141–161. Lawrence Erlbaum Associates.

Mayer, R. E. and Moreno, R. (2002). Aids to computer-based multimedia learning. *Learning and Instruction*, 12(1):107–119.

McConaughy, S. H. (1978). Word recognition and word meaning in the total reading process. *Language Arts*, 55(8):946–1003.

McCrae, R. R. and Costa, P. T. (2003). *Personality in adulthood: A five-factor theory perspective*. Guilford Press.

McGrath, L. M., Smith, S. D., and Pennington, B. F. (2006). Breakthroughs in the search for dyslexia candidate genes. *Trends in Molecular Medicine*, 12(7):333–341.

Mee, M. (1998). Assessment and remediation techniques for dyslexics. *The English Teacher*, XXVIII:1–10.

Melis, E., Andres, E., Büdenbender, J., Frischauf, A., Goguadze, G., Libbrecht, P., Pollet, M., and Ullrich, C. (2001). ActiveMath: A generic and adaptive web-based learning environment. *International Journal of Artificial Intelligence in Education (IJAIED)*, 12(4):385–407.

Meng, H., Smith, S. D., Hager, K., Held, M., Liu, J., Olson, R. K., Pennington, B. F., DeFries, J. C., Gelernter, J., OŔeilly-Pol, T., Somlo, S., Skudlarski, P., Shaywitz, S. E., Shaywitz, B. A., Marchione, K., Wang, Y., Paramasivam, M., LoTurco, J. J., Page, G. P., and Gruen, J. R. (2005). DCDC2 is associated with reading disability and modulates neuronal development in the brain. *Proceedings of the National Academy of Sciences*, 102(47):17053–17058.

Mergel, B. (1998). Instructional design and learning theory. In educational communications and technology. University of Saskatchewan.

Miles, E. (2000). Dyslexia may show a different face in different languages. *Dyslexia*, 6(3):193–201.

Miller-Shaul, S. (2005). The characteristics of young and adult dyslexics readers on reading and reading related cognitive tasks as compared to normal readers. *Dyslexia*, 11(2):132–151.

Mishra, R. and Stainthorp, R. (2007). The relationship between phonological awareness and word reading accuracy in Oriya and English: A study of Oriya-speaking fifth-graders. *Journal of Research in Reading*, 30(1):23–37.

Mitrovic, A. (2003). An intelligent SQL tutor on the web. *International Journal of Artificial Intelligence in Education (IJAIED)*, 13(2-4):173–197.

Mohssine, B., Mohammed, A., Abdelwahed, N., and Mohammed, T. (2021). Adaptive help system based on learners 'digital traces' and learning styles. *International Journal of Emerging Technologies in Learning (iJET)*, 16:288–294.

Moodle (2021). Statistics. `https://stats.moodle.org/`. Accessed November 30, 2021.

Moore, J. L., Dickson-Deane, C., and Galyen, K. (2011). e-Learning, online learning, and distance learning environments: Are they the same? *The Internet and Higher Education*, 14(2):129–135.

Moore, M. G. (1989). Editorial: Three types of interaction. *The American Journal of Distance Education*, 3(2):1–7.

Motti, V. G. and Vanderdonckt, J. (2013). A computational framework for context-aware adaptation of user interfaces. In *IEEE 7th International Conference on Research Challenges in Information Science (RCIS)*, pages 1–12.

Mulwa, C., Lawless, S., Sharp, M., and Wade, V. (2011). The evaluation of adaptive and personalised information retrieval systems: A review. *International Journal of Knowledge and Web Intelligence*, 2(2-3):138–156.

Mustafa, Y. E. A. and Sharif, S. M. (2011). An approach to adaptive e-learning hypermedia system based on learning styles (AEHS-LS): Implementation and evaluation. *International Journal of Library and Information Science*, 3(1):15–28.

Naidu, S. (2005). Evaluating the usability of educational websites for children. *Usability News*, 7(2):1–7.

National Health Service (2018a). Management dyslexia. `https://www.nhs.uk/conditions/dyslexia/living-with/`. Accessed December 12, 2021.

National Health Service (2018b). Overview dyslexia. `https://www.nhs.uk/conditions/dyslexia/#what-are-the-signs-of-dyslexia`. Accessed October 24, 2018.

National Health Service (2021). Symptoms. `https://www.nhs.uk/conditions/dyslexia/symptoms/`. Accessed October 18, 2021.

Nguyen, L. and Do, P. (2008). Learner model in adaptive learning. *World Academy of Science, Engineering and Technology*, 45(70):395–400.

Nielsen, R. D., Ward, W., and Martin, J. H. (2008). Automatic generation of fine-grained representations of learner response semantics. In *International Conference on Intelligent Tutoring Systems*, pages 173–183. Springer.

Nissen, J. M., Talbot, R. M., Nasim Thompson, A., and Van Dusen, B. (2018). Comparison of normalized gain and Cohen's d for analyzing gains on concept inventories. *Physical Review Physics and Education Research*, 14:010115.

Nist, L. and Joseph, L. M. (2008). Effectiveness and efficiency of flashcard drill instructional methods on urban first-graders' word recognition, acquisition, maintenance, and generalization. *School Psychology Review*, 37(3):294–308.

Noor, N. M. M., Mohemad, R., Mamat, N. F. A., FatihahYahya, W. F., Rifin, M. A. S. M., Hassan, M. N., and Hamzah, M. P. (2017). Teaching and learning module on learning disabilities (LD) using RFID technology. *International Journal of Learning and Teaching*, 3(4):251–258.

Nordqvist, C. (2017). What you need to know about dyslexia. *Medical News Today. Retrieved from https://www. medicalnewstoday. com/articles/186787.php.*

Oblinger, D. and Oblinger, J. L. (2005). *Educating the net generation.* EDUCAUSE.

Ohene-Djan, J. and Gorle, M. (2003). An adaptive function for hypermedia-based advanced learning technology. In *Proceedings 3rd IEEE International Conference on Advanced Technologies*, page 464.

Olson, R. K. (2002). Dyslexia: Nature and nurture. *Dyslexia*, 8(3):143–159.

Orfanou, K., Tselios, N., and Katsanos, C. (2015). Perceived usability evaluation of learning management systems: Empirical evaluation of the system usability scale. *The International Review of Research in Open and Distributed Learning*, 16(2):227–246.

Ostrolenk, A., Forgeot dArc, B., Jelenic, P., Samson, F., and Mottron, L. (2017). Hyperlexia: Systematic review, neurocognitive modelling, and outcome. *Neuroscience & Biobehavioral Reviews*, 79:134–149.

Ouherrou, N., Elhammoumi, O., Benmarrakchi, F., and Kafi, J. E. (2018). A heuristic evaluation of an educational game for children with dyslexia. In *2018 IEEE 5th International Congress on Information Science and Technology (CiSt)*, pages 386–390.

Pal, D. and Vanijja, V. (2020). Perceived usability evaluation of Microsoft Teams as an online learning platform during COVID-19 using system usability scale and technology acceptance model in India. *Children and Youth Services Review*, 119:1–12.

Pallant, J. (2011). *SPSS survival manual a step by step guide to data analysis using SPSS for Windows.* McGraw-Hill Education, 3rd edition.

Pang, L. and Jen, C. C. (2018). Inclusive dyslexia-friendly collaborative online learning environment: Malaysia case study. *Education and Information Technologies*, 23(3):1023–1042.

Panigrahi, R., Srivastava, P. R., and Sharma, D. (2018). Online learning: Adoption, continuance, and learning outcome - a review of literature. *International Journal of Information Management*, 43:1–14.

Papanikolaou, K. A., Grigoriadou, M., Kornilakis, H., and Magoulas, G. D. (2003). Personalizing the interaction in a web-based educational hypermedia system: The case of INSPIRE. *User Modeling and User-Adapted Interaction*, 13(3):213–267.

Paramythis, A. and Loidl-Reisinger, S. (2003). Adaptive learning environments and e-learning standards. In *2nd European Conference on E-learning*, volume 1, pages 369–379.

Paramythis, A., Weibelzahl, S., and Masthoff, J. (2010). Layered evaluation of interactive adaptive systems: Framework and formative methods. *User Modeling and User-Adapted Interaction*, 20(5):383–453.

Paredes, P. and Rodriguez, P. (2002). Considering sensing-intuitive dimension to exposition-exemplification in adaptive sequencing. In De Bra, P., Brusilovsky, P., and Conejo, R., editors, *Adaptive hypermedia and adaptive web-based systems*, pages 556–559. Springer Berlin Heidelberg.

Parhiala, P., Torppa, M., Eklund, K., Aro, T., Poikkeus, A.-M., Heikkila, R., and Ahonen, T. (2015). Psychosocial functioning of children with and without dyslexia: A follow-up study from ages four to nine. *Dyslexia*, 21(3):197–211.

Paulesu, E., Démonet, J.-F., Fazio, F., McCrory, E., Chanoine, V., Brunswick, N., Cappa, S. F., Cossu, G., Habib, M., Frith, C. D., and Frith, U. (2001). Dyslexia: Cultural diversity and biological unity. *Science*, 291(5511):2165–2167.

Peres, S. C., Pham, T., and Phillips, R. (2013). Validation of the system usability scale (SUS): SUS in the wild. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 57(1):192–196.

Peterson, R. L. and Pennington, B. F. (2015). Developmental dyslexia. *Annual Review of Clinical Psychology*, 11:283–307.

Peterson, R. L., Pennington, B. F., Shriberg, L. D., and Boada, R. (2009). What influences literacy outcome in children with speech sound disorder? *Journal of Speech, Language, and Hearing Research*, 52(5):1175–1188.

Petrie, H., Weber, G., and Fisher, W. (2005). Personalization, interaction, and navigation in rich multimedia documents for print-disabled users. *IBM Systems Journal*, 44(3):629–635.

Pickering, J. D. (2017). Measuring learning gain: Comparing anatomy drawing screencasts and paper-based resources. *Anatomical Sciences Education*, 10(4):307–316.

Pirani, Z., Molvizadah, V., Sayyed, M. A., and Sasikumar, M. (2013). E-learning framework for learning disabled children. *International Journal of Computer Applications*, 63(19):38–42.

Putnam, C., Puthenmadom, M., Cuerdo, M. A., Wang, W., and Paul, N. (2020). Adaptation of the system usability scale for user testing with children. In *Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems*, CHI EA '20, pages 1–7, New York, NY, USA. Association for Computing Machinery.

Rauschenberger, M., Baeza-Yates, R., and Rello, L. (2019). Technologies for dyslexia. In Yesilada, Y. and Harper, S., editors, *Web accessibility: A foundation for research*, pages 603–627. Springer London.

Read, J. C. (2008). Validating the fun toolkit: An instrument for measuring children's opinions of technology. *Cognition, Technology & Work*, 10(2):119–128.

Read, J. C. and MacFarlane, S. (2006). Using the fun toolkit and other survey methods to gather opinions in child computer interaction. In *Proceedings of the 2006 Conference on Interaction Design and Children*, IDC '06, pages 81–88, New York, NY, USA. Association for Computing Machinery.

Read, J. C., MacFarlane, S., and Casey, C. (2002). Endurability, engagement and expectations: Measuring children's fun. In *Interaction design and children*, volume 2, pages 1–23. Shaker Publishing Eindhoven.

Reid, Gavin (2015). Dyslexia: Teaching approaches. `https://www.drgavinreid.com/free-resources/dyslexia-teaching-approaches/`. Accessed February 08, 2020.

Rello, L., Ballesteros, M., and Bigham, J. P. (2015). A spellchecker for dyslexia. In *Proceedings of the 17th International ACM SIGACCESS Conference on Computers & Accessibility*, pages 39–47, New York, NY, USA. Association for Computing Machinery.

Rello, L., Macias, A., Herrera, M., de Ros, C., Romero, E., and Bigham, J. P. (2017). DytectiveU: A game to train the difficulties and the strengths of children with dyslexia. In *Proceedings of the 19th International ACM SIGACCESS Conference on Computers & Accessibility*, pages 319–320, New York, NY, USA. Association for Computing Machinery.

Rello, L., Romero, E., Rauschenberger, M., Ali, A., Williams, K., Bigham, J. P., and White, N. C. (2018). Screening dyslexia for English using HCI measures and machine learning. In *Proceedings of the 2018 International Conference on Digital Health*, DH '18, pages 80–84, New York, NY, USA. Association for Computing Machinery.

Riding, R. and Rayner, S. (1998). *Cognitive styles and learning strategies: Understanding style differences in learning and behavior.* David Fulton Publishers, 1st edition.

Rodrigues, H., Almeida, F., Figueiredo, V., and Lopes, S. L. (2019). Tracking e-learning through published papers: A systematic review. *Computers & Education*, 136:87–98.

Rose, S. J. (2009). *Identifying and teaching children and young people with dyslexia and literacy difficulties: An independent report from Sir Jim Rose to the Secretary of State for Children, Schools and Families.* Department for Children, Schools and Families.

Russell, G., Ryder, D., Norwich, B., and Ford, T. (2015). Behavioural difficulties that co-occur with specific word reading difficulties: A UK population- based cohort study. *Dyslexia*, 21(2):123–141.

Sasupilli, M., Bokil, P., and Wagle, P. (2019). Designing a learning aid for dyslexic children. In Chakrabarti, A., editor, *Research into design for a connected world*, pages 703–712. Springer Singapore.

Sauro, J. and Lewis, J. R. (2011). When designing usability questionnaires, does it hurt to be positive? In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '11, pages 2215–2224, New York, NY, USA. Association for Computing Machinery.

Sawilowsky, S. S. (2009). New effect size rules of thumb. *Journal of Modern Applied Statistical Methods*, 8(2):597–599.

Sbai, M. A., Biadil, M. E., Mohajir, M. E., and Nahli, O. (2018). The use of ICT in dealing with learning disabilities: A literature review with a focus on reading Arabic texts. In El Mohajir, M., Al Achhab, M., El Mohajir, B. E., and Jellouli, I., editors, *2018 IEEE 5th International Congress on Information Science and Technology (CiSt)*, pages 415–421.

Schiaffino, S., Garcia, P., and Amandi, A. (2008). eTeacher: Providing personalized assistance to e-learning students. *Computers & Education*, 51(4):1744–1754.

Schunk, D. H. (2012). *Learning theories an educational perspective.* Pearson, 6th edition.

Scriven, M. (1991). *Evaluation thesaurus.* SAGE Publications, 4th edition.

Sekovanić, V., Vukovac, D. P., and Podbojec, Z. (2012). Usability case study of adapted e-learning course for dyslexic students. In *Proceedings of the 5th International Conference of Education, Research and Innovation*, pages 1998–2007.

Self, J. (1998). The defining characteristics of intelligent tutoring systems research: ITSs care, precisely. *International Journal of Artificial Intelligence in Education (IJAIED)*, 10:350–364.

Serrano, F., Bravo Sánchez, J., and Gómez Olmedo, M. (2016). Galexia: Evidence-based software for intervention in reading fluency and comprehension. In *INTED 2016 Proceedings 10th International Technology, Education and Development Conference*, pages 2001–2007. IATED.

Shaywitz, S. E., Morris, R., and Shaywitz, B. A. (2008). The education of dyslexic children from childhood to young adulthood. *Annual Review of Psychology*, 59:451–475.

Shaywitz, S. E., Shaywitz, B. A., Pugh, K. R., Fulbright, R. K., Constable, R. T., Mencl, W. E., Shankweiler, D. P., Liberman, A. M., Skudlarski, P., Fletcher, J. M., Katz, L., Marchione, K. E., Lacadie, C., Gatenby, C., and Gore, J. C. (1998). Functional disruption in the organization of the brain for reading in dyslexia. *Proceedings of the National Academy of Sciences*, 95(5):2636–2641.

Shee, D. Y. and Wang, Y. (2008). Multi-criteria evaluation of the web-based e-learning system: A methodology based on learner satisfaction and its applications. *Computers & Education*, 50(3):894–905.

Shershneva, V., Vainshtein, Y., Kochetkova, T., and Esin, R. (2019). Technological approach to development of adaptive e-learning system. In *SHS Web of Conferences*, volume 66, pages 1–6. EDP Sciences.

Shields, B. J., Palermo, T. M., Powers, J. D., Grewe, S. D., and Smith, G. A. (2003). Predictors of a child's ability to use a visual analogue scale. *Child: Care, Health and Development*, 29(4):281–290.

Siemens, G. (2005). Connectivism: A learning theory for the digital age. *International Journal of Instructional Technology and Distance Learning*, 2(1):1–9.

Silliman, E. R., Bahr, R. H., Wilkinson, L. C., and Turner, C. R. (2002). Language variation and struggling readers: Finding patterns in diversity. In Silliman, E. R. and Butler, K. G., editors, *Speaking, reading, and writing in children with language learning disabilities: New paradigms in research and practice*, pages 109–148. Taylor & Francis.

Silva-Maceda, G. and Camarillo-Salazar, B. F. (2021). Reading comprehension gains in a differentiated reading intervention in Spanish based on the simple view. *Child Language Teaching and Therapy*, 37(1):19–41.

Sinclair, J., Boyatt, R., Rocks, C., and Joy, M. (2015). Massive open online courses: A review of usage and evaluation. *International Journal of Learning Technology*, 10(1):71–93.

Siritongthaworn, S. and Krairit, D. (2006). Satisfaction in e-learning: The context of supplementary instruction. *Campus-Wide Information Systems*, 3(2):76–91.

Snow, C. (2002). *Reading for understanding: Toward an R&D program in reading comprehension.* Rand Corporation.

Snowling, M. J. and Hulme, C. (2012). Annual research review: The nature and classification of reading disorders - a commentary on proposals for DSM-5. *Journal of Child Psychology and Psychiatry*, 53(5):593–607.

Sorden, S. D. (2013). The cognitive theory of multimedia learning. In Irby, B., Brown, G. H., Lara-Aiecio, R., and Jackson, D. S. A., editors, *Handbook of educational theories*, pages 155–167. Information Age Publishing Charlotte, NC.

Sosnovsky, S. and Dicheva, D. (2010). Ontological technologies for user modelling. *International Journal of Metadata, Semantics and Ontologies*, 5(1):32–71.

Spencer, K. (1999). Predicting word-spelling difficulty in 7– to 11–year-olds. *Journal of Research in Reading*, 22(3):283–292.

Spencer, K. (2000). Is English a dyslexic language? *Dyslexia*, 6(2):152–162.

Srivastava, B. and Haider, M. T. U. (2020). Personalized assessment model for alphabets learning with learning objects in e-learning environment for dyslexia. *Journal of King Saud University - Computer and Information Sciences*, 32(7):809–817.

Stanovich, K. E. (1994). Annotation: Does dyslexia exist? *Journal of Child Psychology and Psychiatry*, 35(4):579–595.

Stash, N., Cristea, A., and De Bra, P. (2006). Adaptation to learning styles in e-learning: Approach evaluation. In *E-Learn: World Conference on E-Learning in Corporate, Government, Healthcare, and Higher Education*, pages 284–291. Association for the Advancement of Computing in Education (AACE).

Stein, J. (2001). The magnocellular theory of developmental dyslexia. *Dyslexia*, 7(1):12–36.

Stepich, D. A. and Newby, T. J. (1988). Analogical instruction within the information processing paradigm: Effective means to facilitate learning. *Instructional Science*, 17(2):129–144.

Sternberg, R. J. and Sternberg, K. (2012). *Cognitive psychology.* Belmont: Cengage Learning, 6th edition.

Suárez-Coalla, P. and Cuetos, F. (2012). Reading strategies in Spanish developmental dyslexics. *Annals of dyslexia*, 62(2):71–81.

Sun, P., Tsai, R. J., Finger, G., Chen, Y., and Yeh, D. (2008). What drives a successful e-learning? An empirical investigation of the critical factors influencing learner satisfaction. *Computers & Education*, 50(4):1183–1202.

Sun, R. and Peterson, T. (1997). A hybrid model for learning sequential navigation. In *Proceedings 1997 IEEE International Symposium on Computational Intelligence in Robotics and Automation CIRA'97. 'Towards New Computational Principles for Robotics and Automation'*, pages 234–239.

Tadlaoui, M. A., Aammou, S., Khaldi, M., and Carvalho, R. N. (2016). Learner modeling in adaptive educational systems: A comparative study. *International Journal of Modern Education and Computer Science*, 8(3):1–10.

Taipale, M., Kaminen, N., Nopola-Hemmi, J., Haltia, T., Myllyluoma, B., Lyytinen, H., Muller, K., Kaaranen, M., Lindsberg, P. J., Hannula-Jouppi, K., and Kere, J. (2003). A candidate gene for developmental dyslexia encodes a nuclear tetratricopeptide repeat domain protein dynamically regulated in brain. *Proceedings of the National Academy of Sciences*, 100(20):11553–11558.

Tallal, P., Merzenich, M. M., Miller, S., and Jenkins, W. (1998). Language learning impairments: Integrating basic science, technology, and remediation. *Experimental Brain Research*, 123(1):210–219.

Thakkar, S. R. and Joshi, H. D. (2015). E-learning systems: A review. In Choppella, V. and Kinshuk, S. L., editors, *2015 IEEE 7th International Conference on Technology for Education (T4E)*, pages 37–40.

Treiman, R. and Bourassa, D. C. (2000). The development of spelling skill. *Topics in Language Disorders*, 20(3):1–18.

Triantafillou, E., Pomportsis, A., and Demetriadis, S. (2003). The design and the formative evaluation of an adaptive educational system based on cognitive styles. *Computers & Education*, 41(1):87–103.

Truong, H. M. (2016). Integrating learning styles and adaptive e-learning system: Current developments, problems and opportunities. *Computers in Human Behavior*, 55:1185–1193.

Tsang, S., Royse, C. F., and Terkawi, A. S. (2017). Guidelines for developing, translating, and validating a questionnaire in perioperative and pain medicine. *Saudi Journal of Anaesthesia*, 11(Supplement 1):80–89.

Tschofen, C. and Mackness, J. (2012). Connectivism and dimensions of individual experience. *International Review of Research in Open and Distributed Learning*, 13(1):124–143.

Tullis, T. S. and Stetson, J. N. (2004). A comparison of questionnaires for assessing website usability. In *Usability Professional Association Conference*, volume 1, pages 1–12. Minneapolis, USA.

Understood Team (2018a). Signs of dyslexia at different ages. `https://www.understood.org/articles/en/checklist-signs-of-dyslexia-at-different-ages`. Accessed November 01, 2018.

Understood Team (2018b). What is dyslexia? `https://www.understood.org/articles/en/what-is-dyslexia#item0`. Accessed October 23, 2018.

Van Velsen, L., Van Der Geest, T., Klaassen, R., and Steehouder, M. (2008). User-centered evaluation of adaptive and adaptable systems: A literature review. *The Knowledge Engineering Review*, 23(3):261–281.

Vasilyeva, E., Puuronen, S., Pechenizkiy, M., and Rasanen, P. (2007). Feedback adaptation in web-based learning systems. *International Journal of Continuing Engineering Education and Life Long Learning*, 17(4–5):337–357.

Vaughn, S. and Linan-Thompson, S. (2003). What is special about special education for students with learning disabilities? *The Journal of Special Education*, 37(3):140–147.

Verma, K. and Rizvi, M. (2013). Impact of cloud on e-learning. In Tomar, G. S., editor, *2013 5th International Conference and Computational Intelligence and Communication Networks*, pages 480–485.

Wagner, R. F. (1973). 5. Rudolf Berlin: Originator of the term dyslexia. *Bulletin of the Orton Society*, 23(1):57–63.

Wajuihian, S. and Naidoo, K. (2011). Dyslexia: An overview. *African Vision and Eye Health*, 70(2):89–98.

Waldrop, M. M. (2013). Massive open online courses are transforming higher education–and providing fodder for scientific research. *Nature*, 495(440):160–163.

Walker, J. (2014). Dyslexia: Causes, performance differences, and treatment. *Angelo State University Social Sciences Research Journal*, 1(2):1–13.

Wang, L., Liu, D., and Xu, Z. (2019). Distinct effects of visual and auditory temporal processing training on reading and reading-related abilities in Chinese children with dyslexia. *Annals of dyslexia*, 69(2):166–185.

Wang, Y. (2003). Assessment of learner satisfaction with asynchronous electronic learning systems. *Information & Management*, 41(1):75–86.

Waterfield, J. (2002). Dyslexia: Implications for learning, teaching and support. *Planet*, 6(1):22–24.

Weber, G. and Brusilovsky, P. (2001). ELM-ART: An adaptive versatile system for web-based instruction. *International Journal of Artificial Intelligence in Education (IJAIED)*, 12:351–384.

Weber, G. and Brusilovsky, P. (2016). ELM-ART–an interactive and intelligent web-based electronic textbook. *International Journal of Artificial Intelligence in Education (IJAIED)*, 26(1):72–81.

Weibelzahl, S. (2001). Evaluation of adaptive systems. In Bauer, M., Gmytrasiewicz, P. J., and Vassileva, J., editors, *User modeling 2001*, pages 292–294. Springer Berlin Heidelberg.

Weibelzahl, S. (2003). *Evaluation of adaptive systems*. Doctoral dissertation, University of Trier.

Welsh, E. T., Wanberg, C. R., Brown, K. G., and Simmering, M. J. (2003). E-learning: Emerging uses, empirical results and future directions. *International Journal of Training and Development*, 7(4):245–258.

West, C. K., Farmer, J. A., and Wolff, P. M. (1991). *Instructional design: Implications from cognitive science*. Prentice Hall.

West, T. (2005). The gifts of dyslexia: Talents among dyslexics and their families. *Journal of Paediatrics (Hong Knog)*, 10(2):153–158.

Willcutt, E. G. and Pennington, B. F. (2000). Comorbidity of reading disability and attention-deficit/ hyperactivity disorder: Differences by gender and subtype. *Journal of Learning Disabilities*, 33(2):179–191.

Winn, W. (1990). Some implications of cognitive theory for instructional design. *Instructional Science*, 19(1):53–69.

Wolf, C. (2007). *Construction of an adaptive e-learning environment to address learning styles and an investigation of the effect of media choice*. Doctoral dissertation, RMIT University.

World Health Organization (1992). *The ICD-10 classification of mental and behavioural disorders: Clinical descriptions and diagnostic guidelines*. World Health Organization.

Worthen, B. R. (1990). Program evaluation. In Walberg, H. and Haertel, G., editors, *The international encyclopedia of educational evaluation*, pages 42–47. Toronto, ON: Pergammon Press.

Wu, C., Chen, Y., and Chen, T. (2017). An adaptive e-learning system for enhancing learning performance: Based on dynamic scaffolding theory. *Eurasia Journal of Mathematics, Science and Technology Education*, 14(3):903–913.

Wu, H., de Kort, E., and De Bra, P. (2001). Design issues for general-purpose adaptive hypermedia systems. In *Proceedings of the 12th ACM Conference on Hypertext and Hypermedia*, HYPERTEXT '01, pages 141–150, New York, NY, USA. Association for Computing Machinery.

Zaharias, P. and Poylymenakou, A. (2009). Developing a usability evaluation method for e-learning applications: Beyond functional usability. *International Journal of Human-Computer Interaction*, 25(1):75–98.

Ziegler, J. C. and Goswami, U. (2005). Reading acquisition, developmental dyslexia, and skilled reading across languages: A psycholinguistic grain size theory. *Psychological Bulletin*, 131(1):3–29.

Ziegler, J. C., Perry, C., Ma-Wyatt, A., Ladner, D., and Schulte-Korne, G. (2003). Developmental dyslexia in different languages: Language-specific or universal? *Journal of Experimental Child Psychology*, 86(3):169–193.

Zigoris, P. and Zhang, Y. (2006). Bayesian adaptive user profiling with explicit & implicit feedback. In *Proceedings of the 15th ACM International Conference on Information and Knowledge Management*, pages 397–404. ACM.

Appendix A. Research Ethics Statement

Research Ethics Statement
HCI: Adaptive E-Learning System for Dyslexia
Name of PGR student: Weam Alghabban
Principal supervisor: Robert Hendley

Study Details

The study aimed to understand the impact of adapting learning materials based on the characteristics of Arabic students with dyslexia on their learning experience by providing different reading exercises through an adaptive e-learning system. The exercises provided to each student were adapted based on the dyslexia type and/or reading skill level.

The study was conducted at primary schools in Saudi Arabia. The participants were Arabic-speaking female students with dyslexia in primary schools who were aged 6–13 years old.

The consent of the parents or guardians of participants was obtained. Only those students whose parents or guardians gave their permission were eligible to be enrolled in the study.

At the beginning of the study, an overview of the study was provided for the student. Then, they were asked to provide their demographic information, and were asked to complete diagnostic tests to identify their dyslexia type and reading skill levels. Diagnostic tests were available from the Ministry of Education in Saudi Arabia.

At the end of the study, the students were asked to complete 2 post-tests: one after using the system immediately and the other after 2 weeks, to assess their level of improvement in reading skill and understanding. Also, students were asked to complete a satisfaction questionnaire to measure their confidence in using the system and a usability questionnaire to measure their engagement and motivation.

Participants Recruitment

After getting permission from the Saudi Ministry of Education and the heads of primary schools, the researcher visited different primary schools and identified potential participants (students already identified as having dyslexia) to take part in the study with assistance from teachers. The study was conducted at the student's school during the school day with their teacher present. Participants were free to withdraw from the study at any time. Their parents or guardians were informed that they could withdraw the student from the study by emailing one of the researchers before the study was completed.

Data Management

The researcher registered each participant in the system. All the data collected from the participants was encrypted and stored in a secure database. Each participant's data was identified by a unique ID that was only accessible to the researcher. An encrypted connection was used to protect all communication to and from the database. Participants' IDs, dyslexia types, reading skill levels, and results of the pre- and post-tests were saved. All data was stored in the University's BEAR storage facility. Data is archived in university storage for 10 years.

Appendix C. Head Teachers' Consent Form

Dear [Head Teacher Name],

Thank you for your interest in allowing us to run our study in your school. Before starting, we require that you carefully read the following information about the study and indicate whether you agree to contribute learners in your school in this study.

Introduction: The learners will be enrolled in a study on human computer interaction field in the School of Computer Science at University of Birmingham. We need your permission to allow learners in your school to participate in the study as they are younger than 18 years, and we will ask for her age, grade and to complete diagnostic tests. In addition, we will inform parents/guardians about the research and offer the parents/guardians the opportunity to refuse to participate.

Purpose of the studies: This study aims to improve the learning process for learners with dyslexia. We will use a website that provides different reading exercises to train learners and then enhance their reading skill.

What should learners do in this study: At the beginning of the study, we will collect some personal information such as name, age and grade. Then, the learner will complete diagnostic tests to determine dyslexia type and/or reading skill level. Then, the learner will complete pre-tests that assess her initial reading skill and understanding. After that, we will sign up the learner on our website. Then, the learner will be asked to login to our website with our help. After finishing these steps, the learner will use our website that provides different reading exercises. The learner is free to withdraw from the study at any time and her research data is permanently removed. She or her parents/guardians only need to inform us. If the parents/guardians want to completely withdraw the learner from this study, then they should contact the researchers (at the addresses below). All data related to learners will then be deleted and removed from the study. If the learner completes the training sessions, she will take 2 post-tests, one after using the system immediately and the other one will be after 2 weeks, to assess her learning gain and understanding. Also, the learner will complete a satisfaction questionnaire to measure her confidence in using our system and a usability questionnaire to measure her engagement and motivation.

Time required: The study will require four weeks and the learner can access the system 8 times (2 sessions per a week), each one for half an hour.

Risks to participants: We will only collect information on learners, including the diagnostic tests, results of pre-tests, post-tests and follow-up tests. All the collected information will be anonymous, safely secured and encrypted before being stored in a secure database. Data will not be disclosed to any 3rd party. Only the researchers will be able to access the database using specific IDs associated with each participant.

Benefits to participating: Learners will gain knowledge and enhance their reading skill. Also, their motivation and engagement will be enhanced.

Participation in this study is voluntary, and the learners are allowed to withdraw at any time. Please read the preceding information, and then indicate below if you agree or not with the nature of the study and allow learners in your school to participate.

- I agree to let the learners in my school to participate in this study.
- I do not agree to let the learners in my school to participate in this study.

For further information, please do not hesitate to contact us by email:

Name of the head teacher:
Date:
Signature:

Appendix D. Parents' and Guardians' Consent Form

Dear parent and guardian,

Thank you for your interest in allowing your child to participate in our research. Before starting, we require that you carefully read the following information about this study and indicate whether you agree to enroll your child.

Introduction: Your child will be enrolled in a study on human computer interaction field in the School of Computer Science at University of Birmingham. We are seeking your permission as your child is younger than age 18 years, and we will ask for her age, grade and to complete diagnostic tests. For your child to do, we need your permission.

Purpose of the studies: This study aims to improve the learning process for learners with dyslexia, since they need support from all educational institutions, either special or general, to help this considerable slice of our society. We will develop a website that provides different reading exercises to train learners and then enhance their reading skill.

What your child will be required to do in this study: At the beginning of the study, we will collect some personal information such as name, age and grade. Then, your child will complete diagnosis tests to determine dyslexia type and/or reading skill level. Then, the child will complete pre-tests that assess her initial reading skill and understanding. After that, we will sign up your child on our website. Then, your child will be asked to login to our website with our help. After finishing these steps, your child will use our website that provides different reading exercises. Your child is free to withdraw from the study at any time. If you want to withdraw your child from the study, then you should contact us before the completion of the study (by using one of the addresses below). All data related to your child will then be deleted and removed from the study and will not be used either in the analysis or in the research. If you do not wish to delete your child's data, the data will be kept and used confidentially in the analysis.

If your child completes the training sessions, she will take 2 post-tests, one after using the system immediately and the other one will be after 2 weeks, to assess her learning gain and understanding. Also, your child will complete a satisfaction questionnaire to measure her confidence in using our system and a usability questionnaire to measure her engagement and motivation.

Time required: The study will require four weeks and your child can access the system 8 times (2 sessions per a week), each one for half an hour.

Risks to participants: There will be nothing within the study which could cause your child any harm. We will only collect information on your child, including the diagnostic tests, results of pre-tests, post-tests and follow-up tests. All the collected information will be anonymous, safely secured and encrypted before being stored in a secure database. Data will not be disclosed to any 3rd party. Only the researchers will be able to access the database using specific IDs associated with each participant.

Benefits to participating: Your child will gain knowledge and enhance her reading skill. Also, your child motivation and engagement will be enhanced.

Participation in this study is voluntary, and your child may withdraw at any time. Please read the preceding information, and then indicate below if you agree or do not to allow your child to participate.

o I agree to let my child to participate

o I do not agree to let my child to participate .

For further information, please do not hesitate to contact us by email:

Name of parent or guardian:
Date:
Signature:

Appendix E. Dyslexia Type Diagnostic Test

<u>الاختبار التشخيصي لنوع عسر القراءة</u>

<u>القسم الأول: أقرأ الكلمات مع مراعاة الحركات القصيرة والمدود</u>

طُيُورْ	مِفْتَاحْ	دَعَا	بَحَرْ	بَابْ
جِهَازْ	دَلُو	يَمْشِي	عَصِيرْ	كَتَبَ

<u>القسم الثانى: أقرأ الكلمات مع المحافظة على مكان كل حرف فى الكلمة</u>

يَكْتُبْ	تَرْغَبْ	قَلَمْ	جَرَسْ	مَعْمَلْ
قَبْلْ	شَعْرْ	يَحْلُمْ	يَعْمَلْ	يَصْنَعْ

Appendix F. Reading Skill Level Diagnostic Test

اختبار مهارات القراءة

القسم الأول: أقرأ الحروف في الكلمات التالية بحركاتها القصيرة

رَغِبَ	جُبِرَ	كَثُرَ	خَبَزَ	بُرِدَ	تَعِبَ
سُرِقَ	زُرِعَ	رُجِعَ	صَدَقَ	دُرِجَ	خُبِزَ
عُجِنَ	نَضَجَ	طُبِعَ	ضُرِبَ	صُنِعَ	شُرِبَ
مُسِحَ	يَصِلُ	كُتِبَ	قُرِأَ	فُعِلَ	غُسِلَ
أُكِلَ	قُدِرَ	يُحِب	وُلِدَ	هُرِبَ	نُقِلَ
تُرِكَ	حَظِيَ	إِبَر	ذُهِلَ	ظَفِرَ	بَعَثَ
ذَهَبَ	وَثِقَ	ظُلِمَ	نَشِطَ	حُمِلَ	غَضِبَ
أَطَايِب	حَذِقَ	سَخِرَ	عَطِشَ	فَزِعَ	قَوِيَ

القسم الثانى: أقرأ الكلمات التالية مع مراعاة حركة المقطع الساكن

دَمْ	قُمْ	زِرْ	كُلْ	أَبْ
صُمْ	خَيْلُ	قِرْدُ	عُدْ	مِنْ

القسم الثالث: أقرأ الكلمات التالية بالحركات القصيرة والمقاطع الساكنة

مَنْزِلُ	يَصْنَعُ	طِفْلُ	قَلَمْ	حَبْلُ
يَسْتَلِمُ	مَلْعَبْ	تَجْتَهِدْ	تَرْتَبِطْ	يَكْتُبُ

Appendix G. A Sample of Reading Test

اختبار القراءة القبلي والبعدي

القسم الأول: الكلمات المتداولة

أقرأ الكلمات التالية بشكل صحيح

يَحْلُمْ	يَصْنَعْ	زُهُورْ	عَصِيرْ	بَابْ
خُبْزُ	يَغْسِلْ	وَقَفَتْ	يَسْبَحْ	ذَيْلُ

القسم الثاني: الكلمات الغير متداولة

أقرأ الكلمات التالية بشكل صحيح

تَعْلَمْ	تَفْحَصْ	جُنُودْ	ثَمِينْ	دَارْ
حُكْمُ	مَنْطِقْ	حَكَمَتْ	مَقْطَعْ	سَهْمُ

Appendix H. A Sample of Word Understanding Test

<u>اختبار قراءة وفهم الكلمات</u>

<u>أقرأ الكلمة التالية بشكل صحيح ثم اختار صورة واحدة من الصور الأربعة التى تعبر عن معنى الكلمة بالتحديد</u>

تُـوتْ	
	
	

عَصِـيرْ	
	
	

Appendix I. The E-Learner Satisfaction (ELS) Questionnaire

The adapted version of e-learner satisfaction (ELS) questionnaire.

م	الفقرات	المقياس
١-	يقدم البرنامج دروس جديدة.	سيء جدا - سيء - جيد - جيد جدا - رائع
٢-	يقدم البرنامج ما أحتاجه من الدروس.	سيء جدا - سيء - جيد - جيد جدا - رائع
٣-	يقدم البرنامج دروس مفيدة.	سيء جدا - سيء - جيد - جيد جدا - رائع
٤-	البرنامج سهل الاستخدام.	سيء جدا - سيء - جيد - جيد جدا - رائع
٥-	أستطيع تعلم والتعامل مع البرنامج بطريقة سهلة.	سيء جدا - سيء - جيد - جيد جدا - رائع
٦-	دروس البرنامج واضحة ومفهومة.	سيء جدا - سيء - جيد - جيد جدا - رائع
٧-	يعمل البرنامج دائمًا بدون توقف.	سيء جدا - سيء - جيد - جيد جدا - رائع
٨-	يساعدني البرنامج للوصول إلى ما أحتاجه من الدروس بطريقة سهلة.	سيء جدا - سيء - جيد - جيد جدا - رائع
٩-	يساعدني البرنامج في تعلم ما أحتاجه.	سيء جدا - سيء - جيد - جيد جدا - رائع
١٠-	أستطيع معرفة مقدار ماتعلمته.	سيء جدا - سيء - جيد - جيد جدا - رائع

Appendix J. The System Usability Scale (SUS) Questionnaire

The adapted version of system usability scale (SUS) questionnaire.

م	الفقرات	المقياس
١-	أحب أن أستخدم البرنامج باستمرار.	سيء جدا - سيء - جيد - جيد جدا - رائع
٢-	البرنامج بسيط.	سيء جدا - سيء - جيد - جيد جدا - رائع
٣-	البرنامج سهل الاستخدام.	سيء جدا - سيء - جيد - جيد جدا - رائع
٤-	أستطيع استخدام البرنامج بنفسي بدون أي مساعدة من شخص تقني.	سيء جدا - سيء - جيد - جيد جدا - رائع
٥-	خدمات البرنامج متناسقة ومنسجمة فيما بينها.	سيء جدا - سيء - جيد - جيد جدا - رائع
٦-	يوجد توافق/ تطابق عند استخدام البرنامج.	سيء جدا - سيء - جيد - جيد جدا - رائع
٧-	أتخيل أن كثير من الناس سوف يتعلمون استخدام البرنامج بسهولة.	سيء جدا - سيء - جيد - جيد جدا - رائع
٨-	البرنامج مألوف للاستخدام.	سيء جدا - سيء - جيد - جيد جدا - رائع
٩-	أشعر بالثقة التامة عند استخدام البرنامج.	سيء جدا - سيء - جيد - جيد جدا - رائع
١٠-	تعلمت استخدام البرنامج بسرعة دون الحاجة إلى أن أتعلم أشياء جديدة.	سيء جدا - سيء - جيد - جيد جدا - رائع