Developing a Game-Based Mobile Application to Enhance Reading Skills for Dyslexic Students at Primary Schools in Saudi Arabia

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Declaration

I hereby declare that this thesis has not been and will not be submitted in whole or in part to another University for the award of any other degree.

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Abstract

Fluent reading is necessary for any future learning, regardless of discipline. However, dyslexia is a universal reading impairment in which each individual with dyslexia has a set of fundamental reading difficulties that make this fluency challenging to achieve. Human-Computer Interaction (HCI) interventions have become more prevalent in the last couple of decades in addressing dyslexia, where they have been presented to students to help overcome their difficulties. Thus, this thesis presents a novel game-based mobile application that has been designed and developed to increase reading skills for dyslexic students at primary schools in Saudi Arabia. This thesis evaluates the effectiveness of the proposed application by conducting two studies in primary schools in Saudi Arabia. From the studies' findings, it can be seen that the proposed game-based mobile application aids in improving reading skills for dyslexic students. Additionally, the studies showed very positive behaviours towards the proposed mobile application, leading to a high level of satisfaction. Thus, it is considered a supportive tool to enhance students with dyslexia to overcome their reading difficulties and effectively promote the learning process. This work has provided key contributions, including the creation of the novel educational application for dyslexic students learning Arabic and a distinct evaluation approach and methodology.

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Publications

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Abbreviations

AT	Assistive Technology
BCI	Brain-Computer Interfaces
CIS	Child Interactive Storytelling
CAM	Computer Assessment Module
CIM	Creative and Innovative Storytelling
CBM	Curriculum-Based Measurement
DVD	Developmental Visual Dyslexia
ETP	Education Tech Points
HCI	Human-Computer Interaction
IREAD	Individualized Reading Enhancing Application for Dyslexia
IDEA	Individuals with Disabilities Education Improvement Act
ICT	Information and Communication Technology
IDA	International Dyslexia Association
IDA	International Dyslexia Association
LD	Learning Disabilities
LD	Learning Disorder
LPD	Letter Position Dyslexia
MMD	Multimedia Dictionary
SPSS	Statistical Package for Social Science
SETT	Student Environment Tasks Tools
UDL	Universal Design Learning

Chapter 1: Introduction

This chapter presents an introduction to this thesis. It includes the research problem and motivation for working on dyslexia in the Arabic language. Also presented are an introduction to E-learning for dyslexia, research aim and objectives, research questions and hypotheses, and the contributions, respectively. Finally, this chapter describes the structure of this thesis.

1.1 Research Problem

Learning disability is one of the most common types of disability that affect people of different cultures, backgrounds, and abilities (Wajuihian & Naidoo, 2011). For example, Dyslexia is described as "a *distinct and serious impairment in the increase of reading skills, which cannot be accounted for by visual acuity issues, mental age, or insufficient schooling*," according to the main international classification, ICD-10 (World Health Organization, 1992).

A lot of children are affected by different learning disabilities, such as dyslexia, at the early stages of schooling. Almost 15% of the world's population may have dyslexia (Skiada et al., 2014). People have varying symptoms that are usually reading-related (Khakhar & Madhvanath, 2010). People with dyslexia struggle with a variety of problems, including an inability to recognize the written word, spelling, word pronunciation, and written communication. In addition, problems associated with differentiating between alphabet characters are another problem that dyslexics frequently share. Spelling in Arabic language is considered as a challenging for both dyslexic and non-dyslexic children. The connection between the graphemes and their sounds, followed by the application of grammatical rules, is required to learn to read in Arabic. Many aspects of the language's basic features may enhance the emergence of dyslexia in Arabic language.

Dyslexia impacts the standard academic achievement of the students and may even affect their social life (El Kah & Lakhouaja, 2018). It involves the student with unexpected problems in academic performance despite normal intelligence. Indeed, students with dyslexia deserve a fundamental right to learn in a suitable environment and be provided with proper education. However, in a conventional school, which usually consists of many students in the classroom with varied academic levels, it looks like a burden to the teachers to focus on every student individually.

Therefore, Assistive Technologies (AT) interventions have been created to help dyslexic students ‘outside-class’ as additional support for reading skills to overcome their difficulties, as it is believed that students' dyslexia problems can be managed successfully by providing students with the appropriate aids.

1.2 Motivation

The high rate of students with dyslexia should not be ignored. For Arabic countries, especially Saudi Arabia, such rates are still unknown, and the dyslexic issues have not been treated as they should be. Furthermore, Assistive Technology interventions developed for assisting individuals with dyslexia are still weak compared to many languages like English, Spanish, French, and German. Most of the applications are developed for English-speaking students in European countries, whereas there is a minimal research effort to understand and resolve the issue related to reading skills for Arabic students in the Arab countries generally, and specifically for the students in Saudi Arabia. However, the work described in this thesis can be considered an essential addition to understanding and providing a practical solution in assistive technology intervention to improve the reading skills of students with dyslexia in Saudi Arabia. Hence, this research intends to develop a game-based mobile application to address reading issues for dyslexic Saudi students.

1.3 The Benefits of E-learning for Dyslexia

E-learning is defined as "*the electronic delivery of education program, training, or learning* " (Stockley, 2003). In fact, this delivery can take place via computers, smartphones, or other electronic devices connected to a communication network, as well as radio or television.

Technology has played a crucial impact in recent significant scientific discoveries. Without technologies like simulators and computer-aided systems, recent genetic, astronomical, and medicinal discoveries would not have been conceivable. Technological developments in the learning process and education can help to increase the efficacy and value of education.

Technology is not only expanding educational opportunities, but it is also successfully combating several traditional learning barriers, such as a lack of varied learning styles to cater for students who prefer uncommon methods of learning, and lack of learning assistance to allow students to learn topics at their own pace whenever and wherever they want. Thus, students can benefit from these robust new tools that aid in their comprehension of a topic.

E-learning or using online programs to assist students with their work allows for many unique opportunities. For example, students with dyslexia can watch videos, review materials, or interact with content in multiple ways. Applying technology in special education settings breaks the barriers for students with learning disabilities. Traditional education frequently relies on handwritten text, but depending on a child's learning disability, the student may need technical tools to create information or recognize human speech (Alghayth, 2019). Students with dyslexia can benefit from assistive technology to replace absent or weakened skills through support presented with computer technology mediums (Al-harbi et al., 2013).

The assistive technology` types available for people with dyslexia are growing immensely, providing more support to meet the needs of all students (Hasselbring & Goin, 2004). The use of these devices, tools, and systems includes compensation for deficits, thereby minimizing the difficulties and enhancing learning for dyslexic students.

A growing number of digital applications target activity assistance and cognitive training, presenting new possibilities for assistance, rehabilitation, and evaluation of dyslexic individuals (Fage et al., 2018). Assistive applications, including virtual assistants, have been shown to improve the learning process (Fage et al., 2018; Jamaludin et al,. 2018).

The International Dyslexia Association (IDA) confirmed that multisensory instruments, such as mobile applications, could support students in overcoming their difficulties. These customized instruments can help in visual perception, memory, language, auditory, reasoning. Therefore, it is proposed that a mobile application can be utilized to improve reading skills for dyslexic students. Games are noted to be one means of giving students enhanced learning opportunities via mobile mediums. El Kah & Lakhouaja, (2018) indicated that a set of games for children with dyslexia is one means of improving the learning process.

The previous studies suggest that using applications and innovative technology resources leading to engagement with an e-learning resource helps dyslexic students understand the difficulties they frequently struggle with because of their dyslexia (Rello & Ballesteros, 2015).

This research outlined in this thesis seeks to combine technology with learning by designing and developing a game-based mobile application for increasing the reading skills of dyslexic students at primary schools in Saudi Arabia.

1.4 Research Aim

This research aims to investigate the current HCI interventions and to find the best possible ways to design and develop an interactive application in the Arabic language that supports Saudi dyslexic students' reading skills, satisfaction, and engagement.

1.5 Research Objectives

This thesis presents and implements a game-based mobile application and then evaluates it. The application is designed to meet dyslexic students` needs. This research's main objective is to investigate the proposed mobile application's effectiveness in terms of improving students' engagement and reading performance with the application.

The following objectives are designed to achieve the main aim of this study:

OB1: Critically review and investigate the relevant previous research, including the studies conducted in the Arabic language, to understand the requirements of dyslexic students in the Saudi education system.

OB2: An intensive review to find the most recommended features and characteristics that fit the needs of Saudi dyslexic students to be included in the developed mobile application.

OB3: Developing an interactive educational application in the Arabic language that supports Saudi dyslexic students.

OB4: Testing the proposed application to validate its appropriateness and effect on Saudi dyslexic students and examine the perceptions of teachers and students about the usability and adoption of the proposed application.

OB5: Evaluating the proposed application experimentally with Saudi dyslexic students to show its effectiveness.

1.6 Research Questions and Hypotheses

This research aimed to answer the following questions:

1. Will the proposed game-based mobile application improve reading skills for dyslexic students?

2. To what extent will dyslexic students be satisfied and engaged using the application?

To answer the above questions, a game-based mobile application is evaluated using the following evaluation methods:

- *Questionnaires:*

A post-experiment questionnaire to assess students' overall satisfaction toward the proposed mobile application and its features. It also aims to evaluate the participants' feelings, behaviours, and visions with reading through using the application.

- *Tests:*

Questions in pre-test and post-test are used to assess the students' reading abilities before and after they have utilized the proposed application.

- *Hypotheses:*

Four key hypotheses are planned and tested based on students' results in the pre and post-tests and post-experiment questionnaire as follows:

Hypothesis 1: Students will show significant improvement in their reading ability after using the "application" compared to their baseline (pre) reading ability.

Hypothesis 2: There are age differences in students' reading ability at the pre-test phase.

Hypothesis 3: At the post-test level, there will be a significant difference in reading level between the three groups.

Hypothesis 4: The developed mobile application will be experienced as engaging and usable and offering a good level of satisfaction.

1.7 Research Contributions

This research adds to the practice and knowledge concerning e-learning systems by providing a game-based mobile application that positively influences dyslexic students' performance.

The main research contributions are as follows:

1. *Technical contribution:*

   - Development of a novel mobile application based on game functionality that supports dyslexic students learning Arabic as a first language. This application is implemented based on recommendations retrieved from previous research, the feedback from students and teachers, and the researcher's observations (in the 1st study). The features have been used to create an appropriate interactive learning material by games to meet the dyslexic students` needs, increase their reading skills, and maintain satisfaction.

2. *Academic contribution:*

   - A thorough review of the most commonly HCI interventions to support students with dyslexia. While literature exists on such theories and prototypes, these interventions' effectiveness is often limited and purely qualitative. Hence, this review gives a picture of the current level of research and justifies the need for a new mobile application intervention to overcome their lack of essential evaluation of the previous interventions.

   - Mixed methodology contributes to this research using the students' application, questionnaires, test scores, and observation. This has positively reflected the study and helped in accomplishing the objectives. Thus, utilizing mixed methods to gather the data (qualitative and quantitative) supports the importance of the results from the research. Despite the spread of COVID-19, this methodology ensures a safe environment to provide a vital evaluation and reach relevant results.

3. *Practical contribution:*
    - Applying the proposed mobile application in two experiments (first study and second study) in different primary schools in Saudi Arabia to evaluate the proposed application's efficacy.

1.8 Summary

The ability to read is one of the primary skills as we cannot learn without it. As a result, dyslexia concerns must be identified at a young age (i.e., in primary schools) to be managed and minimized, especially given the growing number of dyslexic students globally. Therefore, focusing on improving reading skills at a young age is crucial. It is an essential part of any language learning because it aids in developing other related skills such as grammar, vocabulary, and writing. In Saudi Arabia, the Ministry of Education (MOE) has identified this issue in recent years and made efforts to provide support. However, there has been a general lack of understanding regarding dyslexia in Saudi Arabia resulting in students with dyslexia not obtaining adequate assistance. Such a lack of assistance has been the motivation for introducing projects related to the community-awareness that educated Saudis about dyslexia which has changed substantially in recent years. It is believed there are still challenges; thus, research on how various technologies would serve Saudi dyslexic students needs to be investigated.

Saudi Arabia is following a governmental path called "Vision 2030" to be completed by 2030 to increase the quality of life for its citizens, and which states that "*We intend to embed positive moral beliefs in our children's characters from an early age by reshaping our academic and educational system.*" (Vision 2030, 2022, p. 27). One of the bases of this vision is educational development and the Education system has been given a high priority in general and specifically for students with special needs. Thus, improving dyslexic students' engagement and understanding is a key area of research.

1.9 Research Outline

This section lists the thesis chapters in order and briefly explains each.

Chapter 2:

Provides a literature review covering the relevant HCI interventions and thoroughly reviews commonly used methods, procedures, and techniques to provide the best possible solution to students with dyslexia. This exposes the importance of Assistive technologies in education in helping dyslexic students in general. The review determines the knowledge gaps and the best methods to answer the research questions by analyzing currently limited interventions (i.e., Arabic language interventions).

Chapter 3:

Introduces a summary of the literature, expands the background of the Arabic language, identifies the associated issues that the students with dyslexia are suffering from to be addressed in the proposed application. Then, it presents the main contribution to dyslexic students that consists of the development of a novel application comprising a set of games that enhances reading by giving the main aim of each game and describing more details for each.

Chapter 4:

Provides the research methodology used in both studies (first and second studies). It explains the research design, approach and data collection procedures, and the analytical processes employed in the research.

Chapter 5:

Provides data analysis of the first study carried out. Also, it discusses the results from questionnaires, observation, and extracted data from the application and assesses this alongside their feedback.

Chapter 6:

The first study's findings are analyzed to determine the modifications that should be made for the second study. The resulting changes made in the application are explained in detail. In addition, it includes a collection of the data from the second study (as in Chapter 5). It also discusses the results and an evaluation of the research hypotheses and their feedback.

Chapter 7:

Discusses the general findings of the first and second study.

Chapter 8:

This chapter summarizes the general conclusions of the research performed in this thesis, explains the main contributions, reviews the research limitations, and suggests recommendations for researchers and teachers and future work.

Chapter 2: Literature Review

2.1 Introduction

The following literature review will evaluate existing research available in e-Learning and games in education. Studies of special learning education, especially dyslexia, will be reviewed throughout the literature review, focusing on studies conducted in the Arabic language. This chapter includes a thorough review of academic literature to identify and assess published peer-reviewed publications to evaluate the current state of educating the dyslexia population in general and specifically in Saudi Arabia. These publications draw on the experiences, research practices, and reporting of systematic reviews. Identifying and appraising all key published studies will help the researcher describe the quality of this evidence base, summarize and compare the review's conclusions and discuss the strength of these conclusions in assessing the state of dyslexia awareness and the use of Human-computer interaction (HCI) with the dyslexia population in Saudi Arabia. HCI is a multidisciplinary field that combines human interaction and computers (Nickerson, 1969; Rello & Ballesteros, 2015). This study explores the impact of HCI and assistive technological interventions in a population with dyslexia to improve reading skills, which it has not received as much attention in Saudi Arabia.

2.2 Dyslexia

Reading is the most fundamental skill that a child must attain at school because one must learn to read to help for any future learning. However, the process of learning to read is no simple task. First, brains must learn to connect the letters of the alphabet with sounds, these sounds then have to be placed in the correct order to create words, and then these words are paired together to form sentences. Then, students must proceed to read entire paragraphs and passages. Even with reading the words, comprehension can be lacking when the reader does not understand what they are reading (Waterfield, 2002).

Dyslexia is a universal reading impairment in which each person with dyslexia has a set of fundamental reading problems making fluency hard to obtain. This specific learning disorder is language-based (Khakhar & Madhvanath, 2010) and adversely impacts people's speaking, writing, reading, and spelling abilities.

While the diagnosis may be made when a child is younger, it is possible that they might not know they have dyslexia until they are adults.

Since vision problems do not cause dyslexia, glasses do not help; meanwhile, the time needed to read words and passages is longer than their peers (Knight, 2018).

Genes may play a role passed from one family member to their offspring. In other words, if a parent has dyslexia, their child may have dyslexia, too (Schumacher et al., 2006). These individuals may also have trouble processing words which can lower their written and oral communication skills compared to other individuals. The portion of the brain that processes language is different for dyslexic individuals. When their brains are scanned, these individuals have imaging scans that indicate areas of their brain do not function as expected when they read. For example, ideally, a student learns the three phonemes in 'cat'; the 'k,' 'a', and 't' sounds allow the reader to distinguish that the letters form the word 'cat'; thus, persons without dyslexia can properly connect the sounds and letters. It is common for persons with dyslexia to look at 'cat' and read it as 'tac' or look at 'dog' and read it as 'god' (Ramus & Szenkovits, 2008).

Matching the letters viewed on paper with the correct sounds does not seem difficult for the average learner, but for people with dyslexia, it can be highly challenging. This foundational reading step is only the beginning of more complex problems (Waterfield, 2002). People have varying symptoms that are usually reading-related (Khakhar & Madhvanath, 2010). Spelling, word pronunciation, and written communication are all issues that persons with dyslexia have. In addition, problems associated with sequencing, visual and auditory perception, motor skills, and directional words are present during the early stages of learning. Distinguishing sound components or differentiating between alphabet characters are also considered dyslexic problems. Reading fluently, spelling words correctly, and learning a second language are equally common challenges displayed in the dyslexic population; nonetheless, these struggles have no notable connection to their overall intelligence (Waterfield, 2002). So often, people with dyslexia are noted to have an intelligence that should allow them to read quickly, but this is simply not the case. Even though they are good at reasoning and creative thinkers who may even be witty and fast to process what is happening around them, they are slow readers (Waterfield, 2002).

Some people have milder forms of dyslexia that can be easily managed through learning and troubleshooting. While children may not overcome dyslexia, they can go to college and have a successful life in the workforce (Knight, 2018).

2.2.1 Percentage of People with Dyslexia

Dyslexia affects about ten percent of the world's population, and out of all the learning disabilities diagnosed in humans, eighty to ninety percent of those people fall into the dyslexia category (Knight; 2018; Waterfield, 2002). In comparison, according to some studies, up to 17% of the world's population has Dyslexia (Silva & Sirisuriya, 2019; Madeira et al., 2015). More than 15% of children in Asia have some sort of learning disability, with around 60% to 80% of these children having Dyslexia (Silva & Sirisuriya, 2019). With research showing that a dyslexic individual has varying brain connectivity compared to persons without dyslexia, one can understand why fluent reading is a problem for the dyslexic person. While there are no cures for dyslexia, there are supports that will assist dyslexic individuals in becoming successful students and adults. Rapidly increasing literacy rates have emphasized and recognized educational and social disability, leading to significant research being performed in this area. For example, in Saudi Arabia, a study was completed to measure the frequency of dyslexia among a group of Saudi primary students in varying regions throughout the Middle Eastern country, with the highest percentage found in the Riyadh region at 30.6% of the population studied. However, this value is higher than the general population, likely due to marginalization within groups and improper educational opportunities (AlJaidi et al., 2019). Meanwhile, a similar study in France found that out of the 20 schools and 1062 children used in the study, 12% of those students had reading impairments (AlJaidi et al., 2019). It was noted that the extent of learning disabilities present suggests that estimates of dyslexia in the population vary quite widely, but nevertheless, it is obviously a significant problem.

2.2.2 Testing for Dyslexia

One of the problems with knowing the exact number of persons with dyslexia is the absence of testing, leading to limited testing in some geographic locations (Siegel, 2006; Snowling, 2013). For persons receiving testing, dyslexia screening is the initial phase. During this process, possible indicators are looked for to determine someone's probability of being 'at risk'. Following the initial screening, recommendations can be made to see if a formal diagnostic assessment is received. Screening can be completed online or using traditional paper-based testing (Siegel, 2006). Next, a language and literacy evaluation is administered. The appropriate tests may include the Peabody Picture Vocabulary Test, Clinical Evaluation of Language Fundamentals, Comprehensive Test of Phonological Processing, Gray Oral Reading Tests, or the Test of Written Language (Snowling, 2013). The test results will show the individual's indicators of dyslexia; the delivered report will then indicate whether a full dyslexia assessment should be completed. An Educational Psychologist completes the full dyslexia assessment to explore cognitive processing abilities and the kind of skills displayed (Snowling, 2013). Following a full dyslexia assessment, decisions will be made regarding the next steps. If a student is diagnosed with dyslexia, the lengthy process of beginning an Individual Education Plan will be taken (Siegel, 2006). Meeting the needs of individuals with dyslexia requires utilizing a variety of interventions.

Due to the significant overhead of dyslexia diagnosis using traditional methods, many HCI tools are being developed, from web-based gaming to downloadable applications to assess, diagnose, and provide appropriate interventions for dyslexic students. Rello et al. (2018) discuss the challenges associated with a proper dyslexic diagnosis, naming it a universal problem that often results in school failure; nonetheless, it remains underdiagnosed. The lack of diagnosis is a severe problem since early detection and interventions are vital in assisting students. Reasons for under-diagnosing can be attributed to the cost and the need for professional access (Rello et al., 2018). Using new mediums, the challenges associated with dyslexia diagnosis can be addressed.

Rello et al. (2018) propose using a computer game that records web-page interaction measures; these recordings screen for dyslexia. A study of 267 participants indicated that the computer game was able to determine if someone has dyslexia with 84.62% accuracy. Moreover, other computer-based screening methods are being utilized to arrive at quick diagnosis; these include Lexercise Screener and Nessy, two commercial applications that are widely used (Rello et al., 2018). While other computer games screen for dyslexia, Rello notes that they do not use a machine learning model. The machine learning model is a mathematical representation of a real-world process; in this case, the process is the student's input into the game. The game can find patterns using the learning algorithm, which, in turn, can be used to make predictions (Ubandullah & Hamid, 2012). Once an adequate diagnosis has been obtained, proper interventions can be implemented to address the needs of these individual learners (Alsobhi & Abesinghe, 2013). Eye-tracking measures are often used with machine learning approaches to predict dyslexia in several populations. The games can be adjusted to students' native languages, as seen in *Dytective* for Spanish, with 343 people scoring 83% accuracy in diagnosing the 95 people with dyslexia in this study. The computer games use indicators, as shown in Table 2.1 (Rello et al., 2018); these indicators are relatively standard throughout the research.

Table 2.1 Indicators used for the design of the test items (Rello et al., 2018).

Language Skills	**Working Memory**	**Executive Functions**	**Perceptual Processes**
Alphabetic Awareness Phonological Awareness Syllabic Awareness Lexical Awareness Morphological Awareness Syntactic Awareness Semantic Awareness Orthographic Awareness	Visual (alphabetical) Auditory (phonology) Sequential (auditory) Sequential (visual)	Activation and Attention Sustained Attention Simultaneous Attention	Visual Discrimination and Categorization Auditory Discrimination and Categorization

With the knowledge that a screening program for diagnosing dyslexia in young students with learning disabilities must include assessing language skills, working memory, executive functions, and perceptual processes, Al-Wabil et al. (2012) used screening software for detecting learning disabilities in Arabic-speaking students. Design considerations for the educational interfaces included a total of 85 tasks included in the software that included verbal and non-verbal components within the research design. Al-Wabil et al. (2012) screened 778 children between the ages of 4 to 9 who had been diagnosed with learning disabilities and completed the screening program for young students with learning disabilities. Data were collected through observation, with the thematic analysis used to categorize observations. Performance was noted to be satisfactory with average performance but was limited in that it only focused on software developed exclusively for screening. Therefore, software interventions are needed to teach Arabian LD students effectively (El Kah & Lakhouaja, 2015).

Meanwhile, to further explore and diagnose the learning difficulties in Arabian students with learning disabilities, El Kah & Lakhouaja (2015) used a mixed research design to obtain information via questionnaires and interviews about Arabic learning disabilities in public primary schools on the east side of Morocco. A total of 2,304 students from third, fourth, fifth, and sixth grades were included in the study, and 98 teachers. The teachers and students indicated minimal learning disabilities, although students had dyslexia and faced reading and writing problems. These educators and policymakers turned a blind eye to the learning disabilities with an obvious need to diagnose and develop learning disabilities support. This study showed that individuals who are uneducated about dyslexia need AT applications to assist in the educational process (Almaazmi, 2013; El Kah & Lakhouaja, 2015). The strategies focused on teaching and schools were applied to overcome learning disabilities in a study by Almaazmi (2013) to explore possibilities for developing a diagnosis, interventions, and support techniques for addressing students with dyslexia in UAE. Based on the cost of diagnosis and the uneducated status of many individuals with dyslexia (Al-Wabil et al., 2012), innovative teacher and student-focused techniques are needed. In a study involving 280 students from the higher education level, participants completed the A-DAST test, which is used to diagnose learning disabilities.

Literacy-related cognitive deficit and non-linguistic mental speed were common problems observed in learning disabilities with poor performance in reading passages, memory improvement, self-awareness, and repetitions of reading tasks; meanwhile, the use of standard strategies resulted in substantial improvements with an emphasis on AT applications (Alsobhi & Abeysinghe, 2013; Almaazmi, 2013).

2.2.3 Dyslexia in Arabic

There has not traditionally been much awareness regarding dyslexia in Arabic countries (Mahfoudhi & Everatt, 2009; Alenizi, 2019), and HCI interventions that meet Arabic students' needs with dyslexia have not been heavily studied. Thus, there is only limited research to show the successes and failures associated with these training tools (Jamaludin et al., 2018; AlRowais & Wills, 2014).

However, there have more recently been efforts by Arabic educational institutions to increase awareness about the special educational needs required throughout the 22 countries where Arabic is the official language (Mahfoudhi & Everatt, 2009; Alenizi, 2019). Favorably, an increase in financial resources in this area has brought about an awareness of the needs, leading to the construction of learning disability centers, special educational organizations, and schools designed to meet the needs of students struggling with a learning disability (Mahfoudhi & Everatt, 2009). However, modifications and additions to the standard interventions made for students with dyslexia are needed for the Arabic-specific population (Aboras et at., 2012). Aboras et al. (2012) noted a need to create a remediation program for Arabic-speaking students since the Arabic language is different from western languages. The key differences include: Arabic is written from right to left, rather than left to right, and joined text form is always used in Arabic, rather than using separated block letters (Aboras et al., 2012). Special consideration must be made because Arabic letters have multiple forms based on word positioning. Figure 2.1 (Glossika, 2020) shows what a specific Arabic letter looks like if found at the beginning of a word. Figure 2.2 (Glossika, 2020) shows the same letter in the middle of the word, which is the medial or placed between two other letters. Figure 2.3 (Glossika, 2020) shows what the letter looks like if found at the end of the word.

Figure 2.1 Form of a specific Arabic Letter at the beginning of the Word (Glossika, 2020).

Figure 2.2 The same Arabic Letter in the Middle of the Word (Glossika, 2020).

Figure 2.3 The same Arabic Letter at the End of the Word (Glossika, 2020).

There is a substantial similarity between the written symbols and language sounds; in other words, unlike the English language. Meanwhile, pronunciation can be tricky since short vowel markers are absent in many advanced written works. Students must have a robust phonological understanding to succeed in their learning. Using programs emphasizing phonological awareness training programs is beneficial when dealing with dyslexic Arabian children.

Research has provided some proper direction to support the design and evaluation of different training tools, as indicated by the Arabic Framework for Dyslexia Training Tools (AlRowais & Wills, 2014). Given that Arabic is a Semitic language, its script contributes to the presentation of dyslexia in Arabic children since reading Arabic depends on a "global visual word form" (El Kah & Lakhouaja, 2015, p. 1). As presented in (Table 2.2) the construction for the Arabic framework for dyslexia training tools (AlRowais & Wills, 2014).

Table 2.2 Construction for the Arabic framework for dyslexia training tools (AlRowais & Wills, 2014).

Arabic linguistic features	**Arabic cultural factors**
Arabic principles for dyslexia	**General principles for dyslexia**

These four components fit together like the pieces of a jigsaw to create a framework that targets the unique needs of Arabic learners (AlRowais & Wills, 2014). Furthermore, the low academic performance and frustration that many students may display require early intervention and intensive remediation to manage a student's learning problems effectively (El Kah & Lakhouaja, 2015). The use of assistive technology (AT) provides support to meet the students` needs in a safe and controlled environment. While there are variances in students` needs based on their geographical location and language, research supports that the number of students with dyslexia is close when comparing multiple areas (El Kah & Lakhouaja, 2015). Arabic learners may have complications during reading or spelling activities where similar orthographic words are close, creating difficulties in differentiating between these words.

However, in general, it is believed that older students should perform better due to their longer exposure to reading materials, extended practice time and are being further on in their development. Thus, they are generally able to read the words correctly more of the time and improve their skills in reading faster as well as there being evidence of a significant enhancement in their reading ability when compared with younger students. Even though dyslexia impedes their understanding in general, the older students have the potential to overcome this and learn mechanisms to cope with and manage their dyslexia.

When considering dyslexia, internal connectivity between words, different shapes of Arabic letters within their positioning in a word, and how dots are used to show differences in graphemes can also contribute to a student struggling in reading and writing class within the Arabic language. Diacritical marks and the transition from consonants or vowels having role reversals also required interventions to be used with Arabic students (AlRowais & Wills, 2014; El Kah & Lakhouaja, 2015). Educational technologies are an increasing way to meet the needs of learners with a greater emphasis on the learner rather than the teacher (AlRowais & Wills, 2014).

Designing interactive learning systems to meet the needs of Arabic learners with dyslexia can be difficult, especially if the requirements are not fully understood. Nevertheless, general guidelines have proven helpful in implementing some assistance. These guidelines include using interfaces and colours to promote sustained concentration while drawing attention to specific text components. Customizing background colours, on-screen text colours, and other presentation features improve reading accuracy for Arabic students with dyslexia (AlRowais & Wills, 2014). Furthermore, on-screen texts allow students to manipulate the font size and style. Students' ability to change the font is also essential for readability enhancement and improving reading accuracy.

The above mentioned are some of the key issues related to dyslexia in the Arabic language; however, the Arabic language is covered in more detail in chapter 3.

2.3 Standard Interventions for Dyslexia

Various interventions help students better understand and interact with the materials they encounter on a traditional school day (Al-Odaib & Al-Sedairy, 2014).

When activities or other classroom resources are provided to many students, these materials do not consider the distinct differences among individual students.

Other students, volunteers, or paraprofessionals can implement the various interventions. When making changes to materials, teachers should consider simplifying the written directions. Giving students tips written in paragraph form or containing too many pieces of information can be significant. In this case, the teacher can highlight or underline important parts of the directions or find it easier to rewrite them. In addition to modifying the directions, teachers should present less work to students with a dyslexia diagnosis.

To assist students in feeling comfortable and focused, it is also essential to block out any distractions. For example, students may become distracted by the visual stimuli that are on a worksheet page or a handout; thus, the tutor should consider using a blank sheet of paper to cover sections of the page, allowing the student to work on one smaller section at a time (Al-Odaib & Al-Sedairy, 2014). The use of line markers is another usual intervention that can be made to help students in their reading. Line readers make it easier to focus on one word or a small group of words rather than feeling anxious about many words.

Furthermore, using multi-sensory activities helps dyslexic children process information in a more sustainable way where they may touch and see something simultaneously or move together while hearing instructions. This intervention is helpful for children with dyslexia, but it also benefits other students. Using a multi-sensory approach excites students, extends engagement, and provides a different type of learning (Abtahi, 2012; Rahim et al., 2018). For example, teachers can set up levels where students use tactile materials to write words and sentences. In addition, students can complete physical activities such as jumping rope or hopscotch while they spell out words. Scavenger hunts are another tremendous multi-sensory intervention where teams of students can move from one task to another.

When teachers can change type settings, larger fonts and increasing space between sections are beneficial. Furthermore, if a student can read the textbook but struggles to find essential information, a highlighting pen can mark this information.

Other interventions may include additional practice, instructional games, self-correcting materials, peer teaching, and the use of a dictionary for content classes. Furthermore, a reading guide helps students understand the main ideas, sort out basic details, and connect the various information.

Reading guides can be varied and may be used for paragraphs, pages, and sections, as is needed for the specific age and level of the child.

Lovett et al. (1994) used interventions for older children with similar reading disabilities. Still, their results showed that direct instruction could improve, although they will remain in the severely disabled range.

Students in the study with the two most robust interventions began with an average standard score for word reading ability of 64 or in the first percentile; after thirty-five (1-hour-sessions), their score was 69.5 or less than the second percentile. Pre- and post-score for reading comprehension were 66.4 and 70.8, respectively (Lovett et al., 1994).

Interventions that were studied included rhyming activities to help focus children's attention. In addition, mixing individual sounds to make words was utilized. Sound segmenting activities were also used to assist students in phonological awareness in spelling and reading. It was noted that students needed to be able to manipulate phonemes using a small group of instructions where explicit methods are used to teach students how to process sounds in spoken words and identify and count them in spoken words (Aboras et al., 2012).

After intensive teaching with one teacher working with two students, the children still had a severe reading disability. While these studies did not yield much growth, other studies show that attending special education classes for sixteen months showed more evidence of growth in children with severe to moderate word-level reading difficulties (Lovett, et al., 1994; Kavale, 1988; Deshler et al., 1986; McKinney, 1989; Torgesen, 1993; Lindamood & Lindamood, l998). Interventions to assist with word reading accuracy or phonemic decoding used clear, direct instruction in phonemic awareness and phonemic decoding skills, with gains being made in word reading accuracy, passage comprehension skills, and phonemic decoding (Kavale, 1988; Deshler et al., 1986; McKinney, 1990; Torgesen, 1993; Lindamood & Lindamood, l998).

Clearly, the level of teaching intensity used to obtain favorable results or reasonable progress shows that the growth and outcome can be profitable, yet, these interventions are not sufficient in closing the reading fluency gap for dyslexic students (Snowling et al., 1986; Kavale, 1988; Deshler et al., 1986; McKinney, 1989; Torgesen, 1993; Lindamood & Lindamood, l998).

2.4 E-learning for Supporting Learning Disability

A learning disability is a general term that refers to difficulty with specific skills, including writing or reading, in students with average intelligence (Hasselbring & Glaser, 2000).

These students see and/or hear one thing, but the way they read that information differs based on how their brain links the information. E-learning has spread swiftly in all academic institutions; nevertheless, there is no one set/standardized definition of e-learning.

A review completed by (Rodrigues et al., 2019) described 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 personalized, learner-centered, open, enjoyable and interactive learning environment supporting and enhancing the learning processes*" (p. 95). Much research has been completed over the last two decades, which confirms the benefits of e-learning systems. With the spread of location, time-independent education, and high access to the internet, educational institutions are increasingly utilizing e-learning technology (Ozkan & Koseler, 2009). E-learning has become an important advance in the educational sector, proving that it improves learning quality (Hamidi & Chavoshi, 2018).

The expansion of technology has made digital technologies more accessible, producing new opportunities for students. According to the National Center for Education Statistics, over 6.7 million students were helped in the United States under the Individuals with Disabilities Education Improvement Act (IDEA) in the 2015-2016 academic year. Given that this number reflects 13% of the student population in the United States, no single technological solution can meet the needs of all students. While the statistics for students in other countries are not the focus, the numbers here suggest that multiple resources are needed to generate the best possible outcome for students with disabilities.

Using unique technology creates student independence, allowing students to feel a sense of freedom with less direct teacher involvement. In addition, choosing the most convenient learning speed leads to a personalized learning approach (Hasselbring & Glaser, 2000). E-learning or using online programs to help students with their work allows for many unique chances. For example, dyslexic students can watch videos, review materials, or interact with content in several ways. Students may benefit from modifying their font style and size depending on the specific type of learning disability (Hasselbring & Goin, 2004). Their ability to process the shown information correctly is of the most significant importance, and the alteration of the visual appearance is helpful for students who have a visual processing disorder.

In brief, technology generates a bridge for students with learning disabilities, enabling them to realize their potential.

Teachers should plan effectively to address the needs of students with learning disorders (LD). The decision to use assistive technology relates to four theoretical models that assist in determining how and when it should be used (Edyburn, 2001). Through related research, Edyburn (2001) has shown the benefits of using these models to design modifications for LD students. The SETT framework's first model stands for student, environment, tasks, and tools. Edyburn (2001) notes that "*information is gathered concerning the Student's abilities and needs, the Environment(s) in which the student navigates, the Tasks required for the student's active participation in the activities within the environment, and finally, the Tools needed for completing the tasks*" (p. 17). Edyburn's (2001) second model is Education Tech Points (ETP); this model focuses on creating a plan to assist students with learning disabilities in acquiring technological resources through referral, evaluation, comprehensive assessment, plan development, implementation, and periodic review. The consistent support provided by ETP aids the student in their daily performance. Edyburn (2001) presented the third model in the 'Has technology been considered' model. Edyburn references the creation of this model, noting the Individuals with Disabilities Education Act (IDEA) which states assistive technology should be used as part of an LD student's educational program (Coulon, 2015).

Lastly, Edyburn (2001) references the AT CoPlanner, which utilizes electronic handouts which improve accessibility to collaborative learning. Using AT CoPlanner, students can work together on these electronic handouts in their classrooms (Edyburn, 2001).

There are many ways that students can benefit from assistive technology (Alghayth, 2019; Edyburn, 2001; Hasselbring & Goin, 2004). Reading, writing, memory, listening, mathematics, organization, building access, physical mobility, social interactions, and sports participation are all areas that can be addressed using AT (Hasselbring & Goin, 2004). Applying technology in special education breaks the barriers for students with learning disabilities. Traditional education frequently relies on handwritten text, but depending on a child's learning disability, the student may need technical tools to synthesize information or identify human speech (Alghayth, 2019). Students with learning disabilities can benefit from AT to replace weakened or absent skills through support produced with computer technology mediums (Al-harbi et al., 2013).

Computers can motivate students who are resistant to writing since it aids by providing spelling, editing, and revision opportunities while delivering a readable document that it may otherwise be problematic for students with poor handwriting to produce.

Furthermore, students are more able and willing to make revisions to their writing when done online or in word processing format. Vacc (1987) noted that students with LD devoted more time to composing and revising their written work when completing it via a computer rather than by hand. When students are provided with practical instructions for using computers to word process, they benefit significantly from these tools (MacArthur et al., 1991). Presenting information in ways that visually meet the learner's needs is also attainable with adaptive computer technology (Hasselbring & Goin, 2004). More specifically, these technologies can avoid challenging tasks, such as decoding and determining how the phonemes combine to create words. Meanwhile, for effective communication, students with speech problems will benefit from augmentative communication systems, including books, picture charts, and word prediction (Nganji, 2012; Alghayth, 2019).

Some web-based special education solutions minimize efforts to meet a student's needs. Programs with varying degrees of complexity can provide diverse opportunities for students within a single class.

Meanwhile, distance learning can help students access easy-to-use tools and track academic progress. The availability of types of AT for people with learning disabilities is increasing immensely, providing more resources to meet the needs of all learners (Hasselbring & Goin, 2004). Using these tools, devices, and systems includes compensation for deficits, thereby avoiding disabilities and leveling the capabilities of these individuals.

For example, alternative keyboards are individualized to meet the learner's needs; there are various types, including the Braille keyboard, the Little Fingers keyboard, keyboards with larger images of the keys, and keyboards with specific functions that are integrated directly from the software. Using alternative keyboards gives students access to input devices that give them better control over their learning (Hosseini & Ghazvini, 2016).

Meanwhile, mouse alternatives are another tool that assists students with learning disabilities; these designs may include scroll wheels, trackballs, or other assistive features that help students take more fine motor control. A device called a HeadMouse can track head movements as a way to control software applications (Hasselbring & Goin, 2004). In addition, touch screens, which are the primary input types for smartphones and tablets, provide freedom from mouse controls, enabling students to use their sense of touch for entering commands. In addition to hardware tools that aid students with learning disabilities, many software features can assist (Edyburn, 2001). These include Word Prediction Software, which reduces the number of words students have to type and trains them with spelling correction and grammatical error correction software. Text-to-speech software is another means of helping students read and interact with the text. Some more popular text-to-speech software programs can take text fragments directly from articles and books (Staels & Van den Broeck, 2015; Alghayth, 2019). These various assistive technologies are examples of how HCI makes a difference for students worldwide. The way these ATs benefit students with learning disabilities is released in how it aids in compensating for their weaknesses. Nonetheless, students with dyslexia, a specific type of reading disability that includes problems with phonological processing, reading comprehension, and/or reading fluency, can benefit from HCI more specialized ways.

2.5 Current HCI Interventions for Learning Disabilities

Khakhar and Madhvanath (2010) state, "*Conventional methods of teaching are often not effective for dyslexic children. The effect can be countered with appropriate pedagogic techniques and use of information technology*" (p. 576). The U.K. Assistive Technology Act was passed in 2004 as an addition to the Assistive Technology Act of 1998; following this approval, more support was given for AT to address students' developmental, physical, and intellectual needs (Coulon, 2015).

An increasing number of digital applications target activity assistance and cognitive training, presenting new possibilities for assistance, rehabilitation, and evaluation of dyslexic individuals (Fage et al., 2018). Using modifications that address the lack of organizational skills and time management skills often seen in individuals with dyslexia can assist in countering the negative implications associated with the learning disorder. Assistive applications, including virtual assistants, have improved the learning process (Fage et al., 2018; Jamaludin et al., 2018).

Furthermore, knowing that dyslexia presents reading challenges for individuals and that many life skills require reading and writing at high ability levels, it is imperative to do more than assert that they need to 'try harder' (Svensson et al., 2021). "*Assistive technology has been used for decades to support students with reading and writing disabilities….*" (Svensson et al., 2021, p. 1). Through targeted exercises that use assistive technology, students can become better readers. By helping individuals with dyslexia participate more fully, the learning disability is not as debilitating as it is without HCI (Hemmingsson et al., 2009).

2.5.1 HCI Interventions (Web-Based & Devices) for Dyslexia

Multiple research studies have been conducted to understand how HCI interventions can impact students' learning and specifically target dyslexia (Ubandullah & Hamid, 2012). These studies have obtained an awareness of how varying interventions produce favourable outcomes. Since dyslexia requires variable interventions, it is imperative to explore and integrate several e-learning tools accessible to the appropriate population (Alsobhi & Abesinghe, 2013).

With a continued focus on using e-learning software, Biju et al. (2013) looked at the design and implementation of e-learning software for students with autism (that may apply to dyslexia), using an approach that applied e-learning interventions, including a Computer Assessment Module (CAM) and Daily-Life Skills Module. The e-learning software was implemented successfully with the 3d modeling suite Blender, Graphical user Interface via wxPython and wxGlade libraries, and Panda3D as the programming library. Biju et al. (2013) briefly surmised the technical aspects of using educational software with 3d interactivity as part of a user-friendly interface; however, this software has not been tested in an academic environment. This interface was for students with autism but seemed to offer some hope for dyslexic students who may benefit from the concrete graphics and highly interactive content.

Hamid et al. (2015) proposed a model to help dyslexic children learn the Malay language. Students with dyslexia frequently experience frustration and low self-esteem due to their lack of performance. Therefore, the proposed model helps them in both cognitive issues such as reading and writing difficulties and emotional issues to enhance the efficacy of the learning process. This seems like a promising approach; however, the effectiveness of this study has not been evaluated. Further, Srivastava and Haider (2020) presented a personalized e-learning system for dyslexic children in the English language that provides learning material to increase awareness of alphabet structure. To evaluate the system, interviews with the teachers were conducted, and observations by experts in these fields. Positive comments were provided by them, and the provision of additional learning material does appear promising. However, there is a lack of practical evaluation as it needs further preparation to conduct a giant experiment. The evaluation is based only on feedback from teachers.

In addition to straightforward e-learning materials, various assistive technology devices aid students with dyslexia (Khakhar & Madhvanath, 2010). Text-to-speech technology and online oral readers are examples of HCI support to reduce the effects of dyslexia (Okolo, & Bouck, 2007). Students with learning disabilities frequently also have dyslexia; they cannot recognize words, read fluently, and write. Using text-to-speech software, speech synthesis can convert spoken voice output into text (Ismail & Jaafar, 2015).

While these text-to-speech systems were initially developed to aid visually impaired individuals, these computer-generated spoken voices have proved invaluable in assisting students in improving their reading skills (Staels & Van den Broeck, 2015). This suggests that text-to-speech can be a vital part of any e-learning system aimed at dyslexic students and helps add to a supportive mixed-media approach.

Extending the mixed media approach, Hall et al. (2015) completed a mixed-method study using qualitative and quantitative methods to assess the efficacy of Universal Design for Learning (UDL). This involves multiple types of interaction and representation and Curriculum-Based Measurement (CBM) to improve the reading skills of students with dyslexia. Through a strategic reader intervention created by CAST, 154 students were interviewed and completed questionnaires to assess their use of online CBM. These students had access to a digital learning environment that employed a Strategic Reader. The purpose of the Strategic Reader was to improve their reading comprehension. Specifically, the Strategic Reader tool has three primary components: an interactive digital reading environment; a forum where students could share discussions amongst themselves and the teacher; a CBM to monitor student progress. An alternate control group, consisting of 130 students, received offline CBM. Descriptive statistics confirmed via the use of frequencies, SD, t-tests, interviews, and thematic analysis that the experimental group who used online CBM significantly improved their reading skills compared to the control who used offline CBM. While the study only tested the UDL-CBM in the digital learning environment to test the effect of mobile applications supported on mobile devices. This study demonstrates the effectiveness of a system using multiple forms of support.

The use of text-to-speech software using the Dutch language was further studied by Staels and Van der Broeck (2015); their goal was to assess whether orthographic learning improves students' reading skills with reading disabilities. Through an experimental control research design, 65 Dutch-speaking students with reading disabilities were tested for three to seven days with observations and questionnaires to collect data about their use of the text-to-speech software. The descriptive statistics, including student mean and standard deviations, were used to infer how the intervention improved students' reading skills.

All students were able to develop word-specific knowledge; students' performance across all tasks (i.e., vocabulary, spelling, and reading speech rate in seconds) were significantly improved.

Meanwhile, the IDEAL e-book reader was studied as another HCI intervention with 22 students with dyslexia diagnosis (Kanvinde et al., 2012). While the results were noted to increase readability, accessibility issues showed a need for future work to improve IDEAL ebook Reader's contents, layout accessibility, and mobile features. These results show a clear pattern for using text-to-speech and online reader programs to facilitate growth in dyslexic students using HCI innovations (Kanvinde et al., 2012; Staels and Van der Broeck. 2015).

Jollymate (as shown in Figure 2.4) is a device designed to be used with dyslexic children; this self-learning tool looks like a school notebook, but it helps students practice correctly writing their letters and numbers (Khakhar & Madhvanath, 2010).

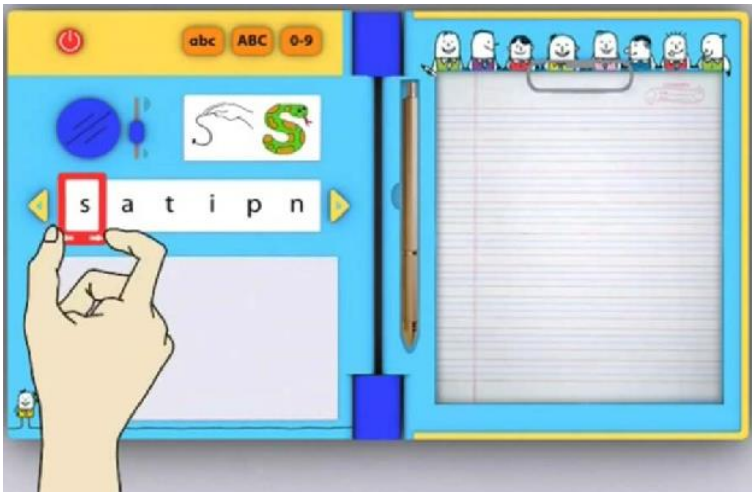

Figure 2.4 Screenshot of Jollymste Device (Khakhar & Madhvanath, 2010).

This tool represents some of the items developed to help dyslexic children. The device teaches letter sounds letter formation and divides the letter sounds into six different groups. Students have access to the visual form of the letter and its sound; it is also linked to an action, which makes it easier for students to remember it better. However, more accurate and extensive testing with children to understand estimating their performance and issues of proposed model usability is needed.

Meanwhile, (Jamaludin et al., 2018) present the concept of virtual assistants in the form of mascots, robots, or avatars that guide users through exercises, processes, and practice to correct dyslexia. Studies focused on how such developments must include attractive platforms that students are excited to use, noting "*it is crucial to tap into their interests and what motivates them to learn to read as we have observed that their preferences have shown to facilitate them to read correctly*" (Jamaludin et al., 2018, p. 1758). This again highlights that any intervention should be attractive and engaging.

While there are games that screen for dyslexia (Rello et al., 2018) as discussed previously, Saridaki and Mourlas (2011) explored the impact of serious games-based AT applications such as mobile interactive platforms to support students.

Students' progress through role-playing scenarios or other multi-level games to demonstrate learning to enhance the educational performance of students with disabilities. Their qualitative study relied on thematic analysis to analyze the data showing that integrating interventions in the educational plan significantly improved the academic performance of Arabian students with intellectual learning-related disabilities. Their conclusion showed a need for more research to test the efficacy of these interventions in community-level schools. Still, it did indicate that games-based learning intrinsically motivates the students to use these innovations and learn more quickly in the digital learning environment. The feedback from teachers agreed that these innovations were favorable in assisting students with learning disabilities, such as dyslexia.

In summary, using diverse e-learning interventions such as those reviewed above has promise for helping dyslexic children address their needs. The use of these web-based and devices-based HCI supports has proven effective; additional support is needed to benefit from the surge in the use of mobile devices (Alqahtani & Schoenfeld, 2014; Biju et al., 2013; Alsumait and Al-Musawai, 2013; Zain & Mahmud, 2018). Text-to-speech software support seems to be effective, as does an engaging system. It provides significant support as hearing the text read aloud in a normal-sounding voice also helps dyslexic students recognize the target written word. In addition, games-based interventions along with multiple forms of media and multiple forms of interactivity, seem to be an effective way forward.

However, most of the above-mentioned studies lack some of the key components which, in turn, assist dyslexic students in improving their reading skills, such as multiple forms of media (i,e., text, sound, images, etc.), multiple forms of interactivity (e.g., drag and drop using a touch screen and mobile devices), and engaging content such as games.

2.5.2 Mobile Applications for Dyslexia support

With the spread of smartphone use in MENA (the Middle East and North Africa) regions, the expected number of smartphone users will likely grow to nearly 28 million by 2025 (Puri-Mirza, 2020). Smartphone devices such as tablets, iPads, and mobiles have already positively impacted educational sectors as they are powerful tools that enrich training and knowledge. For example, some of their key benefits are that they are light and portable, have a go-anywhere nature, and have an intuitive touch screen interface.

As they are ideal for an individualized student-centered approach, they have been used in some dyslexic research highlighted in the following section.

Burac and Cruz (2020) designed a mobile application (Individualized Reading Enhancing Application for Dyslexia) to improve learners' reading skills with dyslexia (as shown in Figure 2.5). It applies text-to-speech technology, and Unity 3D is used to develop the application, with web support to provide the learning resources of the application. Moreover, a usability evaluation was completed to determine the efficiency, effectiveness, satisfaction, quality of support, and ease of learning. The qualitative results indicated that the ten teachers who participated in the study were satisfied with the IREAD application, as it provides individualized learning through engaging and interesting activities.

Text-to-speech technology was used to develop the application to help students learn to read. It encourages teachers to use the method of repeated instruction when teaching. The application's usability evaluation provided a positive result, indicating that it meets the needs of dyslexic students. The participants overwhelmingly agreed that the application's design and functionality are helpful and efficient. The school may use the application to help dyslexic students improve their reading skills.

Figure 2.5 Screenshots of the Gameplay (Burac & Cruz, 2020).

Furthermore, Bryant et al. (2015) designed an iPad application for teaching reading to students with LD to compare the performance of assistive technological intervention and teacher-directed instruction. Four students participated in this study. The findings show that instructional apps have the potential to increase participation in small group reading interventions, especially when they include critical features of effective instruction, such as developing multiple practice opportunities, and are an essential part of effective instruction.

Creating a set of tablet apps by developers and educators that include fundamental parts of effective practice like modeling, examples, and think-aloud exploration, as well as checking for understanding, error correction, and feedback.

Mobile technology is utilized in daily life, and as smartphones become more powerful, efficient, and low-cost, their potential as a tool to promote learning increases. Mobile devices may become essential as a learning aid for students with special educational needs, particularly dyslexic students. Skiada et al. (2014) presented an interactive mobile application called “EasyLexia” (as shown in Figure 2.6) to encourage the learning process and help children improve some of their primary skills, such as spelling, reading, mathematical problem solving short-term memory. The application has four categories, and each one has three games with three levels for each. The first level is called “Words” and is designed to help children improve their reading skills while expanding their vocabulary.

The second level is called “Numbers,” with the aim to enhance and promote mathematical logic. This refers to (visual memory) and is designed to help children improve their short-term memory and focus. The final level is “Books,” which is a unique part targeted at encouraging children's interest in reading while also strengthening their concentration through reading.

Figure 2.6 Screenshots of the Gameplay (Skiada et al., 2014).

A mixed-methods analysis was used. The technology's usability assessment and evaluation of how it affects the learning experience are presented, including learnability, efficiency, and user satisfaction. The application managed to help children with dyslexia concentrate and not be distracted. The results from the observation demonstrated that their overall performance has progressed.

The students also increased their experience and were happy with the applied features, such as the text layout of the application. However, testing the effectiveness of the application is required to obtain results that would be reflected in the students' improvements.

Similar work was completed by (Madeira et al., 2015), who proposed a mobile application (as shown in Figure 2.7) to teach Portuguese dyslexic students aged between 10 to 12 years old. The application has some exercises to determine the start of words, Rhymes (and so the end of words); Letter sequences in words; Words with a syllabic structure. Each of the four exercises has a question and several options. Four dyslexic students participated in this study. The application was tested by them on separate days in a week, testing it in four rounds of fifteen minutes each. They interacted smoothly with the application interfaces; they used all of the functionalities, which confirmed its usability. Mixed methods were used in this study, and the finding showed that the use of technology was appropriate for their needs, allowing people with dyslexia to obtain results comparable to those of regular readers. Various enhancements and additional functionalities could be added, such as the multisensory technique, memory, and sound workouts. However, in order to acquire more conclusive results, expanding the time period and the number of participants is recommended.

Figure 2.7 Screenshot of the Application (Madeira et al., 2015).

Additionally, research is needed to explore further how mobile tablet-based applications can improve students' communication skills (Berninger et al.,2015). To this end, Ismaili & Ibrahmi (2017) completed an exploration of accessing affordable AT applications among students with learning disabilities in Morroc; the applications were downloaded via Android's Google Play store.

The qualitative research design included observations of AT, including audio recording and screen magnification use by Moroccan students with learning disabilities. In this study, 57% of users expressed satisfaction with these mobile applications (Ismaili & Ibrahmi, 2017; Zain & Mahmud, 2018). However, the application's cost made it difficult for students to acquire them, which also impacted its combination with inclusion in the study; additionally, there were some compatibility issues with the AT applications with iOS phones (Ismaili & Ibrahmi, 2017; Pino & Mortari, 2014). It was noted that students who were able to purchase these learning applications were more motivated. However, the number of students who could not access those paid versions of applications would be limited while navigating (Ismaili & Ibrahmi, 2017).

Okolo & Bouck (2007) conducted a research study regarding mobile-based AT applications with 122 articles included in the following inclusion criteria; it was noted that minimal studies address how reading-related issues are targeted via AT applications (Staels & Van den Broeck 2015).

2.6 HCI Interventions for Dyslexic Arabic Students

From the previous sections, it is clear that HCI support can make interventions more effective and maximize learning for Dyslexic individuals. However, the majority of this research has taken place in English and other European languages (Allafi & Newbury, 2020). As noted by Almekhalfi & Tibi (2012), after studying the use of AT applications in academic UAE institutions that included 56 professional male teachers, five female teachers, and five male speech therapists, access to AT applications for all dyslexic students is needed to facilitate the academic achievement of the dyslexic population.

Similarly, Alghayth (2019) examined differences in the use of AT for teaching students with learning disabilities, including mid-tech and high-tech applications, based on the needs of Saudi students with dyslexia. A total of 92 special education teachers in the first phase and five-teachers in the second phase were interviewed to explore the effectiveness of AT applications and barriers to implementing them in classrooms. The researchers found a definite need for mobile-based AT applications to address and meet the needs of dyslexia students (Kanvinde et al., 2012; Almekhalfi & Tibi., 2012; Alghayth, 2019).

Researchers such as Saleh et al. (2013) proposed a fully accessible e-learning system for Arabic-speaking children with moderate learning disabilities in Qatar to support their thinking; The system supports and monitors the learning process for children with learning disabilities through supporting multiple interactive educational forms of media such as text, images, and a short video. The system also provides flexibility in terms of educational multimedia material delivery, taking into account children's skills and engagement speeds. However, this framework is just a proposal and needs to be investigated and examined by conducting an experimental study with dyslexic students to assess its efficacy.

To further assess how to develop and expand AT applications for teaching Arabic students with dyslexia, (Aldabaybah & Jusoh, 2018) proposed a set of needed features to create assistive technology for Arabic students. Two step-usability features for Arabic assistive technology were proposed. The first step was identifying the essential features by conducting experiments on standard educational technologies and receiving feedback from dyslexic students. Step two is creating a low-fidelity prototype and evaluating it.

To extract usability aspects, experiments were completed on two groups of participants (dyslexics and non-dyslexic students); six students between 7 to 10 years old were included. Feedback, accessibility, navigation, representative icons, and menus were all extracted as features. The prototype application has several games such as “letters learning, letters writing, fruits, birds and animals, colours, shapes and words”, as shown in Figure 2.8.

Figure 2.8 Screenshot of Proposed Prototype (Aldabaybah & Jusoh, 2018).

The usability features of the multimedia dictionary and other applications were assessed to gather information about overall responses and uses by special education experts. The results of the experiments showed that several assistive technologies with suitable characteristics were needed to help students read, such as; menu options, design, navigation, phonics and letter sounds, feedback, word comprehension, and program exit. Moreover, the study suggests a high population of students with special needs, specifically Arabic dyslexia children, who can and will benefit from assistive technologies to aid them in becoming better readers, writers, and communicators to increase the performance of reading and writing skills for students with dyslexia. However, this needs to be further expanded beyond the initial prototype as it focused on technology and theoretical frameworks rather than evaluating effectiveness. Additionally, this research needs to increase the sample size of participants to produce more indicative results.

Alsumait and Al-Musawi (2013) created an interactive storytelling tool to support Arabic students with learning disabilities by improving communication skills in an interactive way that also supported critical thinking; through the creation of the multi-purpose tool, enabling kindergarten students to create stories. The system architecture included the elements of a story: setting, characters, plot, and ending. (Figures 2.9 and 2.10).

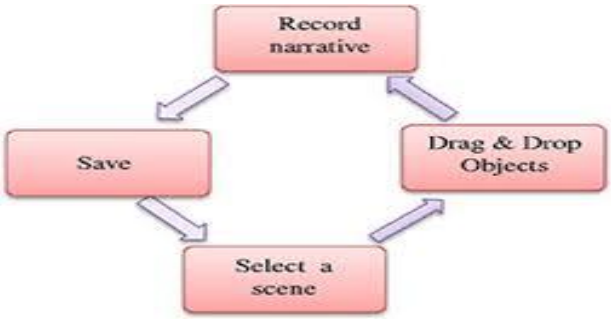

Figure 2.9 Story Creation Process (Alsumait and Al-Musawi, 2013).

Figure 2.10 CIS Tool Framework (Alsumait and Al-Musawi, 2013).

This tool which used a drag-and-drop interaction technique, was well-understood by children, who quickly embraced it. This was used to assess four characteristics which are creativity, self-confidence, general knowledge, and progression between the children and the technology. The participating children were aged four to five years old. The parents and instructors completed a questionnaire to measure their children's progress. Through many designed interactive storytelling tools, instructors and parents observed the child's improvement. Teachers' ratings of their children and those measured by the developed tool were found to be aligned in experiments, indicating that the interactive storytelling tool is valid. Furthermore, the proposed CIS framework for formalizing the design of interactive storytelling tools can be applied to children's educational interventions (Alsumait and Al-Musawi, 2013).

Students with dyslexia frequently struggle with visual attention, working memory, and rapid naming, which led (El Kah & Lakhouaja, 2018) to assess how games can be used to address the needs of dyslexic learners (as shown in Figures 2.11, 2.12, and 2.13).

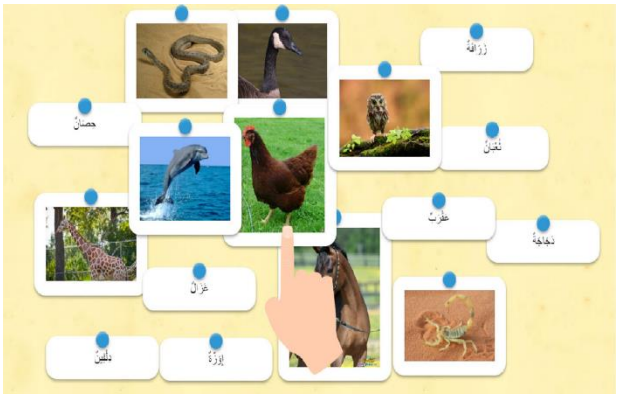

Figure 2.11 Screenshot of Letter Game (El Kah & Lakhouaja, 2015).

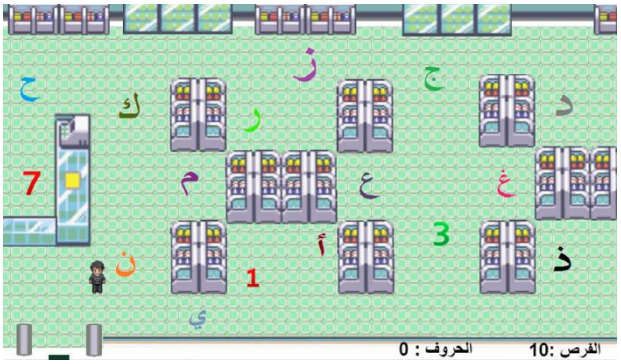

Figure 2.12 Screenshot of Word Game (El Kah & Lakhouaja, 2015).

Figure 2.13 Screenshot of Sentence Game (El Kah & Lakhouaja, 2015).

Noting that the games increase engagement and can potentially address learning deficits for Arabic dyslexia students, letter games, words games, and sentences games were used across multiple platforms. These games were highly motivational and gave students reasons to get the answers correct to advance through the games. In addition, clicking on appropriate letters, sight words, or creating sentences gave them more game experience and reinforced learning.

A total of 46 students from two primary schools participated; group 1 had 20 students with delayed learning, whereas group 2 had six students who were identified as dyslexic; group 3 had 20 students with no learning difficulties and a previous history of strong academic performance. All second-grade students took an examination before the games were implemented to assess their reading and spelling abilities. After using the games with the different content, students completed another exam that assessed reading and spelling tests. All participants were motivated, and it was noted that the user's attention was maintained due to the attractiveness of the system. The results showed that group 1 had 0.016 development in spelling and 0 development in reading; group 2 had 0.028 development in spelling and 0.026 growth in reading; group 3 had 0.025 in spelling and 0.021 in reading. Overall, most students scored equal to or higher on the follow-up exam, revealing that the games benefited each group. In this case, an intervention was used that helped everyone, not just the students with dyslexia.

Similar work was completed by Ouherrou et al. (2018), who designed and developed an educational game called “FunLexia” for children with learning disabilities to evaluate their skills in reading (as shown in Figure 2.14).

Figure 2.14 Screenshots of the “FunLexia” Game (Ouherrou et al., 2018).

It featured significant improvements in design, flexibility, interactivity, and error prevention. The application has three activities with different levels. In the first activity, the student is required to listen to the target word and then drag and drop letters in the right order to form the word. This activity aims to enhance children's reading skills. The second activity provides a set of jigsaw pieces. The child is required to use components to construct the picture and then select the appropriate written word. The third activity aims to improve children writing skills. In this activity, the child requires to write the sentences by completing the missing letters from a provided list.

Only eleven children with dyslexia participated in this study, aged between 8–12 years old, and specialists in special education were also involved in assessing the proposed game. The results indicated that children were satisfied and excited with the game. The obtained feedback from the specialists showed that the game is considered a supportive tool to enhance dyslexic children in increasing their learning process effectively and overcoming their reading difficulties. However, targeting specific dyslexia issues has to be taken into consideration; this research has not specifically targeted known dyslexic problems in terms of letter position dyslexia, visual developmental dyslexia, etc. Moreover, the evaluations have been measured based on `specialists` perceptions and questionnaires rather than quantitative analysis, and a more significant number of participants need to be involved to validate further the findings (Ouherrou et al., 2018; El Kah & Lakhouaja, 2018). Utilizing the online component to address the needs of children with learning difficulties, Alsumait and Al-Musawai (2013) developed interactive storytelling for improving communication and vocabulary building (Figure 2.15).

Figure 2.15 screenshot of Storytelling tool (Alsumait and Al-Musawai, 2013).

A total of 73 children aged 4-5 years old were used in the study to acquire descriptive statistical data for the 36 males and 37 females from three public and private schools. Through child interactive storytelling (CIS), the CIS framework included five dimensions: technology, pedagogy, user interface design, story elements, and cultural conventions. This study used a quantitative evaluation via a questionnaire (Likert scale) to help instructors/parents to assess the progress of the children.

Evaluations from the CIS framework were found to be a helpful tool with implications for future research that can be used to further expand the AT applications, thereby increasing the storytelling abilities of children with learning disabilities showing an interesting but not definitively evaluated intervention.

In Arabic countries, there is still a significant lack of combined tools that provide Arabic dyslexic students with suitable support for their needs. Thus, Benmarrakchi et al. (2017) presented helpful guidelines to foster and support students with dyslexia learning in Morocco using Information and Communication Technology (ICT). The suggested guidelines, such as Font style, should be clear to optimize letter readability and make them more apparent and exact. The text should be 12–14 points in size or greater, with no underlining or italics. Bold is encouraged, and at least 1.5 line spacing should be used between lines. Short, concise, and plain sentences are preferred in a direct approach. Layout refers to the length of the lines, which should be between 60 and 70 characters.

Avoid using narrow columns, bullet points, and numbers instead of continuous text, and avoid beginning a sentence at the end of a line. Use helpful graphics with dark-colored text on a light background. This study includes 28 students where 8 of them have dyslexia. According to the findings, most of the eight dyslexic students are visual and activist learners. This gives the possible benefits of ICT use for dyslexic students and concentrates on developing an adaptive m-learning game that utilizes technology to meet dyslexic students' learning methods. This may assist them in improving core abilities such as reading, writing, and mathematics. The data collected is used to analyze the spelling errors encountered by Arabic students. These guidelines need to be supported by experimental research and tested with an increased number of dyslexic users. However, preliminary findings reveal that dyslexic students improve their interaction skills, and the above-mentioned guidelines were taken into consideration in the application development discussed in chapter 3.

2.6.1 HCI Interventions for Dyslexic Students in Saudi Arabia

In Saudi Arabia, there has traditionally been a general lack of understanding regarding dyslexia. As a result, people with dyslexia did not receive the support they needed. This has changed dramatically in recent years due to community-awareness programs that have educated Saudis about dyslexia.

This assists with early detection and intervention, but there are still obstacles. Although there is a definite need for consistent support to assist persons with dyslexia, the research is limited in showing how the varying innovations help the Saudi dyslexic population (Al-Wabil et al., 2012; Alenizi, 2019). For example, Alghabban et al. (2016) used cloud-based M-learning framework architecture to deliver learning materials to dyslexic students to provide feedback and a forum to promote rich discussions. The most notable features suggested in the proposed framework are its ability to adapt to each student's profile and preferred learning method by integrating content in various formats (pictures, audio, and texts) and allowing students to interact with it by pointing at the screen; The results showed that further data is needed since most current mobile-based applications are not based on the proposed architectural framework. Currently, there is no data regarding the user requirements embedded in the proposed framework for dyslexia students in different regions of Saudi Arabia. Therefore, the practical viability of such frameworks remains questionable.

However, research in this area has confirmed that adopting technologies and interactive approaches can help enhance students' learning with dyslexia. For example, Aljojo (2020) developed an alphabet puzzle application to recognize Arabic words and their meaning by dyslexic students to increase their reading abilities (as shown in Figure 2.16). The application used Eye Tracking and a chatbot to keep dyslexic students motivated and monitor them, leading them to overcome their reading difficulties. This study includes visual-spatial attention to determine the accurate visual for dyslexic students' reading skills and the analysis of multi-decision criteria. Forty-two Saudi Arabian dyslexic students participated in this study. This study showed that the dyslexic students managed to identify Arabic words correctly and were also able to get the missing parts and explain the meaning of Arabic words accurately in a brief period, which helped them increase their reading skills. However, the system took time to set up, leading to a delay in interaction with the games. Additionally, using packages such as eye tracker and chatbot are expensive and impractical in many situations.

Figure 2.16 Screenshot of alphabet puzzle application (Aljojo, 2020).

Similar work has been completed by Al-Harbi et al. (2013), designing and developing an online multimedia language to assist Arabic speakers with dyslexia called MMD. This system uses a web-based multimodal lexicon instrument to help students overcome their disabilities in reading. MMD is a tool that connects words to their various media representations in the form of audio, video, animation, and images (as shown in Figure 2.17). Thus, there is a suitable and adequate method for assisting students with dyslexia in receiving the word`s meaning in a way that is accessible and understandable to their thinking.

However, the efficiency of these systems has not been assessed, and this is true of much of the research in this area.

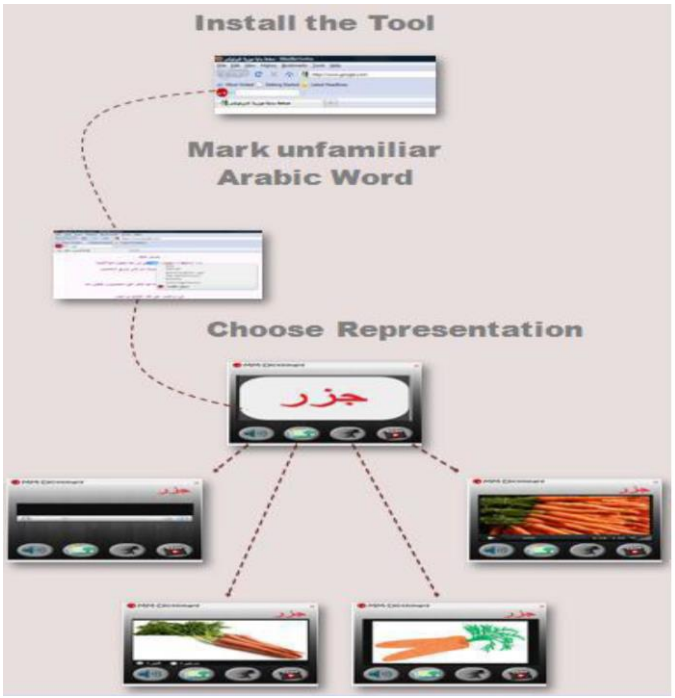

Figure 2.17 Design of MMD (Al-Harbi et al.2013).

In addition, Alghabban et al. (2017) developed a multimedia m-learning application for dyslexic students in the Arabic language. The proposed tool allows for manual interface adaption of the interface as well as multiple inputs and outputs modalities (written text, voice, and picture) based on the user's learning preferences (as shown in Figure 2.18). Twenty-eight students participated and interacted with the tool by using visual and audio support.

After three months of utilizing the application, an evaluation revealed improved reading skills by almost 30% based on their scores in pre and post-test, and the students were satisfied and motivated according to questionnaire findings. However, the sample size is small, and this study does not follow the guidelines stated by (AlRowais & Wills, 2014; Aldabaybah & Jusoh, 2018; Benmarrakchi et al. 2017) to include large font size, dark font color, etc., which might cause interpretation issues for dyslexic students leading to less engagement (Jamaludin et al., 2018, p. 1758).

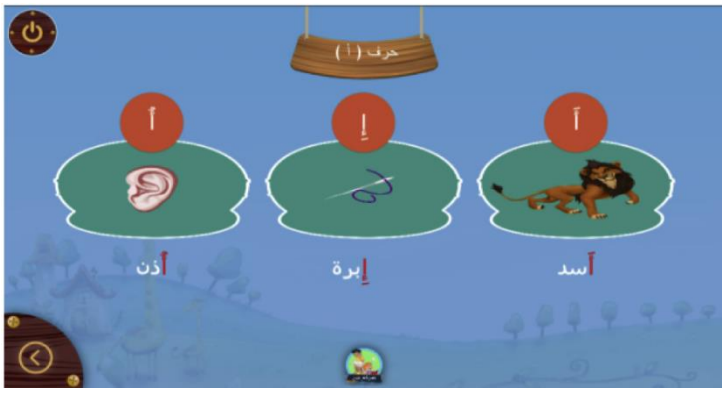

Figure 2.18 Screenshot of Multimedia M-Learning Application (Alghabban et al., 2017).

Other research has considered the mixture between e-learning systems and learning to support reading abilities. For example, Taileb et al. (2013) proposed a software application to aid dyslexic students in increasing their reading levels and spelling by providing a learning environment for students aimed at their senses (vision–speaking– hearing). YUSR is an application designed and implemented to support students' preferences, and learning styles with dyslexia (As shown in Figure 2.19). Over 500 examples of the Arabic alphabet were used in the application with different sounds of males and females. The application reached a recognition rate of 82% (recognition of twenty-three letters out of twenty-eight Arabic letters).

There was high identification of letters such as Jeem جيم and Ha'a حاء, but a low amount of identification in some letters such as Dal دال and Thal ذال and Seen سين and Sheen شين because of the similarity between them. The participants were seven (four girls and three boys) aged four to eight years old. The students were interested and engaged with the application and navigating between words and letters. Thus, this study indicated that the application had met the aim of providing an appropriate and engaging environment for students with dyslexia to enhance their levels in reading with the application. However, the low number of participants leads to low statistical strength, and it is difficult to identify if the results are valid findings. This research also lacks verbal instructions for each level, and the students' difficulties in reading might lead to them not fully understanding the activity of each level. Verbal feedback instead of text feedback is preferred to motivate and interest them with the application, increasing their engagement.

Appling diverse exercises to the application, such as multiple types of games and interactions would also potentially aid engagement.

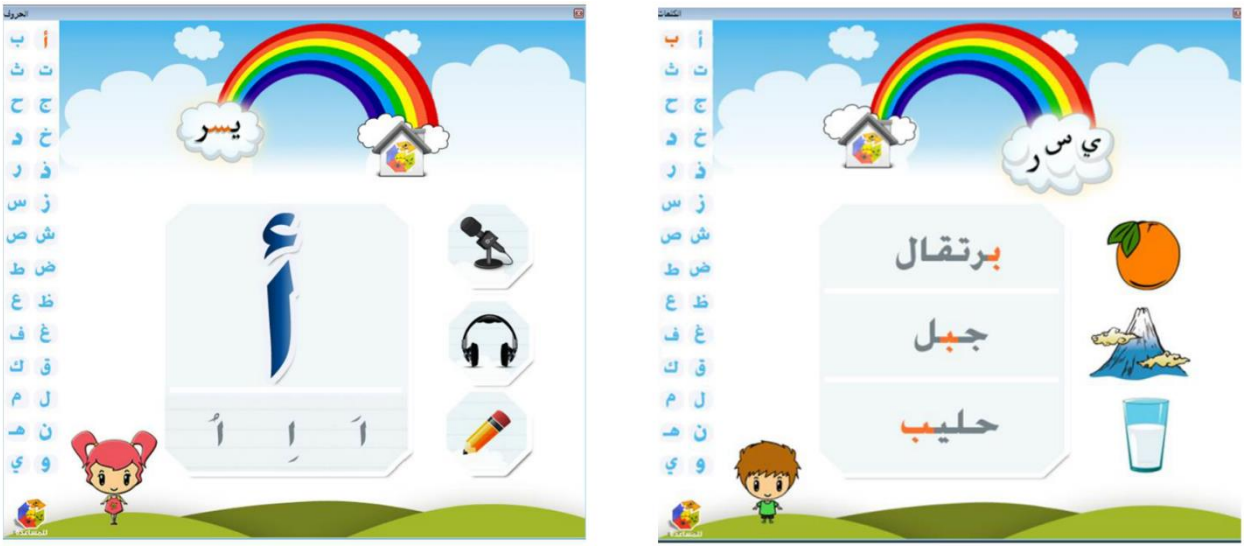

Figure 2.19 YSUR Interfaces (Taileb et al., 2013).

Another E-learning system developed to enhance students' reading levels with dyslexia was developed by Alghabban & Hendley, 2020. DyslexiaTypeTrain is a website designed to help Arabic dyslexic students improve their reading by providing word reading exercises (Figure 2.20). This study targets LPD as a specific issue that dyslexic students struggle with. The students were asked to choose a word that matched a target picture. There were eight sessions with 30 minutes for each. This study used pre, post, and follow-up tests to measure students' reading performance. Forty dyslexic females participated. The results indicated that post-test scores were higher than pre-test scores, meaning there was a significant improvement in the learning process of dyslexic students. (Alghabban & Hendley, 2020).

However, this study targets the specific problem of letter position dyslexia (for example, in English, instead of reading files, they read it flies). Based on the examples shown in Figure 2.20, there are one targeted word and two different words that are expected to be very similar to the targeted word in order to help them in avoiding the transposition of the letters. Still, the two choices are not similar to the target word leading a student to potentially directly recognize the target word without even reading the choices. In this case, once the researcher targets a specific dyslexic issue, the words provided as extra choices must be selected carefully and have to be matched to the symptoms they suffer from; for example when the researcher is targeting the word "walk", the other two choices should be matching the same letters in that word such as "wlak" and "wkal".

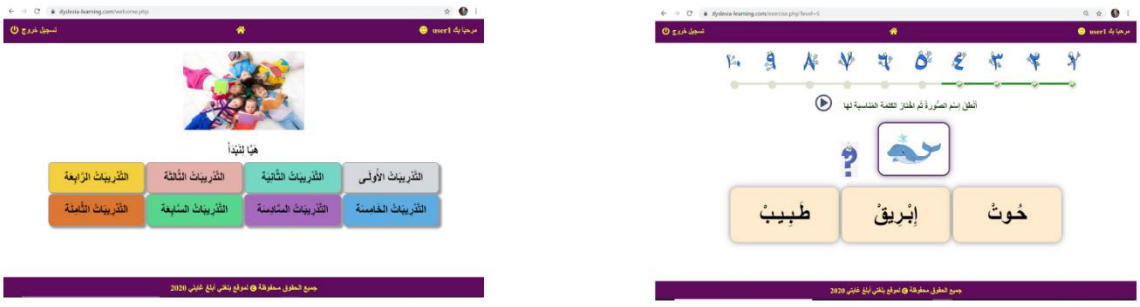

Figure 2.20 Screenshot of DyslexiaTypeTrain (Alghabban & Hendley, 2020).

Similarly, Alghabban et al. (2021) designed and developed a web-based e-learning system to measure the impact on reading performance; two experiments were conducted in this study which used a mixed-methods approach. The data collected in the first experiment was through observation to evaluate the students` interaction with the system (As shown in Figure 2.21). The system trains dyslexic students how to read appropriately using eight different reading activities, each with ten training sessions over a total of 80 exercises. These activities become more difficult once they move to the next activity. A word is spoken, and an image is displayed in each session, along with three options. Every option shows a different word. In this experiment, sixteen dyslexic females at primary schools in Saudi Arabia participated. They were aged from 9–to 14 years (Grades 4 to 6). The results from the qualitative analysis implied that the majority of students were motivated and engaged with displayed images and loud-reading features.

Alghabban et al. (2021) completed a further experiment with a second system to measure learning performance and student satisfaction; therefore, to assess the measurements, pre-and post-tests to evaluate students' reading level, and a satisfaction questionnaire. DysSkillTrain is a web-based e-learning system that follows the same procedure as DysTypeTrain in the first experiment intervention, including introducing the question, target word and its audio icon with three choices.

This study has six different sessions, and in each one, there are 20 activities with a total of 120. The difficulty gradually increases from one activity to another. After completing the activities, the students will receive motivational feedback as well as a total point score. Figure 2.22 shows one of the sessions. The web-based e-learning system was used with forty-one dyslexic females aged 7–10 years (Grade 2 to 4). The results showed a very positive effect which means that the post-test scores were higher than the pre-test scores, which yields significantly better learning. The intervention improved their reading level leading to a high level of satisfaction. However, in this study, using a website via a browser can potentially lead to usability issues for dyslexic students related to accessibility, such as the display of content on a mobile device or different size screens. As shown in Figures 2.21 and 2.22, there are two images in the background and one on the right side, which corresponds to the targeted word; this might lead to confusion.

Also, previous guidelines on reducing visual complexity have not been considered, and many colors and interface components are potentially distracting for dyslexic students.

Additionally, the dark background in the second system is not recommended. There is a lack of verbal instructions in both systems. Moreover, 80 exercises in the first experiment and 120 in the second system seem excessive and likely to be an issue for dyslexic and non-dyslexic children alike. This is likely to demotivate them and make them lose their engagement and interaction over time.

Figure 2.21 Screenshot of DysTypeTrain (Alghabban et al., 2021).

Figure 2.22 Screenshot of a DysSkillTrain (Alghabban et al., 2021).

HCI interventions, including applications, software, and websites that have been applied in Saudi Arabia, were reviewed and discussed, and the methods and findings of each research are shown in Table 2.3. Each intervention was reviewed and investigated to understand its design, development, evaluation, and contribution.

Table 2.3 Summary of Reviewed Interventions in Saudi Arabia.

	Author (s) and Year	Intervention Type	Sample Size	Methods	Findings
1	Aljojo, (2020).	Alphabet puzzle Application	42	Mixed-Method	Reading skills increased.
2	Al-Harbi et al., (2013)	MMD Multimedia Dictionary web-based	N/A	Qualitative	Test the proposed MMD effectiveness would promote the availability of Arabic web content.
3	Taileb et al. (2013)	YSUR Application Software	7	Qualitative	Reading levels enhanced
4	Alghabban et al., (2021)	DysTypeTrain Web-based	16	Qualitative	The students were motivated and satisfied.
5	Alghabban et al., (2021)	DysSkillTrain Web-based	41	Quantitative	Reading skills improved.
6	Alghabban & Hendley, (2020)	DyslexiaTypeTrain Web-based	40	Mixed-Method	Significant improvement in the learning
7	Alghabban et al., 2017	Multimedia m-learning Application	N/A	Quantitative	Students are enhanced in the learning process.
8	Al-Rubaian et al. (2014)	Games - Application	N/A	N/A	The initial prototype would engage users using interactive games.
9	Al-Edaily et al., (2013)	Interactive User Interface System	14	Quantitative	The technology swiftly and reliably gathered and evaluated gaze data in readings.
10	Al-Wabil et al., (2012)	Interface System	N/A	Quantitative	Cultural elements in system design are critical for ensuring acceptance of the created system, especially when it involves interaction context.

To conclude, there are still significant gaps in existing research conducted in Saudi Arabia concerning applying and evaluating assistive technologies that help dyslexic students enhance their reading skills. There is limited information showing how the varying innovations help the Saudi dyslexic population.

2.7 Summary

The task of meeting the needs of students with learning disabilities requires explicit training and instruction to accommodate their unique needs (Hemmingsson et al., 2009; Alenizi, 2019). With different learning disabilities existing, the strategies that work to meet the needs of one individual may be entirely wrong for another student (Kavale, 1988; Alenizi, 2019). Similarly, when looking at the specific learning disability, dyslexia, one must consider the challenges for students trying to learn foundational reading and writing skills (Edyburn, 2001; Saleh et al., 2013). For these students, learning letter sounds is a challenging task (Torgesen, 1993) and there are vast differences in how students with dyslexia learn based on their peers who do not have dyslexia (Saleh et al., 2013). Dyslexia can be a significant impediment to individual learning at schools, and it can also be challenging to achieve everyday activities such as reading and spelling (Sternberg &Sternberg, 2012). Early assistance is critical for people with dyslexia to minimize dyslexic issues. Various e-learning techniques have been established to teach students with dyslexia, and e-learning interventions can help dyslexic students succeed in school and work. Students with dyslexia can benefit from these interventions, which can teach, train or help them. The acknowledgment of these differences has led to various interventions, including HCI support, as reviewed in this chapter. Once again, the way these supports are put in place is not a one size fits all approach because the individual needs of learners are so unique (Okolo & Bouck, 2007).

As presented here (and discussed further in chapter 3), the Arabic language has notable differences from other languages worldwide, thereby requiring specific support for dyslexia learners using the Arabic language (Almekhalfi & Tibi, 2012; Alghayth, 2019). When one combines those differences with students from different cultures who speak other languages, more changes are required (Siegel, 2006). To maximize learning for these individuals, it is imperative to use a variety of HCI support adapting with technological developments to make the interventions more effective.

In many ways, these traditional approaches can be combined with state-of-the-art HCI support to yield favourable results and increased learning (Aboras et al., 2012). There are gaps that exist within this research, thereby solidifying the need for more research.

Currently, there is limited discussion of the interventions that are used to address Arabic populations with dyslexia. These issues can be addressed through targeted efforts that are innovative.

The review has found that based on the small number of available studies specifically related to e-learning, Saudi Schools lack dyslexia awareness (i.e., identified dyslexia type). There are very few studies that draw upon the theoretical understanding of dyslexia and use this to derive adaptive learning. Some of the current research needs to the evaluation of the efficacy of the proposed interventions (Taileb et al., 2013; Alghabban et al., 2016; Al-Harbi et al., 2013), and most of the research in this area has not identified dyslexia type in the given material in their interventions. Much research does not follow the recommended and appropriate guidelines for dyslexic students stated by (AlRowais & Wills, 2014; Aldabaybah and Jusoh, 2018), which leads to less engaging interfaces (Taileb et al., 2013; Alghabban et al., 2017; Alghabban et al., 2021). The symptoms of a specific type of dyslexia are often not matched to the provided learning material in the proposed intervention (Alghabban & Hendley, 2020). The small sample size (Taileb et al., 2013; Alghabban et al., 2017) in much research might also not provide a precise result. The results from some studies also indicate less engagement and interaction with the intervention due to missing some of the engaged components (Taileb et al., 2013; Aljojo, 2020). The experiment's period should also not be extensive as loss of engagement during sessions is more likely with Dyslexic students (Alghabban et al., 2021).

This is a significant gap in current research targeted at dyslexic students in Saudi Arabia. Thus, this research aims to extend the contributions of recent research on dyslexia and adaptation by highlighting the importance of developing a game-based mobile application that specifically targets dyslexia type in an attempt to overcome the limitations mentioned above. Importantly, this research investigates and examines the effectiveness of a proposed mobile application. Even though e-learning is not a new concept, it has yet to be generally adopted as the primary style of instruction (Palacios et al., 2020). After analysing the relevant research, this work aims to address a gap in current research by highlighting how e-learning dyslexia support in education can be effective, and its relevance to Saudi dyslexic students along with practical suggestions for directions to take in implementing change.

This adds novelty and originality to this research supporting the view that providing e-learning to dyslexic students learning Arabic significantly enhances learning skills.

As a result of COVID-19 pandemic closures, educational institutions around the world have become increasingly reliant on e-learning technologies. The prevalent use of smartphones and mobile devices in Saudi Arabia shows high volumes that indicate the need for application-based HCI support (Puri-Mirza, 2020) and the development of mobile applications has been the trend for the last two years to revolutionize the learning and teaching process. Thus, an engaging mobile game-based application with multiple interactions and media support types appears a promising avenue of development.

In the next chapter (Chapter 3), the game-based mobile application that will be utilized in this research to explore and analyze its impact on dyslexic students will be developed.

Chapter 3: Design and Development of An Arabic Game-Based Mobile Application

3.1 Introduction

As presented in Chapter 2, the literature review included a thorough review to identify and evaluate the current state of educating dyslexic students in Arabic countries, especially Saudi Arabia. The review has discovered that based on the small number of available studies explicitly relating to e-learning studies, Saudi schools lack dyslexia awareness. These results require exploring further into this matter with the target goal of helping dyslexic students.

In Chapter 2, some limitations and flaws have been reviewed. For example, very few studies draw upon the theoretical understanding of dyslexia and use this to derive adaptive learning. Some of the current research needs evaluation of the efficacy of the proposed interventions. Most of the research in this area has not identified the dyslexia type in the given material in their interventions. Much research does not follow the recommended and appropriate guidelines for dyslexic students, leading to less engaging interfaces. The small sample size in much of the research might not give a precise result. Some studies indicate less engagement and interaction with the intervention due to missing some engaged components. The period of experimenting should also not be extensive as loss of engagement during sessions is more likely with Dyslexic students. Other studies either did not conduct an experiment to test their proposed systems or employed only qualitative or quantitative methods.

A review of the work in Chapter 2 leads this research to propose a novel game-based mobile application aimed at Dyslexic students, which will endeavor to provide better results by using a set of games to engage students in the learning of the Arabic language and evaluate it and show the students' performance for each game. These games will target the most advantageous features identified in chapter 2 and apply these to increase the reading skills of dyslexic students. This chapter discusses the design of this application and its technical implementation and a description of each game in detail.

3.2 Game-Based Interactive System

The literature review in chapter 2 confirmed that using a game-based interactive system is likely to enhance the learning opportunities for students with dyslexia.

These findings are summarized here. Skiada et al. (2014) stated that "*Current research shows that games designed for mobile devices have considerable potential to encourage learning in the dyslexic population*". Giving students access to additional materials, including technology-based exercises they can access anytime and anywhere, will aid in combating their specific problems (i. e., visual and auditory perception, motor skills, and directional words) presented during the early stages of learning. El Kah & Lakhouaja, (2018) noted that a set of games for children with dyslexia is one means of improving the learning process. The previous studies confirmed that using applications and innovative technology will lead to engagement with an e-learning resource which helps dyslexic students to understand the difficulties that they frequently struggle with (Rello & Ballesteros, 2015). Madeira et al. (2015) noted that game-based applications are robust and highly useful while also being low-priced, making them excellent tools to support learning. The games have positive results; they are used as a source of information and assist dyslexic children in education. They have interested many researchers due to their potential to engage the children's attention. Therefore, games are generally very engaging, which is an issue for dyslexic students in general. Well-designed games use lots of mixed forms of media and interaction, which again has been highlighted as a key support feature for dyslexic students. Following research aimed to determine the best way to provide these modifications to dyslexic students, a game-based mobile application is proposed by this thesis as an ideal solution for providing assistive technological intervention to improve reading skills for dyslexic students.

3.3 The Benefits of Technology for Dyslexic students

Through multiple research studies, awareness of how varying interventions yield favourable outcomes has been obtained concerning dyslexia. Khakhar and Madhvanath, (2010) state, *"Conventional methods of teaching are often not effective for dyslexic children; the effects can be countered with appropriate pedagogical techniques and the use of information technology*" (p. 576). Fage et al. (2018) confirmed that the successful implementation of a growing number of digital applications assists dyslexic students with cognitive training. This means that there are new possibilities for assistance, rehabilitation, and evaluation of dyslexic students.

Jamaludin et al. (2018) illustrated that multiple exercise usage assists students in developing their reading skills, thereby creating a game-based interactive system ideal. Building auditory texts into the application support a student's desire to listen to it instead of reading it. "*Assistive technology has been used for decades to help students with reading disabilities*" (Svensson et al., 2021, p.1). Research is evident in supporting the benefits of using applications to support learners with dyslexia, thereby making it apparent that application development is key to meeting dyslexic students' needs (Svensson et al., 2021; Hemmingsson et al., 2009).

The need to assist dyslexic students in meeting their needs is great. Almmazmi, (2013) explored possibilities for developing interventions and support techniques for addressing students with dyslexia in UAE, thereby further supporting the development of game-based interactive applications.

Providing learning support via an application is an effective mechanism in a society with the ever-expanding use of technology. Applications accessed via tablets, smartphones, and other mobile devices have been noted to provide intervention effectively. Many Saudi Arabian people have multiple devices (i.e., smartphones and tablets), thereby providing a population with the basic framework required to access application-based e-learning support, with smartphone use in Middle Eastern and North American regions (Puri-Mirza, 2020). Study findings conducted via telephone interviews and observations confirmed significant improvements in the students' handwriting, spelling, written sentence syntax, and oral syntax composition when they have access to them (Berninger et al., 2015). Equally favourable according to the previously conducted literature review, Ismaili & Ibrahimi, (2017) note the ease of accessibility to AT applications based on prices in Android's Google Play store, with fifty-seven percent of users expressing satisfaction with these mobile applications. Purchases of these learning applications led to increased motivation (Ismaili & Ibrahmi, 2017).

According to the above mentioned, research shows that mobile applications with mixed types of media and interaction are a key way forward. Further review of the literature, specifically a mixed-method study design, relied on descriptive statistics to demonstrate the need for letter writing skills utilizing a multisensory approach to be further embedded within an application to assist Arab students with dyslexia. Thereby, this would further help in representative feedback and letter-sound comprehension (Aldabaybah & Jusoh , 2018).

The results of the usability features for Arabic assistive technology for dyslexia indicate the increased performance of reading and writing skills for students who used the prototype; meanwhile, this research shows the mere desire to use features that are already possible in applications with the need for further expansion (Aldabaybah & Jusoh, 2018). An additional literature survey confirmed that educators need more access to AT applications; Almekhalfi & Tibi, (2012) presented their findings with 56 professional male teachers, five female teachers, and five male speech therapists responding.

3.4 Introduction of the Arabic Language

Arabic is the official language in twenty-two countries, and it is used by approximately 230 million speakers worldwide (Boumaraf & Macoir, 2016). Arabic is written from right to left and contains 28 letters that form a morphological structure in both nouns and verbs. These letters are written in a cursive style, with all 28 being able to be consonants. Meanwhile, three can also be long vowels (ا و ي). Orthography or the typical spelling system does not represent the short vowels except for those short vowels found in beginning readers' texts. These short vowels do not allow the vowel to repeat its name. Verbs are typically constructed from three-consonant roots used in verbal templates, whereas nominal templates are usually used for three-consonantal nouns.

One also has to consider if the letter blends with the letter following it, which is based on the letter that follows it and refers explicitly to the letters: ا , د , ذ , ر , ز ,و (A, D, ð, R, Z, W). Different forms are based on mergers with other letters and positions. As shown in Table 3.1, 20 of the 28 letters vary in shape between initial, medial, and final positions to further understand the complicated nature. The other eight letters only change their positioning if litigation is involved. Another area that impacts how people with dyslexia interact with the language is diglossia.

This term refers to the dialects of vernacular ways the language can be spoken. For example, speaking Palestinian Arabic is quite different from speaking Standard Arabic (Friedman, 2014). While these other vernaculars use the same letters, there are notable differences.

Table 3.1 Variation in the form of letters (Friedmann & Manar, 2012).

Final non ligated	Final ligated	Medial ligated	Initial (or medial non ligated)	IPA	Graphemic transcription
ا	ا	ا	ا	a	A
ب	ب	بـ	بـ	b	B
ت	ت	تـ	تـ	t	T
ث	ث	ثـ	ثـ	θ	θ
ج	ج	جـ	جـ	ð	J
ح	ح	حـ	حـ	ħ	Ħ
خ	خ	خـ	خـ	x	X
د	د	د	د	d	D
ذ	ذ	ذ	ذ	ð	ð
ر	ر	ر	ر	r	R
ز	ز	ز	ز	z	Z
س	س	سـ	سـ	s	S
ش	ش	شـ	شـ	š	Š
ص	ص	صـ	صـ	ṣ	ṣ
ض	ض	ضـ	ضـ	ḍ	ḍ
ط	ط	طـ	طـ	ṭ	ṭ
ظ	ظ	ظـ	ظـ	ð	ð̣
ع	ع	عـ	عـ	ʕ	ʕ
غ	غ	غـ	غـ	ɣ	Ɣ
ف	ف	فـ	فـ	f	F
ق	ق	قـ	قـ	q	Q
ك	ك	كـ	كـ	k	K
ف	ف	فـ	ف	f	F
ق	ق	قـ	ق	q	Q
ك	ك	كـ	ك	k	K
ل	ل	لـ	ل	l	L
م	م	مـ	م	m	M
ن	ن	نـ	ن	n	N
ه	ه	هـ	ه	h	H
و	و	و	و	w/u:	W
ي	ي	يـ	ي	y/i:	Y
ة	ة				Ħ
ء (أ و ى)	ء (أ و ى)	ء (أ وئى)	أ / إ	ʔ	ʔ

Each Arabic letter is formed based on different factors. For example, is the letter found in the beginning, middle, or end of the word. Friedmann & Manar, (2012) discuss the dual-route model for single word reading with a cyclic process beginning with orthographic visual analysis. The diagram below in Figure 3.1 fully outlines the process. This diagram shows the dual-route model of reading loudly, which specifies the distinct parts of the reading process that are essential for each reader to learn, and was later used to interpret these diversities of dyslexia. The lexical and non-lexical routes are the two reading paths in this approach at a high level. When readers can recognize a word without using phonological knowledge or performing deep analysis, they use the lexical pathway. The non-lexical method, on the other hand, identifies letters and creates graphemes; after that, it maps these to phonemes that can be spoken aloud—the conceptual system relating to vocabulary and the meaning of the words. From there, the word's visual appearance and sound are examined to convert the graphemes and phonemes.

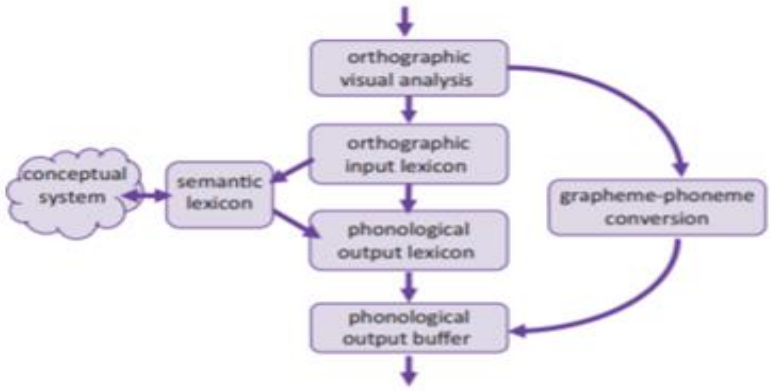

Figure 3.1 dual-route model for single word reading with a cyclic process (Friedmann & Manar, 2012).

3.4.1 The Similar Forms in Arabic Letters

The similar orthographic letters that share the same shape in Arabic language are 22 letters out of 28 such as (بـ , ثـ , نـ , تـ) can cause dyslexia signs to manifest. Moreover, the letters (خ ح ج) share the same shape, and the position of dots is the only difference between them. Aljojo et al., (2018) discuss the Arabic letters that the dyslexic students cannot distinguish between because of the similarities between them in shape (For example ر , ز , د, ذ).

Aljojo et al. (2018) also discuss how dyslexic students should have an education founded by helping them learn their letters. Then, they can begin to learn to say those words that contain the letters correctly. Finally, this builds into the various cases of the word.

Alamri and Teahan, (2017) noted the problems that dyslexic students may face in differentiating between letters such as ('غ') "ghyn" and letter ('ع') "ayn". These letters have similar forms and different sounds. When dyslexic students write these words, there are various errors made.

3.4.2 Dyslexia Types Addressed in the proposed application

There are multiple problems associated with Arabic letters. These various problems can make it difficult for dyslexic learners to read at a functional level. Understanding these problems can assist in better meeting the needs of dyslexic learners and creating assistive technologies to aid in reading skills. Friedmann & Manar, (2012) conducted a study to look at 150 children referred to the Language and Brain Lab for more diagnoses related to their dyslexia. The Arabic TILTAN screening test was used; this test includes 27 non-words, 23-word pairs, and 207 words that can detect different types of dyslexia. Students may show problems with the text-to-speech conversion route through this process, misreading words as other words, migratable words such as "يعلمون" (YALAMUN) being written as "يعملون" (YAMALUN) such a migration changes the word from they know to they work, words with middle letter migration problems, and letter position dyslexia. The results indicated that 40% of letter position errors mean transposing a letter's position to be in another position within the same word. A Full discussion of the tests' ability to assess visual and deep dyslexia was also part of Friedmann & Manar 's, (2012) study. The most common mistakes include omitting letters, adding letters, substituting letters, and transposing letters (Alamri & Teahan, 2017). Meanwhile, to further explore and diagnose the learning difficulties in Arab students with learning disabilities, the two key types of dyslexia error are outlined below:

1. Letter position dyslexia (LPD) is also called transposition of letters, and it occurs when letters are transposed, letters may get reversed by changing the position of letters. A specific example of this can be found in "يكبتون" (YAKBETWN) being written as "يكتبون" (YAKTEBWN) such a transposition would change the meaning from the pent up to they write. Predicting LPD generates more errors in reading while recognizing a word.

For example, "تمهل" – "تهمل" (TMHL-THML) in this example the meaning is changed from ‘slowed down’ to ‘ignore’, in which the letters H and M change positions but maintain their form.

Discussion of the templates with the same root may vary in the letter positioning; for example, "كاتب" and "كتاب" (KATEB) and (KETAB) 'writer' and 'book'. (Friedmann & Manar, 2012). Other target words can create new words because of letter position errors. This issue can be seen when a ligated letter moves to a position after a non-ligating letter like "جهاز" (JEHAZ) being written as "جاهز" (JAHEZ). The meaning of the former word is 'device', while the latter means 'ready', in which the H alternates between middle-ligating and initial/middle non-ligating forms. With the same letter in different shapes and positions, transposing middle letters in a word while keeping the original letterforms creates an orthographically illegal sequence.

These examples reflect an orthographically impossible sequence within frequently used Arabic fonts, thereby showing that fewer words are truly migratable (Friedmann & Manar, 2012).

2. Developmental Visual Dyslexia (DVD) is visual errors involving substitutions, omissions, and additions of letters (Friedmann & Manar, 2014). For example, omission of letter occurs if the student writes the "منزل" (MANZEL), which means a house instead of "منازل" (MANAZEL) which means houses. The addition of letter occurs when, for example, instead of writing " ولد" (WALAD), which means a boy, they write, "والد" (WALED), which means a father. Another example is "كتان" (KETAN) which means linen " كتان" when they meant to write "كتاب" (KETAB) which means a book. This is an example of the substitution of letters.

These errors, as mentioned above, create further increase students' problems as dyslexic individuals. Acknowledging these difficulties requires taking some action to remedy the situation.

Many steps were taken to assist the above issues in the application, and features were built into the application to help target both LPD and DVD.

3.5 Design of The Proposed Application

3.5.1 Applied Features

Previous research was used to acquire the top features to be included in this application. The goal of creating a learning environment that is specifically targeted at dyslexic students' providing more support than the traditional learning environment was the primary focus for this contribution.

Furthermore, it is imperative to use a multi-faceted approach to meet the needs of students with dyslexia as there are many different related interventions needed to enhance their learning experience. This section presents an overview of the application for the first experimental study. Technical implementation and a description of the application are included here.

AlRowais & Wills, (2014); Aldabaybah and Jusoh, (2018) have discussed the origins and key design decisions within the theoretical framework, including specific guidelines for helping Arabic students with dyslexia advance their reading skills.

They noted that the following components in assistive technologies are needed to support dyslexic populations. The following recommendations were applied in the proposed application:

First: *Simple design*

Since many dyslexic students cannot recognize a specific icon's purpose without great mental effort, it is essential to design an application or other assistive technology with this in mind. Navigation should be possible via a simple design. Students should easily navigate between options and words. Navigation can be difficult for dyslexic students, so an arrow to move forward or backward direction is a problematic design feature. Instead, minimizing navigation and having only the required arrow on the screen is better, or even choosing to have the program designed to follow a set study path automatically. Developing the identity of a home icon is one way to address this problem. In addition, being mindful of not including too many shapes or colours is essential, so these should be limited to only a few primary colours. No more than two images should be layered in the interface to encourage understanding rather than confusion. Design an application with fewer main menu options that will appear full screen even on mobile devices.

Second: *Auditory support*

Students with dyslexia need to hear the pronunciation of the words; consequently, having an audio feature is vital. Providing audio with each image and text, if possible, is very important.

Third: *providing feedback*

Giving encouragement and motivational feedback to the students during the learning process is fundamental; thus, students are aware of their mistakes and can self-correct them. Since reading the words correctly may be unusual for these students, including simple design, encouraging sounds, and feedback to help with immediate correction of misconceptions. The audio format will help students be interested; thus, verbal feedback in the proposed application is provided, they may hear clapping or encouragement words such as excellent or a good job, which is very motivated.

The proposed game-based mobile application included the above-mentioned recommendations.

3.5.2 Application Framework

The developed novel mobile application is cross-platform and uploaded to Google Play and the Apple store. This provides easy access from any mobile devices, including mobile devices and tablets. The application was developed using the Unity3D engine for the front end and visual studio from Microsoft to write the code in C# programming language.

3.5.3 Application Users

Two types of users are supported in this application, each with pre-defined functionalities :

1. **Admin**: The admin (e.g., teachers) is responsible for adding the list of words, audio, and images for the students.
2. **Student:** The students are the primary users; the application was built to address the common needs of students with dyslexia.

3.6 Implementation of The Proposed Application

In this section, the functionality of the application and its tools are discussed in detail. The proposed application is formulated with four-games; each game is distinct from each other. They are: matching up, word construction, letters bank, and listening words.

The games have common characteristics, including the font size and colors, instructions, wording, questions format, etc.

Madeira et al. (2015) noted that Arial is one of three fonts to help dyslexic individuals. In addition, this font should be presented using a minimum font size of 12 points and with dark-colored text. Green and red/pink colours should also be avoided. Thus, the ¨Arial¨ font is used in the application; this is a simple font that is clear on all devices and easy to read with a Heading size of 80, sub-heading of 30, and normal text size of 18. The font colours are dark for the text with a light background.

There are clear instructions given verbally and shown on the screen at the beginning of each game. These instructions aim to help each student to know how to play. In addition, the Menu page has a suitable colour palette and nominal graphics that are created without distracting stimuli.

The mobile application has forty words in thirty-five questions; they were intentionally chosen because they are part of students' standard Arabic curriculum. There is a clock that times how long the student spends on a question starting at 00:00; thus, they can observe how quickly they responded to a question. These data are apparent on-screen while the student is playing.

A report is generated at the end of each game that students can view, such as the number of correct and incorrect answers and the total time spent on all questions in each game. More data are not apparent to the students, such as date, time, the percentage of correct answers, time taken for each question, and the status of each question which is either right or wrong to measure the performance and speed of recognition of words; however, these data are collected as a part of the research.

When students start the application, a self-opening window (as shown in Figure 3.2) asks them to enter their name and ID, giving a random number to each participant.

If the students do not enter their ID, then a message will be displayed asking them to enter their ID (as shown in Figure 3.3).

Figure 3.2 Student Data.

Figure 3.3 Message for entering student ID.

After entering the correct data, the application will move to the Home Page, which has the menu of the games (as shown in Figure 3.4). The application has an arranged list of games from right to left on the home page, like Arabic style. The games begin from the first game and then move to the next game after the students end each game.

There is access only to a specific game at a time simplifying navigation and restricting the student to one particular game at any time. In the beginning, the first game will be opened, and the rest will have a lock on them. After completing the first game, the second game will be opened while the first game will be locked (and so for other games). This also helps avoid completing a particular game twice; thus, students' data will be consistent and not duplicated.

Figure 3.4 Home Page of the Proposed Game-Based Mobile Application.

3.6.1 First Game: Matching Up

The Arabic language has 22 letters out of 28 letters that are similar to each other in shapes such as (the letters Jeem جيم and Ha'a حاء), (the letters Dal دال and Thal ذال), and (Seen سين and Sheen شين). Thus, this game aims to assist dyslexic students in distinguishing between similar letters in shapes, which reinforces the visual developmental awareness to avoid the substitution issue of a letter with another letter that is similar in the form. This game is introductory to the application, thus it has five questions.

First, the student has the verbal instruction interface (Figure 3.5). Then the student starts playing and answering the game's questions, as shown in Figure 3.6.

The game uses matched columns; thus, there are two words on the left with two corresponding pictures on the right. Students can match the columns from both sides, either matching the text to the image from left to right or the opposite, by touching the text on the screen and dragging the finger to its corresponding picture. To help students understand the words, corresponding audio is available by clicking the microphone icon next to each image. Students can play the sound as much as they need to recognize the words accurately.

If the answer of the first word is correct (as shown in Figure 3.7), a line will stay on the screen then move to answer the next word; however, a cross mark will appear if the answer is wrong (as shown in Figure 3.8). After the correct answer, the student will move to the next question. Wrong answers also lead students to the next question.

Students will respond to five questions, and each question has two texts and two corresponding images. Upon completing this game, a report will be generated at the end of the game (as shown in Figure 3.9).

This report displays the overall performance in a current game (i.e., total correct answers, total wrong answers, and total time taken to complete a game). The verbal instruction for moving to the next game is available, and by clicking on the next game in a blue bar, the second game begins.

Figure 3.5 Instructions of 1st game.

Figure 3.6 Gameplay of 1st game.

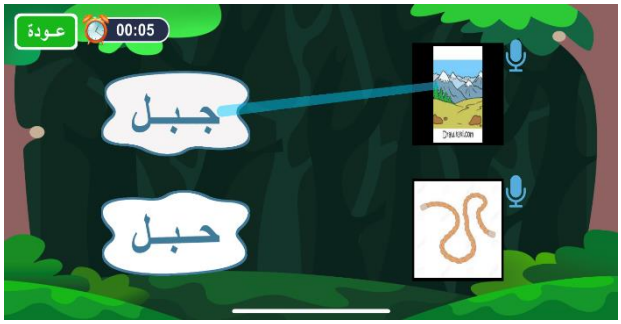

Figure 3.7 Correct answer.

Figure 3.8 Incorrect option.

Figure 3.9 Report of 1st game.

3.6.2 Second Game: Word Construction

This game aims to help students develop a more advanced ability to distinguish between similar letters in shapes. It is believed that students will be very enthusiastic about continuing a game; thus, this game extends the challenge for the students over the first one. This game has ten questions, thus increasing the difficulty from the five questions in the previous game. After moving to this game, the instruction interface will be shown (as shown in Figure 3.10).

In this game, students are provided three or four letters in different balloons with related pictures and audio; thus, this helps students recognize a word easily (as shown in Figure 3.11).

Students need to select an appropriate letter by tapping a specific balloon to pick a letter and making a completed and correct word (as shown in Figure 3.12.). Once the right balloon (i.e., letter) is selected, that balloon is removed, and the letter will be apparent in the grey box. There are two chances for each question in this game; a cross sign comes up if a student picks the incorrect letter (as shown in Figure 3.13); therefore, the student loses one chance. After two wrong attempts, then automatically navigate to the next question. At the end of the game, a report is generated as same as in the first game.

Figure 3.10 Instructions of 2nd game.

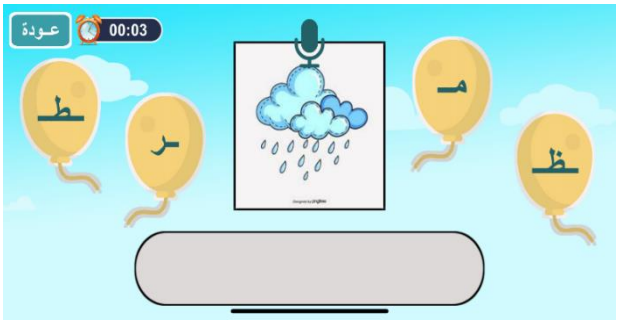

Figure 3.11 Gameplay of 2nd game.

Figure 3.12 Correct answer.

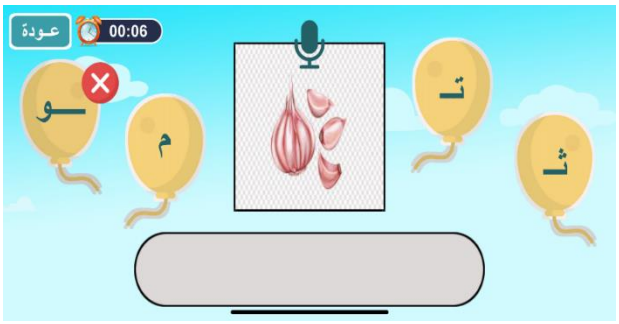

Figure 3.13 Incorrect option of a letter.

3.6.3 Third Game: Letters Bank

This game aims to help students avoid letter omission and addition, these two types of Visual Developmental Dyslexia. This game is more challenging than the second game as sequence letters need to be formed in a proper word; thus, the choices are only two, one of them is the correct answer and the second one is incorrect, the difference between them is only one letter. There are a total of ten questions in this game. After moving to this game, the instruction interface will be displayed (as shown in Figure 3.14).

In this game, three to four letters are provided with an accompanying image and audio as assisting tools. Students' task is to combine those letters to form a word by clicking the correct option (as shown in Figure 3.15). They can click on the Microphone icon to listen to the word to recognize words properly. Students will be directed to the next question whether they answered correctly or wrongly. However, this game only has one chance. Then, automatically move to the next question after a wrong answer (as shown in Figure 3.16). After completing the third game, a report is generated, as mentioned in previous games.

Figure 3.14 Instructions of 3rd game.

Figure 3.15 Gameplay of 3rd game.

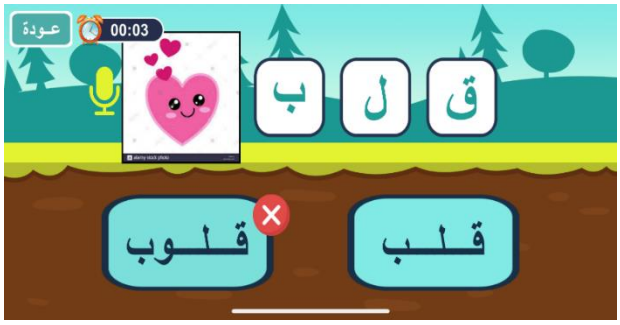

Figure 3.16 Incorrect answer.

3.6.4 Fourth Game: Word Listening

This game has targeted the issue (LDP) when words have the same letters; letters may get reversed by replacing the position of letters to select the order for the letters that form the word. Thus, this game assists students in avoiding letter order confusion which means the transposition of letters in a word. There are a total of ten questions in this game. After the student has moved from the third game to the fourth game, verbal instruction will be provided (as shown in Figure 3.17).

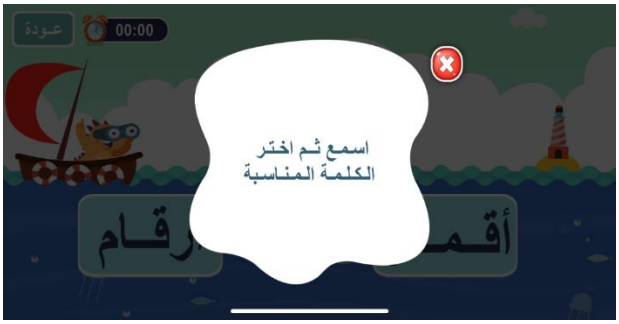

Figure 3.17 Instructions of 4th game.

In this game, an image and audio are provided. The audio as speaker icon helps students understand the images leading to accurately identifying the word. Moreover, students can play the audio as much as they need. The task for students is to recognize the image by the guidance of the audio and then select an appropriate text for it; there are two choices in each question. The difficulty here is the choices; because they contain the same letters, but the letters are different in order (as shown in Figure 3.18). Whatever the student clicks on the right or wrong option, they automatically move to the next question. There would be no chance for multiple attempts if the student picked the wrong option (as shown in Figure 3.19). After the student completes the fourth game, a report is generated as mentioned in the previous games, and at this point, the student has completed all the games. Students can simply terminate this game and log out of the application by clicking on the exit button in blue bar (as shown in Figure 3.20).

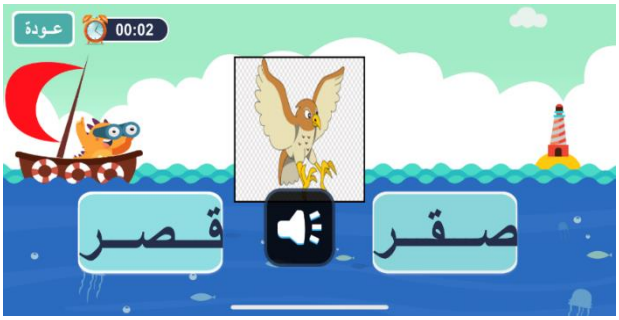

Figure 3.18 Gameplay of 4th game.

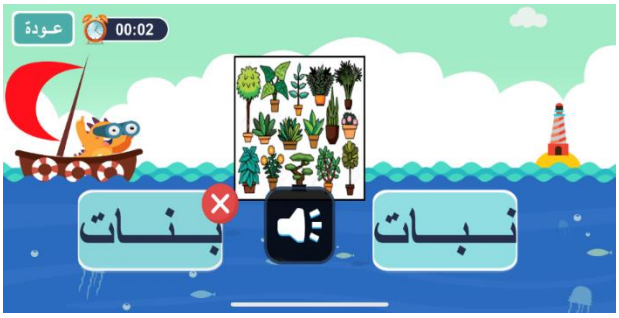

Figure 3.19 Incorrect answer.

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Figure 3.20 Log out.

After completing each game, the student's data is saved as a separate report and directly sent to the backend server (as shown in Figure 3.21).

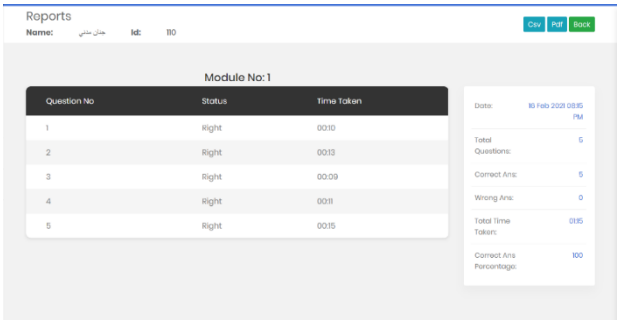

Figure 3.21 Students` Data saved in Server (i.e., 1st game).

3.7 Summary

This chapter has described the design and development of a novel game-based mobile application which is the significant contribution to this research. Mobile applications may become necessary as a learning aid for students with special educational needs, particularly dyslexic students. Thus, the proposed mobile application was tailored around the Saudi dyslexic students' needs based on research evidence for use in the first study. It offers a focused and efficient experience by using a set of games to accomplish good reading performance levels. The features have been used to construct suitable interactive learning material to meet the dyslexic students` needs and help them improve their reading performance and retain satisfaction. The stakeholders (i.e., students and teachers) are involved in updating the mobile application for use in the second study.

Therefore, the expectation is that the system will produce measurable achievements in the students' reading performance and have a significant positive impact. The general components and characteristics of the application have been explained in detail. In the next chapter (Chapter 4), the methodology will be applied to assess the proposed mobile application.

Chapter 4: Methodology

4.1 Introduction

The literature review included a thorough review in determining and appraising the current situation of dyslexic education in Saudi Arabia. According to the review, Saudi schools need to apply more HCI interventions that are helping in enhancing reading skills for dyslexic students based on the tiny number of published studies specifically relevant to e-learning studies. These results require to delve further into this matter with the target goal of helping dyslexic students. Thus, the game-based mobile application was designed and developed (as presented in Chapter 3). The main features assisting dyslexic students are used in the mobile application to support dyslexic students in improving their reading skills. The methodology outlined in the chapter aims to verify the effectiveness of the proposed game-based mobile application to increase students reading performance and satisfaction.

This chapter shows an overview of the study's methods, including an overview of the research methods, the acquisition of data, and the educational application used for experiments.

An experimental study was carried out with the participants in distance due to Covid-19 restrictions (first study). After analyzing the obtained results from the first study, the mobile application was improved based on findings and feedback for use in the second study. In this chapter, the procedures for both studies are included together. Additionally, each study is discussed in more detail in separate chapters (Chapters 5 and 6).

This chapter will explain the research approach used, followed by the research design, ethical considerations, sampling and participants, and the data collection procedure. Furthermore, analysis procedures will also be explained in this chapter, including statistical tests used to confirm/reject the research hypotheses.

4.2 Research approach

In academic research, data is often collected using a quantitative method, a qualitative method, or a mix of both. Previous research is generally used as a guide to facilitate any study’s approach along with its aims, objectives, and hypotheses.

Because of the researcher's planned observations, laboratory tests, studies, and other quantitative data gathering methods, the quantitative approach has been characterised as producing consistent data (Matveev, 2002). This approach considers a particular study problem and attempts to quantitatively (numerically) examine it. Quantitative research is based on a positivist philosophy, which holds that knowledge is objective and that information and experiences can be numerically measured and understood (Creswell and Creswell, 2017). The majority of quantitative methodologies are also deductive in character, meaning that the researcher builds their argument from the broad to the narrow (top-down approach). This enables the researcher to look up past studies, verify earlier ideas, present new hypotheses in response to such hypotheses, and then conduct tests, i.e., the process of theory leading to hypotheses, followed by observation and finally confirmation (Bryman, 2016). Quantitative data is commonly produced using closed-ended questions in a questionnaire. Thus, quantitative data allows the researcher to respond to the research hypotheses; accept or reject them. The quantitative approach, or using quantitative tools, allows for generalizability from a small sample to the bigger population; it is considered dependable, cost-effective and data is analysed using descriptive and inferential statistics to test the hypotheses.

Despite these advantages, the quantitative approach and the use of numerical data have drawbacks like any other method. The quantitative approach suggests that people have identical perceptions of a phenomenon; hence this approach is likely to produce abstract or shallow understanding of the research problem and is also likely to miss essential experiences. Using only a quantitative technique may restrict the participants' responses to the inflexible answers as pre-defined provided by the study designer via questionnaires and system data. As a result, the usage of questionnaires may limit users' responses to specified outcomes and offer no space for ideas or perspectives not included in the survey. Because of the limited nature of quantitative research, there may be a complete lack of a meaningful variable (Creswell, 2013).

The qualitative approach, which aims to produce subjective inductive knowledge and implies that people have varying viewpoints and experiences and that their experiences and knowledge are built based on their unique understandings (Cohen et al., 2011). More specifically, qualitative research often follows the interpretive research philosophy.

It is described as an "*iterative process that increases scientific community understanding by establishing new meaningful distinctions, by getting nearer to the phenomenon studied*" (Aspers & Corte 2019, p.139). Through the use of qualitative data gathering methods (such as observation and open-ended questions from questionnaires), this strategy provides the researcher with greater understanding and possibly knowledge which is considered new to the researcher and that the quantitative data could miss.

Although this approach holds certain advantages over the quantitative approach, it also has several limitations. The use of qualitative tools such as semi-structured interviews is expensive, and difficult to analyze, and the results are often not generalizable. Such studies are considered inductive in their nature, and do not seek to answer research hypotheses or determine correlations or causalities. Because qualitative data is subjective, it is problematic to generalize the results to the public. When the findings are widely utilized for broad populations because of the subjective nature of data and generally small samples, the validity of the qualitative findings may be reduced (Creswell, 2013).

According to Pathak et al. (2013), the qualitative research design is based on a humanistic or idealistic approach to understanding the research questions. It's used to figure out how people think, behave, believe, experience, and interact. It generates non-numerical data compared to the numerical information obtained by a quantitative research approach. Therefore, a single method based on either quantitative or qualitative data can make findings vague.

In this thesis, results (from a small sample to a bigger population). The mixed method approach is considered the best option for this study because it seeks computerized observable data and quantitative data from questionnaires and test results (i.e., pre-test and post-test in the second study). Pre-test/post-test designs are crucial assessment tools that support direct and efficient evaluation of the intervention to enhance students learning (Alam, T., 2019). To present accurate and comprehensive data that reflects the educational progress, a pre-test and post-test as an assessment process should be used. Pre-test and post-test evaluation methods are designed to assess participants' prior knowledge levels before using the application to measure their reading level and compare it with the information attained following the application to evaluate their reading performance. It is possible to determine whether the activity successfully improved participants' understanding of utilizing the

intervention by comparing the participants' post-test scores to their pre-test scores. The qualitative methods used were observation and the answers to the open-ended questions in the post-questionnaires to assess their interaction in terms of satisfaction with the mobile application.

To collect data and answer the research question, quantitative and qualitative approaches (mixed-methods) were used in both studies (first and second studies). The quantitative method is utilized for the results from the application, and some of the closed questions in pre and post-experiment questionnaires, along with the students' test scores (second study). The qualitative method is used for the findings of the observation (first study) and open-ended questions in the post-experiment questionnaires.

The chosen method was influenced by previous research in the field (Skiada et al., 2014; Madeira et al., 2015; Alghabban et al., 2021; Aljojo, 2020). Following a similar methodology to similar previous research allow the researcher to compare findings and relate to previous research findings. Although the quantitative and qualitative approaches are different in their purposes and underlaying philosophies, researchers can combine the two. One method compensates for the disadvantages or the limitations of the other. Combining different research approaches is referred to as the “mixed methods” approach. This follows a pragmatic research philosophy, i.e., the researcher uses different methods to generate different answers and understanding of the research problem.

There are different types of mixed method research designs, as Creswell and Plano Clark (2007) combined them into four basic typologies: the triangulation design, the embedded design, the explanatory design, and the experimental design (as shown in Table 4.1).

Table 4.1 Types of Mixed Methods Research Designs (Creswell and Plano Clark, 2007).

Designs Types	Definition	Challenges
Triangulation Design	Aiming to collect relevant but distinctly different data on a single subject that can subsequently be analyzed and interpreted.	The significant time and skill needed to put everything together and the possibility that differences between data sets will necessitate additional study and/or investigation.
Embedded Design	Employing one method of inquiry in a secondary supporting capacity lets researchers and readers understand the study as a whole.	In qualitative research, there aren't many instances from which researchers can model their study; therefore, it might be challenging to integrate data.
Explanatory Design	This is a two-stage approach because qualitative data is generated and interpreted using quantitative data as the base.	Lies in the time-consuming nature of this way of approach and the selection of participants to ensure that meaningful information is available.
Exploratory Design	When a researcher has no previous data or only a few studies to rely on, researchers use an exploratory research design to address their study challenge.	Due to the second phase is time-consuming, and participants may not be interested or able to engage in both phases due to the adequately prepared second phase.

In this thesis, the researcher defines this study as deductive (i.e., Exploratory design); however, other methods were rejected due to their disadvantages mentioned in Table 4.1. Thus, a mixed-method approach was used as an experimental design that aims to answer the research questions and hypotheses and achieve the research objectives.

When quantitative and qualitative approaches are used in tandem to eliminate uncertainty, a sequential, integrated research technique is recommended to ensure the validity of the data (Mertens and Hesse-Biber, 2012). Moreover, the flexibility of this study design, which Harwell (n.d., p. 160; supported by Bryman) says offers a "*promising path towards the use of research design in ways that promote thorough assessments of interesting educational concepts*," is another advantage of this approach. In that, the researcher is given a chance to address a problem using numbers and words and approach their study using the means with which they feel most comfortable (Almalki., 2016). Therefore, the data collected will be quantitative and qualitative. This approach examined the research's importance by analyzing the experimental results in several aspects, such as measuring improvements in student performance and how they feel regarding the application. These mixed-methods used for collecting data reflect the application's efficacy, reliability, and validity.

4.3 Experimental Design

The design of the research is distinctive because two different designs were used in this research, within-subjects design and between-subject design. The term "within" refers to comparing variables for the same group of individuals, whereas "between" refers to comparing variables between two or more independent groups.

The design used for each study is as follows:

4.3.1 First Study

A within-subjects design was used for the first study. All participants in the sample are subjected to the same treatment. The key independent variable here is “time/phase” (Pre-experiment and Post-experiment); an independent variable is a variable the researcher “manipulates”, which might have an impact on the research dependent variables (DVs: variables measured). The participants are questioned more than once (pre and post-experiment) to measure changes in outcomes (DV’s) such as attitudes, learning, and performance over time or due to different interventions (Bhandari, 2022). In this study, the participants are questioned before (using the application) by a pre-experiment questionnaire and after by a post-experiment questionnaire.

4.3.2 Second Study

In the second study, mixed designs "within-subject" and "between-subject" are used. Within-subjects design refers to pre and post experiment conditions (time/phase), while the between-subjects design refers to age as an independent variable with three different groups (i.e., 8 years, 9 years, 10 years). Between-subjects design usually has multiple groups that differ by age. The outcomes will be compared of different groups with each other (Bhandari, 2022).

The same within-subjects design was used compared to the first study; however, in this study, the researcher is also interested in seeing the possible differences between age groups when it comes to assessing/examining the DVs.

Each age group is exposed to the pre-test and post-test, which means each group is subjected to pre-test and post-test separately and combined for the purpose of analysis. This design is “within-subject” for each of these groups to test Hypothesis 1.

For Hypotheses 2 and 3, the researcher utilized Age (3-groups) as an independent variable; it measured groups differences in participants' scores in phase 1 (pre-experiment) and at phase 2 (post-experiment), i.e., measured differences between groups in students’ test scores (DVs) at both times separately.

4.4 Ethical Considerations

Both studies followed the ethical guidelines set by the University of Sussex and the Ministry of Education rules in Saudi Arabia. They were ethically approved by the Science & Technology Research Ethics Committee ER/RA480/1 and ER/RA480/2 (Appendix B) and Ministry of Education in Saudi Arabia. The researcher has the permission of the education authority and schools before data collection. The research has raised many ethical difficulties in the study because the research was carried out with children and had a set of heightened ethical responsibilities. Each researcher must follow the strictest ethical guidelines. Hammersley and Traianou, (2012) reduced ethical problems into five main concepts to make them easier to understand. First, limiting and reducing any actual or possible harm to participants, such as financial, physical, or psychological harm.

The research must not harm anyone, including researchers. Second, participants must be guaranteed their freedom and independence in participation; they are responsible for this (i.e., deception) must be avoided. Third, ensuring that they are aware of their privacy rights and what research will be made public and shared. Anonymity and confidentiality are crucial. Fourthly, presenting reciprocity requires participants to devote some of their convenience and own time to take part, which may disturb their everyday routine. Finally, the participants have a right to fair treatment without discrimination or favoritism.

The researcher verified participants' voluntarily informed consent in a way that was suitable for the individual and proportionate to the requirements of relevant law and research ethics. The researcher has followed the core research principles stated by Alderson and Morrow (2020) and Ofsted guidelines (Ofsted, 2022). Considering that the participants must be notified that the information will only be kept for the purpose for which it was gathered. The researcher made sure that the participant, especially if they were children, were given information in an age-appropriate manner. Additionally, the participants were informed of their freedom to withdraw for any reason or without giving any reason at all.

The researcher took all reasonable steps to protect the identification of data belonging to data collection, data storage, data analysis, and reporting. This is done to ensure the security of the personal and sensitive data of the participants. Only those who need to see the data, including the researcher and supervisor, can access it.

The researcher determined the length of protected data for the duration of the Ph.D. research. The researcher explained why they were gathering and storing data and let participants understand what would be done with it. Furthermore, data reduction rules were followed to minimize the possibility of identifying a specific participant from stored data. Adequate measures were taken to guarantee that personal data is periodically evaluated and removed when it is no longer needed for the work. The data was saved and deleted in line with data protection policy (Data Protection Act 2018), existing legislation, and the information provided to participants.

The materials for children were age-appropriate. All study designs were suited to children's attributes, including age and any specific educational requirements or disabilities.

Any potential harm to participating children was taken into account, as well as any measures that could be taken to lessen the impact (Ofsted, 2022; Alderson and Morrow., 2020).

Therefore, this study followed strict ethical guidelines. Participants were informed about the experiment/study (information sheet) and obtained their consent to participate (by signing a consent form). Participants were also questioned before and after the experiment. The study's consent form, information sheet, recruitment letter, experiment details, and pre and post-questionnaires were exposed to an ethical review.

The aim of each material used for this study is as follows:

1. *Information Sheet*:

This sheet explains why the study is taking place: to evaluate the reading experience and satisfaction level of participants using the mobile application during participation and provide all necessary information to participants before the experiment begins. The information sheet was for students` parents and teachers (Appendix B.3, B.6).

2. *Consent Form*:

The participants (teachers and students` parents) must complete a consent form before participating in this experiment; they will be notified that their participation is entirely voluntary and that all their information will be kept confidential. (Appendix B.4, B.7).

3. *Recruitment letter*:

The recruitment letter describes the aim of the research, offers all the information related to the experiment, and gives the schedule of the experiment. Additionally, researcher`s contact information is given to allow the participants to ask any questions regarding the experiment. This recruitment letter is mailed to all participating teachers and students` parents. (Appendix B.2, B.5).

4. *Pre and post-Questionnaires*:

These questionnaires were created to collect information on students' backgrounds and experiences before using the application and their opinions and feedback after using the application. Also, post-questionnaire for teachers to obtain their input regarding utilizing the application as a learning tool. A copy of the ethical review procedure is provided to the ethical review team (Appendix A.1, A.2, A.3).

4.5 Sampling Participants

A sample is a small selection of individuals/units from a population to determine and examine how accurate the population's results are (Field, 2005).

Research has two basic approaches: randomized and non-randomized (Groves and Fowler, 2004). Randomized sampling is the best method since it ensures that every person in the target people has the equal and same chance of being picked to participate. However, random sampling is time-consuming, challenging, and expensive; hence, this research has followed a non-randomized sampling method. The fact that some of the participants have a better probability of being selected than others is reflected in the non-randomized sampling method.

The benefits of this approach are that it is easy to implement and relatively cost-effective. According to (Groves and Fowler, 2004), there are two main methods of non-randomized sampling: convenience and purposeful sampling. The technique used in this research is purposeful sampling which means the researcher selects a person/participant due to their suitability to the experiment. To collect the sample for both studies, the participants were already diagnosed as dyslexic students based on the standardized tests approved by the Saudi Ministry of Education.

They were native Arabic-speaking students with a dyslexia diagnosis who were identified from different primary schools (i.e., three public schools in the first study and five public schools in the second study from three cities which are Aljouf, Jeddah, and Riyadh); their grades were third to the fifth year. The students were selected with the help of the teachers. Before the students participated in the experiment, their parents/guardians had to give their full agreement. The parents/ guardians were asked to read the information sheet to explain the experiment procedures to their children. Then the parents/guardians must sign the consent form on behalf of their children. Additionally, the researcher will briefly explain the experiment's steps for each student and ask for their verbal agreement before participating and collecting any information.

The first study was conducted to validate the experimental design and instruments before the second study (main study). A total of fifteen students (5 per group) and five teachers participated in the first study.

For the second study, forty-five students (15 per group) and six teachers participated. As both studies were conducted remotely due to Covid-19, there were limited participants.

4.6 Data Collection Procedures

This section covers the procedure of data collection in the first and second studies in detail.

4.6.1 First Study

This study aims to test the application's functionalities to obtain feedback from the participants before conducting the second study. The participants were already diagnosed as dyslexic students based on the standardized tests approved by the Saudi Ministry of Education. They were native Arabic-speaking students with a dyslexia diagnosis who were identified from different primary schools (i.e., three public schools from Aljouf, Jeddah, and Riyadh) in Saudi Arabia.

First, an information sheet was emailed to the schools' managers that included the experiment's nature and aim; after they agreed to allow their teachers and students to participate, they signed the consent form (Appendix B.1). Then, they have directed the researcher to the teachers.

Second, a recruitment letter was emailed to the teachers to explain the research's objective, giving all information relating to the experiment, and outlining the schedule of the experiment (Appendix B.2). After they agreed to participate, they were told that the experiment would take approximately forty to forty-five minutes to correspond to an entire lesson when students attend classes. More details were emailed as an information sheet (Appendix B.3). Consent forms were signed electronically (Appendix B.4).

Third, the teachers provided the parents/guardians of the dyslexic students a recruitment letter to explain the aim and steps of the experiment (Appendix B.5). Then, they were asked for permission to allow their children to participate by returning a consent form (Appendix B.7). Once parents/guardians have agreed to let their children participate, the researcher contacted them directly to discuss the experiment process.

As mentioned in the information sheet, the contact will be via the University email for more information about the experiment (Appendix B.6).

Fourthly, the parents/guardians were contacted to prepare a schedule and send the link to the pre-questionnaire (Appendix A.1). Then the applications` link was then sent to them to be downloaded on smartphones or tablets before starting the experiments.

The application was available on the Apple Store:

https://apps.apple.com/sa/app/إقـرأ-والـعـب/id1553130448/.

and Google Play:
https://play.google.com/store/apps/details?id=com.seraphic.withfunreading/.

Finally, a schedule was arranged with parents/guardians and teachers and time allocated to conduct the study.

The experiment was completed remotely via Microsoft Teams - the official learning platform in Saudi Arabia because of the closure of schools due to COVID-19. The participants were located in Saudi Arabia and were able to access the proposed application online. Before beginning the experiment, the students were greeted and informed about the experiment's goals. Then the students started using the application and playing the games from the first game to the fourth. They used all the mobile application features available during the experiment, including displaying pictures and reading-aloud features.

The experimenter and teacher attended virtually during the experiment to observe (via MSTeams) the participants` interactions regarding their improvements, engagement, and satisfaction during the experiment. The sessions were not recorded because of the schools` policy. Upon completing all four games, students completed a post-questionnaire (Appendix A.2). Additionally, after the study, the teachers completed a post-questionnaire to obtain feedback and their perspectives toward using the application (Appendix A.3). The questionnaire questions were translated into Arabic because it is the official language in Saudi Arabia. Therefore, the feedback from teachers and dyslexic students is obtained in the Arabic language and then translated into the English language for this thesis.

Data was collected using several tools; mentioned shortly below but detailed in the following chapters:

- **Pre-experiment questionnaire:**

This questionnaire aims to assess users' experience with electronic devices and a brief background about their reading to build an idea about their familiarity with using electronic devices such as phones and tablets. In this questionnaire, closed questions were used. (Appendix A.1).

- **Post-experiment questionnaire:**

This questionnaire aims to evaluate the participants' attitudes and behaviours and assess the participants' overall satisfaction and insights toward using the application. This questionnaire includes ten close-ended questions and four open-ended questions.

Some of the questions used in this questionnaire were stated by Ouherrou et al. (2018). (Appendix A.2).

- **Post-experiment questionnaire (Teachers):**

This questionnaire aimed to assess the teachers' points of view about using the application as an educational technique to increase the reading ability of dyslexic students. (Appendix A.3).

- **Generated data from the mobile application:**

This data aims to determine which age group improved the most and find observable age differences.

- **Researcher observation**:

This refers to the researcher's observations created during the experiment.

4.6.2 Second Study

The general methodology for the second study was similar to that of the first study. The procedure was explained in detail in chapter 6.

Following the modification of the mobile application (Chapter 6 Section 6.3) and adding pre-test and post-test, the second study was conducted with an increased sample size.

The target population of the second study was from different primary schools (i.e., five public schools from Jeddah, Riyadh, and Aljouf) in Saudi Arabia). This study was conducted again remotely due to the prevalent Covid- 19 restrictions.

Data was collected using similar tools used in the first study but with the addition of a **pre-test and post-test**. They include ten random words taken from the student's curriculum. Then, each participant was asked to read aloud the words one by one; hence, this took ten minutes approximately. The aim was to evaluate users' reading levels before and after using the application (Appendix A.4). After the pre-test was conducted, the students were not told their scores or which questions they answered wrongly, which means there was likely to be no intrinsic learning in taking the actual test. Thus, the improved results were considered solely down to the application.

In both studies, the students were assured that the procedure followed strict ethical guidelines based on informed consent, voluntary participation, anonymity, and confidentiality. Participants were informed that only the researcher and supervisor would access their data, and the data given would only be used for this study. Further information was provided to the participants before starting the session.

They were informed that their participation was voluntary and that they might leave at any time, without giving a reason, if they so desired. It was also emphasized that their school grades would not be impacted (not part of their study). Identifying information about the participants was removed (e.g., no names were kept). Furthermore, the data provided was retained on the researcher's computer in a safe (password-protected).

4.7 Analysis Procedures

In this section, the used methods to analyze the results from both studies are described as follows:

4.7.1 First Study

Once gaining the data from the first study, the findings were analyzed using a mixed method. The results from closed-ended questions in pre and post-experiment questionnaires, along with data extracted from the game-based mobile application, are evaluated quantitatively and descriptively using MS Excel 2019 and Statistical Package for Social

Science (SPSS). This statistical tool is widely utilized in educational research and is reasonably simple to produce statistical results.

Next, the results from open-ended questions' results in post questionnaire for (students and teachers) are qualitatively assessed using Thematic Analysis, along with the obtained observations.

Descriptive statistics are commonly used to interpret sample characteristics, such as questionnaire responses, demographic information, etc. The following are the descriptive statistics used to utilize in this study:

1. Frequency: This refers to the overall number of people who responded to a specific question.
2. Percentage (percent %): This indicates the percentage of people (out of the entire sample).
3. Mean: This is a scale's average score.
4. Standard Deviation (std.): This metric shows how far something deviates from the mean.
5. Median: The median of a range of ordered scores (in ascending/descending order) measures central tendency.

4.7.2 Second Study

This study follows the same methods of analyzing data in the first study. The second study tests the research hypotheses using two well-known statistical tests. The results from gaining data from the second study were analyzed using descriptive and inferential statistics. Adding to the first study's descriptive statistics, the Median was used, the median of a range of ordered scores (in ascending/descending order), a measure of central tendency.

Inferential statistics differ from descriptive statistics because they aim to confirm/reject research hypotheses and extrapolate results from a larger population sample. A repeated measures design (measuring differences between the results` pre and post-experiment) and a between-subjects design (measuring differences between groups (i.e., 8 years, 9 years, 10 years) were used in this study. This design was used according to the research hypotheses.

The data were analyzed using the two tests, with a significance level set as alph (α) = 0.05 to obtain a 95% confidence level that the differences are related to Independent Variables employed (i.e., pre-test, post-test conditions, and group ages).

Two inferential tests were used to test the hypotheses as outlined in the following sub-sections.

4.7.2.1 Two-Related-Sample Test Wilcoxon Signed-Rank Test

Following within-subjects design, this non-parametric test indicates that if scores from two times (pre and post) for the same participants significantly differ ($p<0.05$). This test enables the researcher to decide whether students' scores are different between pre-test and post-test in all groupages in general and then separately. The level of significance of the difference between two times is displayed in this test. The researcher can evaluate whether the first hypothesis can be rejected or accepted by checking them.

This test is utilized when the data (for the dependent variables) is not distributed normally. The Median has reflected an excellent indicator of the main tendency.

4.7.2.2 Kruskal-Wallis Test

Following the between-groups design, this test enables the researcher to determine whether participants' scores differ between groups at the pre-test and post-test stages. Then the researcher can evaluate whether the second and third hypotheses can be accepted or rejected. This is also a non-parametric test and used because the data does not support normal distribution i.e., the frequency of scores (for a particular variable) does not follow a bell-shape distribution, implying that the mean does not accurately reflect central tendency. It should be noted that using the non-parametric tests in the second study due to the small sample of participants and the results` distribution did not follow the parametric rules.

Qualitative analysis: Simple form thematic analysis was used to evaluate several open-ended questions. This qualitative data analysis method seeks to find themes/ patterns within data that are textual (Braun & Clarke, 2006).

4.8 Summary

This chapter has explained the methods and design used in this research study as well as how they have influenced the collected data. It first presented the general introduction, then described the quantitative method is ideal for this study. The design of the experiment is considered experimental. They were using the game-based mobile application as an intervention. The researcher followed a mixed approach to facilitate studying age differences (i.e., 8 years, 9years, 10 years) while also measuring potential differences between students' pre-test and post-test reading levels. The first and second studies followed an ethical technique using two related statistics to test the hypotheses (second study) and questionnaires (both studies). The first study to assess the application's functionality and to gain a better perception and understanding of the research procedure and potential design flaws. The first study was conducted with fifteen dyslexic students and five teachers. This was followed by the second study with forty-five dyslexic students and six teachers, in line with the research design, methodology, and procedure. The proper procedures for data analysis are employed in the following chapters.

Hence, the findings from the first study will be reported and discussed in the next chapter.

Chapter 5: First Study

5.1 Introduction

A game-based mobile application was presented in chapter 3. This application aims to enhance the reading skills performance of students with dyslexia in Saudi Arabia. This chapter provides details of the first study that has been carried out. The primary purposes of the first study were to ensure that the application was usable for those students, test the experimental methodology in practice, and analyse qualitative and quantitative data of the effect of the game-based mobile application on students' reading performance. Overall, in this experiment, dyslexic students who are the focus of this experiment - were aged from eight to ten years old (Grades third to the fifth year) primary schools Saudi Arabia. The participants were already diagnosed as dyslexic students based on the standardised tests approved by the Saudi Ministry of Education. This chapter presents a quantitative data analysis method taking into account closed-ended questions in the surveys and the students' responses with respect to the developed mobile application. The score data from the actual games were analysed to quantify any effect on learning.

Additionally, a qualitative data analysis method was generated from the observation findings and the open-ended questions in the surveys. These results generated evidence concerning the participants' satisfaction and engagement while using the proposed mobile application. As well as concerning the validity of the experimental methodology. The following subsections provide details about the experiment's objectives, participants, the location of the evaluation, the experiment procedures, and the data analysis approach.

5.2 Objectives of Experiment

The main reason for carrying out this study is to test the proposed game-based mobile application's usability, functionalities, and interfaces. Aiming to understand how students with dyslexia interact and engage with the application before launching the second study. In addition, it is aimed at ensuring that the game-based mobile application works very well and has no usability problems (i.e., glitches, synchronization, storing issues). The outcome of this experiment is to assess both the performance and opinions of the dyslexic students and consider the teachers' views to develop a game-based mobile application that can be used confidently in education to meet the dyslexic students` needs.

5.3 Sampling Participants

Initially, fifteen native Arabic-speaking students with a dyslexia diagnosis were identified from different primary schools (i.e., three public schools from Aljouf, Jeddah, and Riyadh) in Saudi Arabia. The students were aged from eight to ten years old (Grades third to fifth). Generally speaking, all the participants had previous experience with electronic devices based on the pre questionnaire findings. In addition, students had approximately the same prior reading skill level, with no observed difference between them.

5.4 Experiment Location

The experiment was completed remotely via Microsoft Teams - the official learning platform in Saudi Arabia due to the closure of schools because of COVID-19. The participants were located in Saudi Arabia and were able to access the proposed game-based mobile application online.

5.5 Experiment Procedures

Ethical approval was obtained from Sussex University Sciences & Technology C-REC to carry out the experiment (Ref: ER/RA480/1) (Appendix B). Each student has completed the experiment individually. For the first step of the study, the dyslexic students were asked to answer a pre-experiment questionnaire with the help of their parents/guardians before beginning the practical session. The questionnaire evaluates their previous experience using electronic devices to identify how familiar they are with them. Additionally, their attitudes towards reading (i.e., words or sentences) to have a background about their engagement with reading in general. This questionnaire included a little information about the study, and it required parents/guardians to consent on behalf of their children before starting the experiment. The parents were then asked to download the application from either the Apple Store or Google Play store. The features of the mobile application were described to the participants, including how to login to the application, how to start the games from the first game up to the fourth one, how to use visual and auditory tools, the process for each game, how many numbers of trails they have for each game, and how to log out from the application when completed.

The participants spent approximately forty to forty-five minutes with the games. The application was accessible via tablets or smartphones and enabled participants to play the games by interacting with pictures, words, and audios.

During the session, the researcher and the teachers observed each participant while using the application via Microsoft teams. Notes were taken during the observations. The session did not use video screen recording or audio recordings during observations. Upon completing the games, the participants were requested to contribute to a post-experiment questionnaire about their experience with the application and evaluate their overall satisfaction. After that, the teachers were asked to complete a post-experiment questionnaire to capture their feedback toward the game-based mobile application and participants' performance.

5.6 First Study Findings

In this section, the results of the closed-ended questions are assessed quantitatively using MS Excel 2019 and descriptive analysis, along with data extracted from the game-based mobile application. Next, the open-ended questions' results are qualitatively assessed using Thematic Analysis, along with the obtained observations. Once the observations, questionnaires, and participants' data are analysed, they will be discussed in (Chapter 7) aiming to shed light on their contribution to the research outcomes.

5.6.1 Pre-Experiment Questionnaire

As mentioned above, fifteen dyslexic students participated in the first study, as shown in Table 5.1. Closed-ended questions were designed in this questionnaire.

Table 5.1 Sample description-Age

Age	No. Participants	Percentage
8 years	5	33.3%
9 years	5	33.3%
10 years	5	33.3%
Total	15	100%

As shown in Table 5.1, the participants who participated in the first study were equally divided. Therefore, each group represents 33.3% out of the whole number of participants. They are in the range of age between eight and ten years.

This section discusses each question of the distributed pre-experiment questionnaire as follows:

Q1. Using Electronic Devices at home:

Table 5.2 Do you use your own electronic devices at home?

Responses	No. participants	Percentage
Yes	13	86.7%
No	2	13.3%
Total	15	100%

All students had experience and access to using electronic devices at home, but as can be seen from Table 5.2, most of the dyslexic students who participated in the pre questionnaire (86.7% ≈ n=13) have experienced using their own electronic devices at home, while only 13.3%, n=2 have not owned personal electronic devices.

Q2. Types of Electronic Devices participants used at homes:

Table 5.3 What type do you use?

Types of Electronic Devices	Responses		Percentage of Using Device
	No. Participants	Percentage	
Mobile	15	62.5%	100%
iPad	5	20.8%	33.3%
PlayStation	2	8.3%	13.3%
Laptop/Computer	2	8.3%	13.3%
Total	24	100%	N/A

Note: Multiple choices were available.

As presented in Table 5.3, all the dyslexic students who participated in the pre questionnaire (100%≈n=15) have access to mobiles, which represents the most frequent device amongst devices; since it represents 62.5% of the total responses, followed by iPad, which was owned by 33.3% (n=5) of the participants. iPad comes in the second rank since it represents 20.8% of the total responses. As seen in Figure 5.1 the percentage of using these devices by the participants. Since we have fifteen participants and the total responses were 24, this gives an indication that most participants owned more than one electronic device.

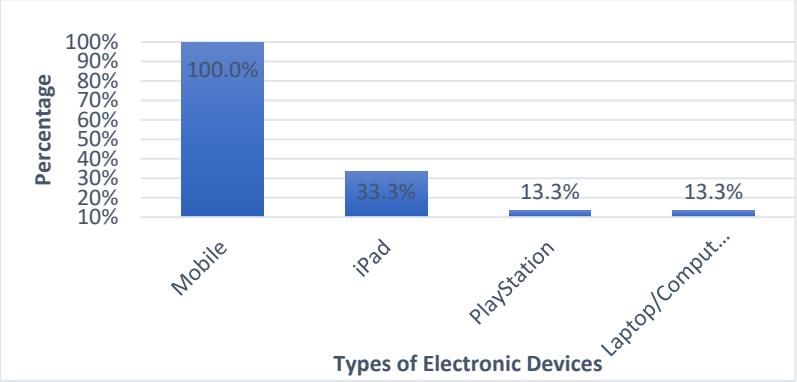

Figure 5.1 represents the percentage of Electronic devices that have been used at homes.

Q3. Purposes of using Electronic Devices

Table 5.4 What do you use it for?

Purposes	Responses		Percentage of students
	No. Participants	Percentage	
Playing games	13	40.6%	86.6%
Watching YouTube	14	43.7%	93.3%
Communicating with friends\family	5	15.6%	33.3%
Total	32	100%	N/A

Note: Multiple choices were available.

As it was displayed in Table 5.4, most of the dyslexic students who participated in the pre-questionnaire (93.3%≈ n=14) used their electronic devices to watch YouTube, and this purpose represents the most frequent purpose amongst purposes (common purpose); since it represents 43.7% of the total responses—followed by using electronic devices for playing games (86.6%≈ n=13). Finally, using electronic devices for communicating with friends/family came at the least, since n=5 (33.3%) of the participants reported using their electronic devices for that purpose. as seen in Figure 5.2 the percentage of the purpose of using these devices by the participants. Since there are fifteen participants and total responses of 32, this would give an indication that most of the participants had answered with more than two purposes for using the electronic devices. It is worth mentioning that watching YouTube and playing games can be considered the common purpose of using a device. This demonstrates that the participants have a solid understanding of how to use games in general, which supports the idea for the proposed mobile application.

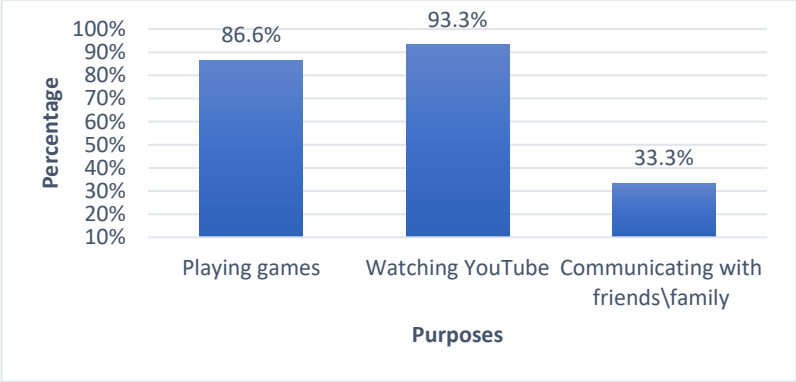

Figure 5.2 represents the total percentage of the frequency purpose while using electronic devices.

Q4. Time spent using electronic devices

Table 5.5 How often do you use per day?

Responses	No. Participants	Percentage
Three hours	4	26.7%
More than three hours	11	73.3%
Total	15	100%

As can be seen from Table 5.5, almost three-quarters of the dyslexic students who participated in the pre questionnaire (73.3%≈ n=11) spent more than 3 hours a day using electronic devices at home. In contrast, the rest of them (26.7%≈ n=4) spent 3 hours or less a day using electronic devices.

Q5. Students` attitudes towards enjoying reading words or sentences

Table 5.6 Do you enjoy reading words or sentences?

Responses	No. Participants	Percentage
Yes	9	60%
No	6	40%
Total	15	100%

As shown in Table 5.6, slightly more than half of the dyslexic students who participated in the pre-questionnaire (60%≈ n=9) responded positively "=Yes" when they were asked, "Do you enjoy reading words or sentences"; In comparison, the rest (40%≈ n=6) have negative attitudes towards enjoying reading words or sentences.

This question asked dyslexic students about reading enjoyment in words or sentences at school, whereas the application targets only words. This lets them distinguish between reading for fun and reading for learning in schools.

Q6. Preferring reading the word with an expressed picture and a loud reading:

It is worth mentioning that all the dyslexic students who participated in the pre-questionnaire (100%) indicated that they preferred reading words with expressed pictures and a read-aloud feature for support.

5.6.2 Post-Experiment Questionnaire

This section reviews the participants' post-experiment questionnaire to evaluate the application useability and participants' overall satisfaction and insights, including closed and open-ended questions. As mentioned previously, fifteen dyslexic students participated in the first study. The analysis is based on MS Excel 2019 and SPSS.

1. **Attitudes of the dyslexic students towards reading from smartphones:**

Upon completing the experiment (i.e., playing an educational game-based mobile application), the dyslexic students were asked, “Do you think learning reading through applications will be useful”?. It was found that all students (100%) responded positively “yes”. This result indicates that all the participants have good attitudes towards reading by games from electronic devices.

In addition, all of the participants responded positively “yes” when they were asked, “Did you feel happy when you were playing the games?”. Even though six participants did not enjoy reading words or sentences as they answered question five in the pre questionnaire, they enjoyed reading by using the application according to their answers.

Moreover, all participants responded positively yes” when they were asked, “Do these types of games make the reading easy?” This result indicates that all the participants had good attitudes towards the ease of using the mobile application in enhancing reading skills for dyslexic students.

2. The similarity of letters when playing the games:

Table 5.7 Were you able to distinguish between similar letters while playing the games?

Responses	No. Participants	Percentage
Yes	11	73.3%
No	4	26.7%
Total	15	100%

As presented in the Table 5.7, almost three-quarters of the dyslexic students (73.3%≈ n=11) indicated that they were able to differentiate between similar letters (which can be confusing) when they were playing the games. In comparison, only four participants (26.7%) responded negatively. This question is related to the similarity of letters in words in the application. An issue needs to be addressed by using the application, which is the substitution between similar letters in a word. Thus, the first and second games aim to distinguish orthographic and similar letters in shapes (there are 22 similar letters out of 28 in the Arabic language).

3. Blurring of letters during reading:

Table 5.8 Do the letters become fuzzy or blurry when you read ?

Responses	No. Participants	Percentage
Yes	1	6.7%
No	14	93.3%
Total	15	100%

As shown in Table 5.8, the participated were asked that "Do the letters become fuzzy or blurry when you read" it was found that most of the participants (93.3%≈ n=14) responded negatively "No". Letters appearing blurring is a common effect of dyslexia (NHS, 2021). The results of this question seem to suggest that the application is good at avoiding this issue with participants in the post-experiment questionnaire, meaning that they saw the letters clearly and easily distinguished them through the mobile application.

4. Items that participants liked in the application:

Table 5.9 What features did you most like in the application?

Items that participants liked	Responses		Percentage of students
	No. Participants	Percentage	
Displaying Words	7	28%	46.7%
Pictures	5	20%	33.3%
Easiness of using	5	20%	33.3%
Sounds	4	16%	26.7%
Layout	3	12%	20%
Verbal encouragement	1	4%	6.7%
Total	25	100%	N/A

Note: Multiple choices available.

As Table 5.9 shows, the most common answers were retrieved from the participants when they answered the above open question about the most exciting items. Hence, the items in the above-mentioned table were categorized based on the participants' answers. Almost half of the dyslexic students who participated in the post questionnaire (46.7%≈ n=7) responded that they liked how the words were displayed while using the application. This choice represents the most common choice enjoyed by participants. Hence, this response represents 28% of the total responses (25 responses). In addition, the participants preferred the pictures/images and Easiness of using the mobile application (33.3%≈ n=5) of the sample. The sounds used in the mobile application were in third place, where it was preferred by 26.7% of the participants. Only one participant out of fifteen participants liked the verbal motivational after the correct answer as their top choice (6.7%). As seen in Figure 5.3 the percentage of each feature that participants like . Thus, four of these (displaying words, using images, sound, and verbal encouragement feedback) are features that mainly engaged the students. This is a key thing available from a mobile game-based application and not necessarily from standard book-based learning. Ease of use is also a good result suggesting that this is a key thing that the students found. The responses above show that the features available from a mobile game-based application are very well received.

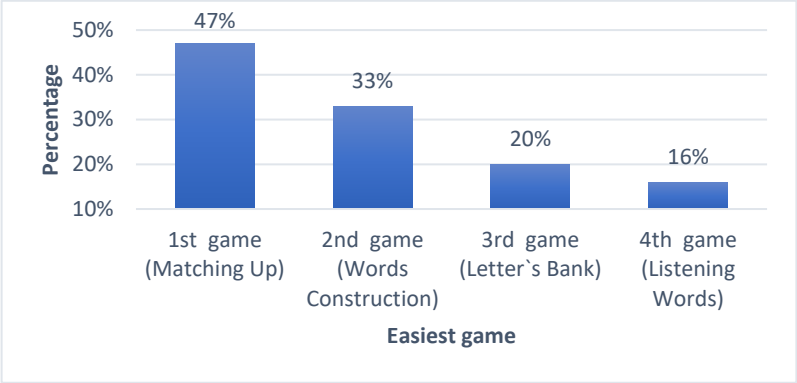

Figure 5.3 represents the total percentage of each item that participants like.

5. The Easiest parts in using in the application:

Table 5.10 Which part of the mobile application was easy to use?

Easiest parts of the application	Responses		Percentage of students
	No. Participants	Percentage	
Displayed pictures	10	25.6%	66.7%
Words pronunciation	8	20.5%	35.3%
Dragging and dropping game	7	17.9%	46.7%
Navigating between games	7	17.9%	46.7%
All parts in the games	7	17.9%	46.7%
Total	39	100 %	N/A

Note: Multiple choices available.

As presented in Table 5.10, most of the dyslexic students who participated in the post questionnaire (66.6%≈ n=10) indicated that they enjoyed the reading with displayed pictures part and stated that it was the easiest part when were experimenting. This response represents a quarter of the answers (25.6% of the total responses). The Speech pronunciation was in the second place that the participants liked (35.3%≈ n=8%). Then, Dragging and dropping game, Navigating between games and all parts in the games (46.7%≈ n=7) for each, respectively. As can be seen from Figure 5.4 the percentage of the each feature that considered easy by participants. These findings indicate that the parts in the mobile application that the participants found most straightforward to use are not necessarily the exact parts that they liked most; this suggests that their engagement is not just driven by ease of use and that characteristics and the features of the mobile application make it enjoyable even if that component is not considered the easiest part to use.

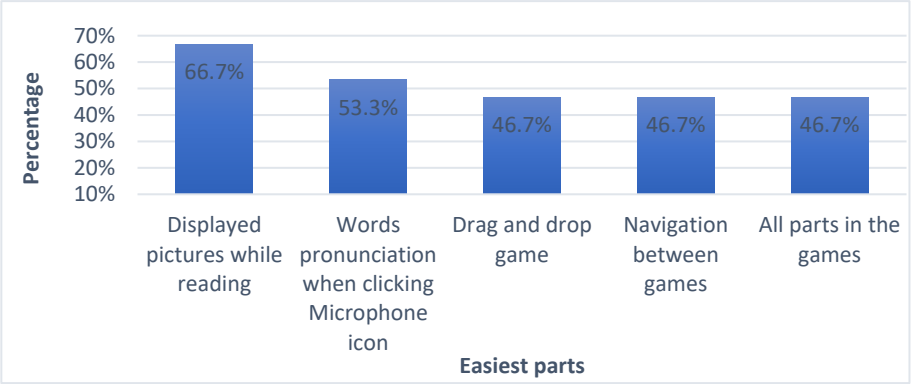

Figure 5.4 represents the total percentage of each item considered easy by participants.

However, all of the dyslexic students who participated in the post-experiment questionnaire (n=15) had no comments regarding the question "Which game/s in the mobile application was difficult to use" nor regarding the question "What feature did you most dislike in the mobile application?" for example, the application has many graphics, the chances of each question are not sufficient … etc.". This can conclude that participants did not experience specific difficulties in terms of both usability and playability while navigating through the games.

In addition, all of the dyslexic students who participated in the post-experiment questionnaire (n=15) responded positively "yes" when they were asked, "Did the pictures and read-aloud reading help improve understanding of the words/texts?". This finding indicates a higher level of acceptance for the application among the participants; since they agreed that pictures and read-aloud reading help improve understanding of the words/texts.

Moreover, all participants in the post-experiment questionnaire (n=15) responded positively "yes" when they were asked, "Does the way the words are presented attract you to focus on them?". Thus, the result indicates that participants have an excellent and positive attitude towards the attractiveness of the way the words are presented in the application.

6. Attitudes towards the use of games in the application in enhancing reading:

Table 5.11 How do you feel about using games in the application in enhancing reading?

Responses	No. Participants	Percentage
Satisfied	13	86.7%
Not satisfied	2	13.3%
Total	15	100%

As can be seen from Table 5.11, the dyslexic students were asked, “How do you feel about the use of games in the application in enhancing reading” it was found that most of the participants (86.7%≈ n=13) were satisfied, while a couple of them were not (13.3%≈ n=2), these two students are discussed in more detail in the next section. This result indicates that participants in the post-experiment have positive feelings towards the belief that the games-based mobile application is useful in enhancing reading.

7. **A trade-off between the reading from the traditional way using textbooks and the HCI mobile application (games-based):**

Table 5.12 Would you prefer reading from softcopy or hardcopy books?

Preferences	No. Participants	Percentage
Softcopy (Games- applications)	13	86.7%
Hardcopy (School textbooks)	2	13.3%
Total	15	100%

As presented in the table 5.12, most of the participants in the post questionnaire (86.7%≈ n=13) prefer the games-based approach. In contrast, only two preferred reading from school textbooks (13.3%≈ n=2). These two students were unsatisfied with using the mobile application because they liked reading the school textbooks. Also, based on the observation, they were not convinced of the dyslexia diagnosis they have; hence, they resisted the additional support, which they thought was too easy for them. Overall, this result indicates that participants in the post-experiment questionnaire had supportive opinions towards reading through the proposed mobile application.

In the post-experiment questionnaire, the participants asked, “Do you find the design of choices (i.e., fonts, colours, … etc.) making reading easier?”. The results indicate that all participants (n=15) felt that their reading skills improved while playing the games.

5.6.3 Post-Experiment Questionnaire – Teachers

This section discusses the teachers' point of view when they were surveyed.

1. **Attitudes of the teachers towards the proposed game-based mobile application :**

The participating teachers were asked “Do you think the application is useful for dyslexic students? Justify?”. All of the participating teachers (n=4) answered “Yes”.

Their common responses were that the students interacted with the proposed mobile application positively. Some of them said:

(Teacher 1) "*The mobile application is excellent and wonderful*".

(Teacher 2) "*The mobile application has effective features that are easy to use, and will contribute to solving many issues related to dyslexia in Saudi Arabia*".

In addition, all of the teachers (n=4) agreed that the proposed mobile application is a reliable tool that can improve students' reading skills. Moreover, the participating teachers believe that students would become more engaged while reading and learning via the mobile application, so they realize information better and faster. Two teachers stated:

(Teacher 3) "*since the written words in the school textbooks are not enough for dyslexic students to improve their reading skills*".

(Teacher 4) "*the mobile application provides helpful features such as audio-visual tools to help students identify words more easily*".

2. Improving understanding of the words/texts provided by the game-based mobile application:

All the participating teachers agreed that the application assisted in improving the dyslexic students' comprehension of visual and auditory tools when they were asked, "Did the pictures and aloud featured help improve understanding of the words/texts? Explain". The found answer was that teachers indicated that pictures and aloud features attract students' attention while reading. Three teachers said:

(Teacher 1) "*It was increasing students' concentration. In addition, pictures are used as a tangible tool in which the sense of sight can be a sufficient to help students in remembrance".*

(Teacher 2) "*Since the student does not understand the written word only while reading from the school textbook, they can see the word's picture*".

(Teacher 3) "*Students can hear a voice repeating the pronunciation of that word, then the word becomes clear to them, and they can read it clearly and more correctly*".

3. Teachers' points of view regarding the most positive aspect of the game-based mobile application that make the students more satisfied and engaged:

The participating teachers were asked, "What is the most positive aspect of the application?" Two teachers stated:

(Teacher 1) "*The application is exciting, characterised by audio-visual means that increase students' attentions*".

(Teacher 2) "*It is easy-to-use, full with appealing pictures, clear and pure engaging sounds, and the game-based mobile application's theme is attractive and picks students' attention".*

In addition, all of the participants (100%) believe that the mobile application will make the reading process more easier and fun due to the students' enthusiasm towards the games. Two teacher stated:

(Teacher 1) "*When games strategy is applied, it will improve the educational process; as dyslexic students need a new and entertaining method to help and empower them while reading*".

(Teacher 3) *"The dyslexic students would engage and interact with games in general. Therefore, if entertainment is mixed with reading, this could be an effective way to improve the reading skills of students with dyslexia*".

At the end of the questionnaire, the teachers were asked whether they would add anything to improve the proposed mobile application. The participated teachers were engaged with this question, and one of them suggested making the colours of fonts dark and the background light which is the recommended way for dyslexic students.

Also, the pronunciation of the words should be repeated multiple times; this helps them in better reading. Overall, they stated that this mobile application hopefully becomes the future helping tool for dyslexic students.

5.7 Students Data from the Game-based Mobile Application

This section will discuss the descriptive analysis of students` responses obtained from the application.

The application consists of four distinct games, and fifteen dyslexic students from three age groups (i.e., eight to ten years old) participated in the study. The participants' total scores of each game were stored in a database for further analysis.

1. Students` Performance at the First Game:

The first game composes five questions. This game aims to distinguish orthographic and similar letters in shapes as there are 22 similar letters in the Arabic language. It is considered an introduction to the proposed game-based mobile application; so the students with dyslexia would become more familiar with it and pique the participants' attention and concentration.

Table 5.13 Descriptive analysis of the students' performance in the first game.

Age	No. Participants	Total Scores	Mean	Percentage	Std.
8 years	5	18	3.6	72%	0.55
9 years	5	20	4.0	80%	0.71
10 years	5	21	4.2	84%	0.84

Std.= Standard Deviation.

As presented in Table 5.13, the ten-year-old participants have scored the highest percentage in the first game (84%, Total= 21, Mean=4.2, Std=0.84). Followed by participants at age nine years old (80%, Total=20, Mean=4.0, Std= 0.71), while students at age eight years old have the lowest scores in the first game (72%, Total=18, Mean=3.6, Std=0.55). A might be expected the first game results indicated that students aged ten years old were the best and have a better base reading performance when compared with others as seen in Figure 5.5 .

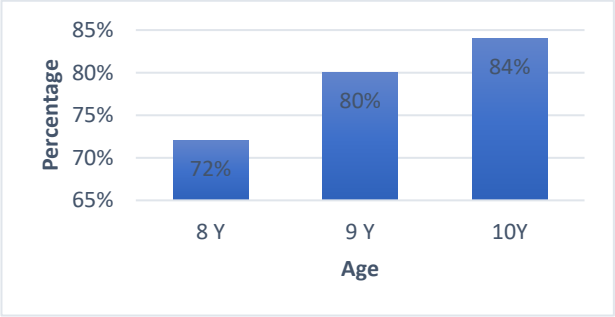

Figure 5.5 Participants' scores in the1st game.

2. Students` Performance at the Second Game:

The second game composes ten questions. As mentioned previously, the Arabic language has 22 letters similar in format; this game is also considered to help dyslexic students differentiate between those similar letters.

Table 5.14 Descriptive analysis of the student's performance in the second game.

Age	No. Participants	Total Scores	Mean	Percentage	Std.
8 years	5	32	6.4	64%	1.82
9 years	5	37	7.4	74%	0.55
10 years	5	46	9.2	92%	0.84

Std.= Standard Deviation.

As Table 5.14 shows, again students at age ten years old have the highest scores (92%, Total=46, Mean=9.2, Std=0.84), followed by students at age nine years (74%, Total=37, Mean=7.4, Std= 0.55), while students at age eight years have the lowest scores in the second game (64%, Total=32, Mean=6.4, Std= 1.82). The second game results indicated that participants at age ten years old have a substantially better reading performance when compared with others as can be seen in Figure 5.6. It was expected that the older participants get better results in reading performance due to higher educational attainment in terms of vocabulary. Interestingly, the ten-year-old`s performance increased with respect to the first and second games, while the eight and nine-year-old did less well in this second game, although not significantly worse. This suggests that the second game level works well for the range of students, but that eight and nine years old did find it more challenging.

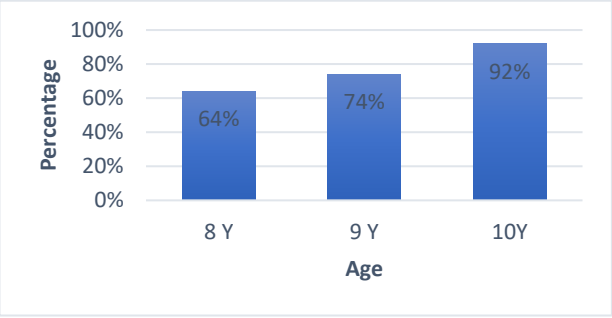

Figure 5.6 Participants' scores in the 2nd game.

3. Students` Performance at the Third Game:

The third game composes ten questions. This game aims to help students to avoid the omission and addition of the letters in a word.

Table 5.15 Descriptive analysis of the student's performance in the third game.

Age	No. Participants	Total Scores	Mean	Percentage	Std.
8 years	5	40	8.0	80%	1.58
9 years	5	42	8.4	84%	1.67
10 years	5	38	7.6	76%	1.14

Std.= Standard Deviation.

As Table 5.15 shows, students at age nine years have scored the highest when compared to others (84%, Total= 42, Mean= 8.4, Std=1.67), followed by students at age eight years (80%, Total= 40, Mean= 8.0, Std= 1.58), while surprisingly students at age ten years have scored the lowest (76% ,Total= 38, Mean= 7.6, Std= 1.14). It was clear from the observation that two participants in the ten-year-old group lost their engagement with the application at this point impacting the results. Thus, the participants in the nine-year-old were the best and scored highest marks as can be seen in Figure 5.7.

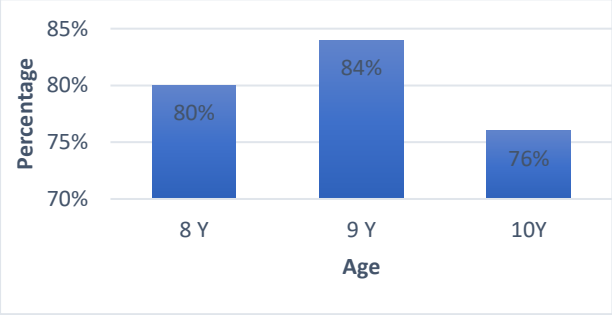

Figure 5.7 Participants' scores in the 3rd game.

4. Students` Performance at the Fourth Game:

The fourth game composes ten questions. This game aims to help students avoid transposing the letters into a word.

Table 5.16 Descriptive analysis of the student's performance in the fourth game.

Age	No. Participants	Total Scores	Mean	Percentage	Std.
8 years	5	35	7.0	70%	2.24
9 years	5	39	7.8	78%	2.49
10 years	5	47	9.4	94%	1.34

Std.= Standard Deviation.

As Table 5.16 shows, participants at age ten years have the highest scores when compared to others (94%, Total=47, Mean=9.4, Std=1.34), followed by participants at age nine years old (78%, Total=39, Mean=7.8, Std= 2.49), while the participants at age eight years have scored the lowest (70%, Total=35, Mean=7.0, Std=2.24). Interestingly, the ten-year-old's performance increased concerning the fourth game (as seen in Figure 5.8) and they have improved their reading in the first, second and games , whilst the eight and nine-year-old did less well in them, although not significantly worse. This suggests that the games` levels work well for the range of students but that eight- and nine-years-old found it more challenging.

To sum up, the majority of results are as expected with older participants doing better on average than younger participants. However, the good results (all results between 65% and 94% would suggest that the application is at the right level, i.e. no group was failing badly, and no group achieved 100%.

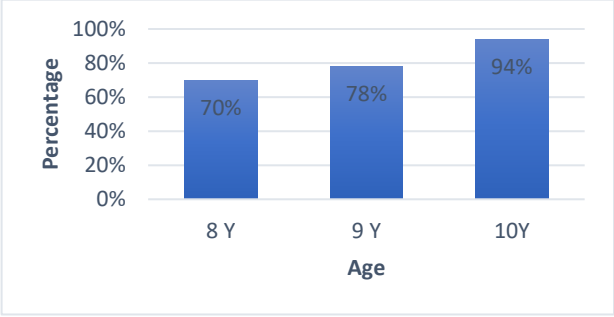

Figure 5.8 Participants' scores in the 4th game.

5.8 Observation

The observation's purpose is to observe the participants` interactions regarding their improvements, engagement, and satisfaction during the experiment. The sessions were not recorded because of the schools` policy, and students` observations were collected and analysed using Thematic Analysis. Thus, organized notes were taken by the researcher.

The method stated in (Braun & Clarke, 2006) was used during the observation. Firstly, generating the initial notes\ideas and ordering them into themes. Secondly, these ideas\notes should be associated with each other within a theme, and these themes should be associated with each other and the entire data set. Finally, naming the themes as giving a definition to each theme.

The process of observing participants is as follows:

1. Notes were taken by researcher .
2. Participant's behaviours were observed and noted by the researcher.
3. Facial expression was a focus during the observation; as it gives additional information during the experiment. For example, when the students smile, they are generally happy and engaged with using mobile application, or when they scowl, they are potentially not satisfied, and so on (Barrett L. et al., 2019).

Several findings were noted when the participants were observed during their interaction with the proposed mobile application regarding study mode, participants, and using the application.

1. Regarding study mode, fifteen participants were observed remotely using the Microsoft Teams platform. In the online mode, some participants were unable to hear the audio of some words properly. They mentioned that the sound is not clear; thus, the researcher had to pronounce the target word during the session to allow them to proceed.

2. **Regarding participants**, the majority of the participants were engaged and satisfied. They mentioned that the mobile application was better than the school textbook. Thus, they stated reasons such as (Student 1) said: "*Because it has images and audio and I can choose*"

(Student 2) said: "*I liked it because there is a challenge to win and better than the textbook.*"

(Student 3) said: "*Because it allows me to recognize my mistakes.*"

(Student 4). "*It has nice and encouraging words after I get the correct answer which excites me to continue all the games.*"

Therefore, the visual and auditory features were the predominant reasons for their engagement and satisfaction. However, two students were unhappy when they were in the experiment.

One student was tired and discouraged because the experiment was conducted approximately at the end of the school day. Another student was also demotivated because she preferred studying from the textbook, and the reason she mentioned that "*I have my own way to write my notes while I am reading to be more focused*."

Three students encountered difficulty choosing the correct answer in the 3rd and 4th games and complained, so they said "*The choices are very similar*."

3. <u>Regarding using the application</u> in terms of understanding the questions and words from displayed pictures and audio tools:

_ All students tried to realize the correct choices by focusing on pronouncing the targeted word and displaying pictures, and some of them used their fingers to spell out the targeted word.

_ Five students showed significant positive feelings towards the displayed images, which helped them find the correct answers.

There are additional problems that students faced in terms of using the game-based mobile application:

_ Two of the students clicked on the word to listen to its pronunciation instead of the Microphone or speaker icon, and then they asked the researcher about the icon to hear the pronunciation of words.

_ Three of the students took a long time to realise that they needed to click on the audio as a helping tool to get the correct answers.

_ Six of them complained of the colours used in the application; the font colour used in words was light. Also, the font size was small, making them confused in choosing the correct answers as the choices were similar.

_The rest of the students were interested in using the mobile application. They found the interfaces were suitable and had nice colours, and the way of written words attracted their attention.

5.9 Summary

This chapter introduced and analysed the findings of the first study. This study aimed to test the game-based mobile application functionalities, ensure the experimental methodology is effective, and analyse qualitative and quantitative data of the effect of the application on students' reading performance. The study was conducted smoothly, and no severe usability issues were identified. The obtained results from the game-based mobile application showed that participants, in general, had positive and motivating results as the content was set at a reasonable level for each group.

Based on the feedback from the students, it is clear that they found the proposed mobile application helps improve their reading. Most of the participants were satisfied with the proposed mobile application and expressed how it improved their reading ability. Based on the first study results, the experimental methodology was further enhanced to address identified issues in this study. In addition, the participants (students and teachers) feedback was considered in the next stage of developing the game-based mobile application before running the second study in the next chapter (Chapter 6).

Chapter 6: Second Study

6.1 Introduction

This research includes two intensive studies based on the development of a proposed game-based mobile application that is suitable for dyslexic students. As discussed previously, an application was implemented and examined by participants who gave feedback about the useability and functionality. The analysis results of the first study showed promising prospects for using applications in education, especially for dyslexic students. Furthermore, students showed very positive attitudes towards the proposed mobile application, leading to better engagement and satisfaction with reading. This chapter discusses the second study, which builds upon and extends the first study, with the feedback from both the participants and teachers in the first study applied to innovative the application. The second study uses a separate group of dyslexic students from those who participated in the first study. The primary purpose of this study was to carry out a more detailed quantitative and qualitative analysis to investigate to what extent the developed application presented in chapter 3 will improve reading skills for dyslexic students at primary schools in Saudi Arabia. Additionally, it aims to investigate the research hypotheses and the technical contributions. This study also intends to optimize the application and modify it based on issues found in the mobile application from the first study. This chapter used a mixed-method to present quantitative and qualitative data analysis. Closed-ended questions in the surveys, the students' responses for the developed game-based mobile application, and pre and post-test scores were analyzed quantitatively. Furthermore, a qualitative data analysis method was created from the findings of the open-ended questions in the surveys. These results generated confirmation regarding the participants' satisfaction and engagement while using the proposed mobile application. This study was similar to that carried out for the first study. However, some modifications were made to the proposed application and the experimental procedures. The following sections provide details about the participants, the objectives of the second study and application modifications, the location of the evaluation, the data analysis method.

6.2 Target Participants

Dyslexic students who are the focus of this experiment - were aged from eight to ten years old (Grades third to the fifth year) primary schools in Saudi Arabia.

The participants were already diagnosed as dyslexic students based on the standardised tests approved by the Saudi Ministry of Education. Initially, forty-five native Arabic-speaking students with a dyslexia diagnosis were identified from different primary schools (i.e., five public schools from Jeddah, Riyadh, and Aljouf). All the participants had previous experience with electronic devices based on the pre-questionnaire findings.

6.3 Objectives of Experiment and Application Modifications

There are two measurements considered in this study. Reading performance for each dyslexic student was evaluated directly after using the application. Also, measuring their overall perception of the application concerning their satisfaction and engagement. Which, in turn, influences reading performance by using the application. Thus, the main reason for this study is to test the hypotheses (Chapter 1, section 1.6). Testing the first hypothesis by quantitatively measuring each group's reading performance and efficiency when averaged over each of the three groups (i.e., 8 years, 9 years, 10 years) from pre and post-tests. Testing the second and third hypotheses also quantitively to find the age differences at pre and post-experiment stages. In addition, testing the fourth hypothesis by measuring their overall satisfaction in terms of engagement with the application, thus, this was measured in the post questionnaire as the open-ended questions were evaluated qualitatively and closed-ended questions evaluated quantitatively. Removing the technical issues found in the application from the first study was one of the critical aims. The modifications were made in the application before conducting the second study. Focusing on the font used in the application, which was not clear enough; therefore, it was changed to be clearer, making the fonts colours of the words dark and the colours of the background light. In addition, size was increased to ensure that readability by all dyslexic students is guaranteed when they view the application. The pronunciation of the targeted words was modified so students can iterate words unlimitedly. There were issues with some phones when displaying the Arabic words as they appeared in distinct letters rather than being in a complete format. This problem was overcome by converting text into images to ensure that all devices provided a consistent interface.

Furthermore, verbal instructions were provided before each game to ensure that dyslexic students understood how to play each game, re-recording the pronunciation of some unclear words to make sure the audio played properly to engage the students` attention and get their concentration. Some of the reports were not successfully stored at the web panel; after debugging this issue, it was found that the configuration had to be modified. Thus, the problem was resolved by introducing pages in the web panel; each of them can store up to ten records. These modifications have been completed to ensure that the game-based mobile application can be used confidently in education to robustly meet dyslexic students` needs.

6.4 Experiment Location

The experiment was completed remotely via Microsoft Teams - the official learning platform in Saudi Arabia due to the closure of schools because of COVID-19. The participants were located in Saudi Arabia and were able to access the proposed application online. The application was available on the Apple Store and Google Play as with the previous study.

6.5 Experiment Procedures

Ethical approval was obtained from Sussex University Sciences & Technology C-REC to carry out the experiment (Ref: ER/RA480/2) (Appendix B). Firstly, the dyslexic students were asked to answer a pre-experiment questionnaire with the help of their parents/guardians before beginning the practical session. The pre-questionnaire evaluated students` familiarity with electronic devices, in general. Additionally, their attitudes towards reading (i.e., words or sentences) to have a background about their engagement with reading in general. This questionnaire included a little information about the study, and it required parents/guardians to consent on behalf of their children before starting the experiment. After that, the session began with a pre-test before using the application to test the targeted students' ability to read and determine their reading level. The pre-test includes ten random words taken from the student's curriculum (Appendix A.4). Then, each participant was asked to read aloud the words one by one; this took ten minutes approximately. The parents/guardians were then asked to download the application from either the Apple Store or Google Play store.

The instructions and features of the mobile application were described to the participants, including login to the application, starting playing the games from the first game up to the fourth, using visual and auditory tools, the activity for each game, the numbers of chances they have for each game, and log out from the application when finished. The participants spent approximately forty to forty-five minutes with the games. Each participant has completed the experiment individually. The application was accessible via tablets or smartphones and enabled participants to play the games by interacting with pictures, words, and audio. Upon completing the games, they were asked to contribute to a post-test to re-evaluate the participants' reading performance after using the application. This post-test was identical to the pre-test, including the number of words (the selected words were identical to gauge their engagement with the difficulties around these words). They were asked to read the words loudly. This procedure took approximately ten minutes. Later, the participants were asked to contribute to a post-experiment questionnaire about their experience regarding using the application and evaluate their overall satisfaction. After that, the teachers were asked to complete a post-experiment questionnaire to capture their feedback and insights toward the application and participants' performance.

6.6 Second Study Findings

In this section, the hypotheses and the obtained data from questionnaires, the application, and pre and post-tests were assessed and statistically analyzed. The responses to the closed-ended questions in questionnaires and the pre-and post-test results, along with generated data from the game-based mobile application, are evaluated quantitatively using MS Excel 2019 and IBM SPSS Software (Ver. 26). The data were analyzed using descriptive and inferential statistics. However, responses to the open-ended questions from questionnaires were analyzed qualitatively using thematic analysis.

It should be observed that the study suggests that there are differences between pre-test and post-test phases in students' performance separately and combined (as indicated by the first hypothesis), and between the three groups at the pre-test stage and post-test stage (as noted in the second and third hypotheses). Thus, to test the hypotheses, it was initially planned to use a One-Way Analysis of Variance (ANOVA) test and a Paired-Sample t-test.

However, due to the skewed data, where some results are not distributed normally, then non-parametric tests were selected to analyze the experiment results.

Thus, it was essential to use the Kruskal-Wallis and the Two-Related-Samples Test Wilcoxon Signed-Rank tests (Field, 2013). Therefore, in a repeated measures design (within-subjects design), the Wilcoxon Signed-Rank test was conducted to identify the significant statistical difference in medians between pre and post-tests in all groupages in general and then separately (MacFarland & Yates, 2016).

Furthermore, in a between-subjects design (age as an independent variable), the Kruskal-Wallis test was also conducted to identify a statistically significant difference between medians of more than two groups to test the second and third hypotheses (Ostertagova et al., 2014). The two tests were utilized to analyze the findings with significance level set as alph (α) = 0.05 to obtain a 95% confidence level that the differences are because of the Independent Variables employed (i.e., pre-test, post-test conditions, and group ages). Once the questionnaires, participants` data, and hypotheses are analyzed, they will be discussed in Chapter 7 to shed light on their contribution to the research findings.

6.6.1 Pre-Experiment Questionnaire Findings

Assessing students' experience with electronic devices and background about their reading was evaluated using the pre-questionnaire. In this questionnaire, six closed questions were designed. The questionnaire results provided information concerning students' enjoyment of reading and the experience of their electronic devices. As mentioned above, forty-five dyslexic students participated in the second study, as shown in Table 6.1

Table 6.1 Sample description-Age

Age	No. Participants	Percentage
8 years	15	33.3%
9 years	15	33.3%
10 years	15	33.3%
Total	45	100%

As shown in Table 6.1, the participants who participated in the second study were equally divided. Therefore, each group represents 33.3% out of the whole number of participants. They are in the range of age between eight and ten years.

This section discusses each question of the pre-experiment questionnaire as follows:

Q1. Using Electronic Devices at home:

The participants were asked "Do you use electronic devices at home? ". All the dyslexic students who participated in the pre-questionnaire (100%≈ n= 45) have experienced using electronic devices at home. It is an expected result as this study was carried out remotely due to the closure of schools because of the spread of Covid-19. Thus, all participants were familiar with electronic devices and had access to them.

Q2. Types of Electronic Devices participants used at homes:

Table 6.2 What type do you use?

Type of electronic Devices	Responses		Percentage of Using Device
	No. Participants	Percentage	
Mobile	28	47%	62%
iPad	16	27%	36%
PlayStation	10	17%	22%
Laptop/Computer	6	10%	13%
Total	60	100%	N/A

Note: Multiple choices were available

As presented in Table 6.2, most of the dyslexic students who participated in the pre questionnaire (62%≈ n=28) had used a mobile, which represents the most frequent device amongst devices; since it represents 47% of the total responses, followed by iPad, which was used by 36% (n=16) of the participants. iPad comes in the second rank since it represents 27% of the total responses as seen in Figure 6.1 the percentage of using these devices by the participants. Since the total responses were 60 and we have forty-five participants, this suggests that the majority of the participants have used multiple electronic devices. That gives a good indication that they are very familiar with touchscreen devices such as phones and tablets, which supports the idea behind developing this type of technology.

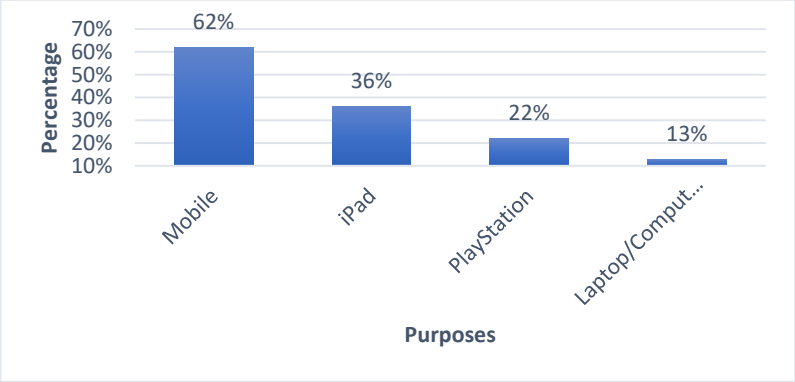

Figure 6.1 represents the percentage of electronic devices` types used at homes.

Q3. Purposes of using Electronic Devices

Table 6.3 What do you use it for?

Purposes	Responses		% of Students
	No. Participants	% of Using Devices	
Playing games	32	43%	71%
Watching YouTube	27	36%	60%
Communicating with friends\ family	16	21%	36%
Total	75	100%	N/A

Note: Multiple choices were available.

As displayed in Table 6.3, most of the dyslexic students who participated in the pre-questionnaire (71% ≈n=32) used their electronic devices for playing games, and this is the most common purpose among all purposes; since it represents 43% of the total responses—followed by using electronic devices to watch YouTube (60%≈ n=27). Finally, using electronic devices for communicating with friends/family came at the last rank, since n=16 (36%) of the participants reported using their electronic devices for that purpose as showed in Figure 6.2. It is worth mentioning that playing games are more common for using a device. This shows that the participants have good background knowledge in general of using games which supports the idea of the proposed mobile application. Since the total responses of 75 and there are forty-five participants. This implies that most of the participants had answered with multiple purposes for using electronic devices.

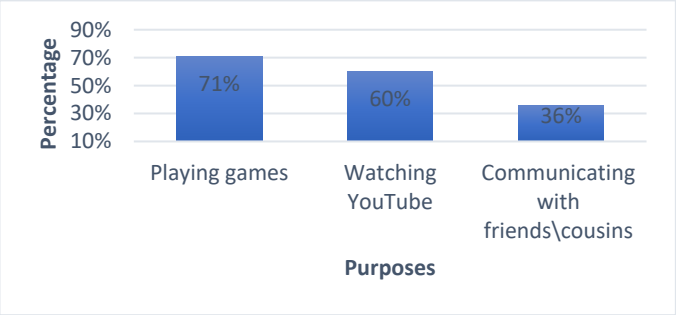

Figure 6.2 represents the total percentage of the purposes of using electronic devices.

Q4. Time spent using electronic devices

Table 6.4 How often do you use per day?

Responses	No. Participants	Percentage
Three hours	5	11%
More than three hours	40	89%
Total	45	100%

As Table 6.4 shows, the majority of the dyslexic students who participated in the pre questionnaire (89%≈ n=40) spent more than three hours a day using electronic devices. In contrast, the rest of them (11%≈ n=5) spent three hours or less a day using electronic devices. This again supports the theory that the students will have significant experience with the devices used in this experiment.

Q5. Students` attitudes towards enjoying reading

Table 6.5 Do you enjoy reading words or sentences?

Responses	No. Participants	Percentage
Yes	32	71%
No	13	29%
Total	45	100%

It can be seen from Table 6.5, most of the dyslexic students who participated in the pre-questionnaire (71%≈ n=32) responded positively "=Yes" when they were asked, "Do you enjoy reading words or sentences"; In comparison, the rest (29%≈ n=13) have negative attitudes about enjoying reading words or sentences. Thus, the participants` levels of engagement and involvement with reading words or sentences are not the same, and there is potential for this to be noted during the study.

Q6. Preferring reading the word with an expressed picture and a loud reading:

It is worth mentioning that 100% of the dyslexic students who participated in the pre-questionnaire (n= 45) answered that they like to read words with expressed pictures and a read-aloud feature for support. This result is very positive as the application includes these visual and auditory features. This is considered one of the recommended features in helping dyslexic students recognize a word, which increases their reading ability.

6.6.2 Hypotheses Testing

To test the first hypothesis, the Wilcoxon Signed-Rank test was used. It is generally used when measurements are obtained from the same subjects (i.e., 8 Years, 9 Years, and 10 Years) before and after using the application (i.e., at two different times). The Wilcoxon Signed-Rank test was used to measure the significant differences statistically between the correctly read answers pre (before application) and post-test scores (after application) for the dyslexic students within the same group (i.e., 8 Years, 9 Years, and 10 Years) and all groups combined. If there is a significant difference, it is clear that the application has altered the observed variable; thus, the alternate hypothesis is confirmed. The significance of the difference when using the Wilcoxon Signed-Rank test is based on a 'p-value', if the result of p-value is less than or equal to the alpha, which means ($p< 0.05$), then there is a statistically significant difference between the two times (pre and post application), and the null hypothesis is rejected. If the p-value is greater than alpha ($p > 0.05$), then failing to reject the null hypothesis, and that the result shows no statistically significant difference between the two times. In the evaluation, three different confidence levels were taken: 0.05, which means 95% confidence level is achieved; 0.01, which represents 99% confidence level is achieved; and 0.001, which means 99.9% confidence level is achieved (Trochim, 2000).

6.6.2.1 Differences Between Pre-Experiment and Post-Experiment Tests

This section of the analysis supposes that there would be a significant difference between participants' reading levels at pre and post-test scores. The first hypothesis is:

Hypothesis H1: "Students will show significant improvement in their reading ability after using the "application" compared to their baseline (pre) reading ability".

To test this hypothesis, the Wilcoxon Signed-Rank test was performed to determine if there was a statistically significant difference between pre-test scores and post-test scores within the same group using a significance level of p = 0.05 with a 95% confidence level. Wilcoxon Signed-Rank test was conducted for the whole sample and then separately for each age group. The Wilcoxon Signed-Rank test results are shown in Table 6.6.

Table 6.6 Results of Wilcoxon Signed-Rank test to Compare Two Test Medians Pre- and Post- Scores within the Same Group.

Group	Variable	N	Mean	Std. Deviation	Median	Z-Value	P-value
All groups	Pre-Test	45	5.11	2.298	5.00	5.754	p<0.01
	Post-Test		7.51	2.160	8.00		
8 Years	Pre-Test	15	4.47	2.532	4.00	3.332	p<0.01
	Post-Test		7.13	2.264	7.00		
9 Years	Pre-Test	15	5.07	1.907	5.00	3.319	p<0.01
	Post-Test		7.47	2.356	8.00		
10 Years	Pre-Test	15	5.08	2.366	6.00	3.446	p<0.01
	Post-Test		7.93	1.907	8.00		

For overall samples, there was a statistically significant improvement of the participant's performance ($p < 0.05$) between pre and post-tests. Thus, the Wilcoxon Signed-Rank test gives a value that was significant at ($Z=5.754$, $p <0.001$). This clearly shows a significant development in the post-test (Median = 8.00) compared to the pre-test (Median = 5.00).

Therefore, the difference between pre-test and post-test can be inferred to be statistically significant. Hence, it could be concluded that the application has improved the reading ability for all samples.

For the eight-years-old group, there was statistically significant difference ($p < 0.05$) between pre-test and post-test ($Z = 3.332$, $p =0.001$). This illustrates that there is a significant enhancement in the post-test (Median = 7.00) compared to the pre-test (Median = 4.00).

For the nine-year-old group, there was a statistically significant difference ($p < 0.05$) between pre-test and post-test ($Z = 3.319$, $p=0.001$). This shows that there is a significant improvement in the post-test (Median = 8.00) compared to the pre-test (Median = 5.00).

For the ten-years-old group, there was statistically significant difference ($p < 0.05$) between pre-test and post-test ($Z = 3.446$, $p =0.001$). This proves that there is a significant improvement in the post-test (Median = 8.00) compared to the pre-test (Median = 6.00).

Overall, it can be concluded that hypothesis H1 is accepted based on the results of the above tests as can be seen in Figure 6.3 the post-test scores are higher than pre-test scores.

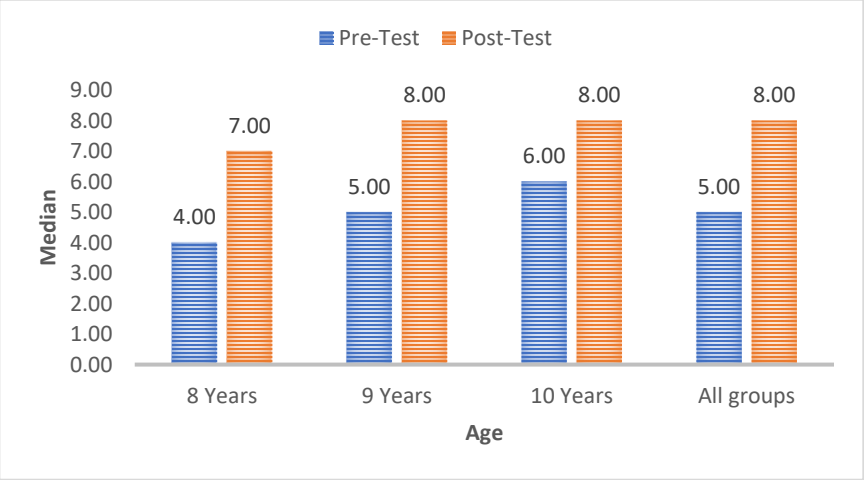

Figure 6.3 Results of comparison between Two Test Medians Pre- and Post- Scores in groups separately and combined.

Overall, post-test results were found to be significantly higher than pre-test results.

6.6.2.2 Differences Between Groups

This part is interested in differences between the three groups (i.e., 8 years, 9 years and 10 years) at the pre-experiment and post-experiment stages. Hence, the Kruskal-Wallis test was used to measure whether or not there are statistically significant differences between the three groups.

6.6.2.3 Differences between Groups: Pre-Experiment Stage

This part of the analysis supposes that there would be a significant difference between participants' reading levels at pre-experiment.

The second hypothesis is:

Hypothesis H2: "There are age differences in students' reading ability at pre-test phase."

To test the above hypothesis, the Kruskal-Wallis test is used to determine whether or not there is a statistically significant difference in the reading level of the three groups of their pre-test scores to find out if there was a statistically significant difference to a 95% confidence level. The results of the Kruskal-Wallis test are shown in Table 6.7.

Table 6.7 Results of Kruskal-Wallis Test for Differences between the Medians Pre-test Scores of the three Groups.

Variable	**Age**	**N**	**Mean Rank**	**Median**	**H- value**	**P-value**
Reading pre-experiment	**8**	15	19.40	4.00	2.425	p> 0.05
	9	15	22.80	5.00		
	10	15	26.80	6.00		

H-value= The Difference Among Groups

As shown in Table 6.7, there is a small difference in the mean rank scores between the medians of the three age groups; however, this difference is not significant when using the Kruskal-Wallis test for students` reading ability at pre-experiment (H = 2.425, P =.298). The p-value is greater than 0.05. This means that statistically significant differences between the pre-test results for the three groups cannot be confirmed to a 95% confidence level due to the small number of participants. Also, it might be because this study was conducted during the spread of Covid-19. The pandemic adversely affected the students educationally in terms of less quality of learning as they might learn from different resources.

In this case, the result indicates that hypothesis H2 is rejected and that the participants in each of the three groups are not likely to have had a different reading level. Thus, the dyslexic students in each of the three groups reflected similar reading levels in the pre-test. The medians for participants aged 8, 9, and 10 years were 4.00, 5.00, and 6.00, respectively as seen in Figure 6.4.

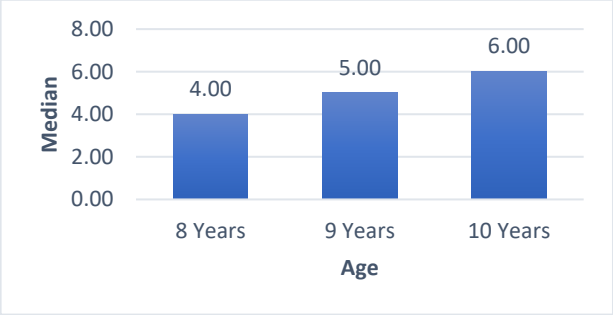

Figure 6.4 Results of the Kruskal-Wallis Test in the medians of the three groups of participants` pre-test scores.

6.6.2.4 Differences between Groups: Post-Experiment Stage

This part of the analysis supposes that there would be a significant difference between participants' reading levels at post-experiment. The third hypothesis is:

Hypothesis H3: "At post-test level, there will be a significant difference in reading level between the three groups."

To test the above hypothesis, the Kruskal-Wallis test is used to determine whether or not there is a statistically significant difference in the reading level of the three groups of their post-test scores to find out if there was a statistically significant difference to a 95% confidence level. The results of the Kruskal-Wallis test are shown in Table 6.8.

Table 6.8 Results of the Kruskal-Wallis Test for Differences between the Medians Post-test Scores of the three Groups.

Variable	Age	N	Mean Rank	Median	H- value	P-value
Reading Post-experiment	**8**	15	20.67	7.00	.946	P> 0.05
	9	15	23.07	8.00		
	10	15	25.27	8.00		

H- value= The Difference Among Groups

As shown in Table 6.8, there was no statistically significant difference between the group medians at the post-experiment level as determined by the Kruskal-Wallis test (H = .946, P = .623). The medians for participants aged 8 Years, 9 Years, and 10 Years were 7.00, 8.00, and 8.00, respectively as seen in Figure 6.5. The p-value is greater than 0.05.

This accepts the null hypothesis assumed (there are no significant differences between groups). It is clear that the dyslexic students in each of the three groups had similar reading levels in the post-test (after application).

To conclude the results from the Kruskal-Wallis tests, it is clear that the game-based mobile application effectively benefits all groups of ages in the same way, and it worked properly for all the targeted age groups as there were no statically significant differences between the relative participant's scores in both pre and post-test.

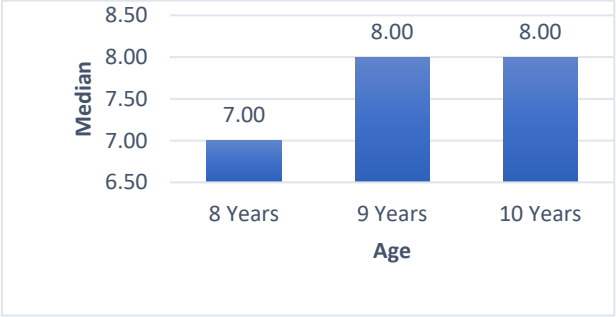

Figure 6.5 Results of the Kruskal-Wallis Test in the medians of the three groups of participants` post-test scores.

6.6.3 Post-Experiment Questionnaire Findings

This section reviews the participants' post-experiment questionnaire to evaluate the participants' attitudes and behaviours and assess the participants' overall satisfaction and insights toward using the application. This questionnaire includes ten closed-ended questions and four open-ended questions. As mentioned previously, forty-five dyslexic students participated in the second study.

1. Attitudes and behaviours of the dyslexic students towards reading from smartphones:

After completing the experiment (i.e., playing four educational games by using a mobile application), the dyslexic students were asked about the usefulness of reading through mobile applications.

Table 6.9 Do you think learning reading through applications will be useful?

Responses	No. Participants	Percentage
Yes	43	96%
No	2	4%
Total	45	100%

As shown in Table 6.9, It was found that the majority of dyslexic students (96%≈ n=43) responded positively "yes". This result implies that the participants have highly positive attitudes regarding reading through mobile applications, while only two participants (4%) have negative attitudes towards reading. Learning by using mobile applications is considered a new tool to enhance the educational process, especially in reading. Thus, it is worth mentioning that these two participants were potentially hesitant to use games in education and are more content to read through a traditional known way rather than using the application.

In addition, the students were questioned regarding if they felt happy while using the application. All of the participants (n=45) responded positively "yes" when they were asked, "Did you feel happy when you were playing the games?". However, in question five in the pre-questionnaire, thirteen participants did not enjoy reading words or sentences when they asked whether they enjoyed reading or not. Thus, according to their answers above, these findings imply that the participants had a high level of engagement and enjoyment reading by using the application.

Moreover, all participants (n=45) responded positively yes" when they were asked, "Do these types of games make the reading easy?" This result indicates that all the participants had a high level of agreement regarding the useability of the types of games in enhancing reading skills. This result asserts that the application was simple and clear to use.

2. The similarity of letters when playing the games:

This question is about the similarity of letters in the application's words.

Table 6.10 Were you able to distinguish between similar letters while playing the games in the application?

Responses	No. Participants	Percentage
Yes	29	64%
No	16	36%
Total	45	100%

As presented in Table 6.10, most of the dyslexic students (64% ≈ n=29) indicated that they were able to differentiate between similar letters (which can be confusing) when playing the games. In comparison, only sixteen participants (36%) responded negatively. As a result, the first and second games were designed to help them distinguish between orthographic and comparable letters in terms of shape (there are 22 similar letters out of 28 in the Arabic language). The substitution of similar letters in a word is an issue that dyslexic students struggle with. Thus, this issue needs to be addressed by using the application.

3. Blurring of letters during reading:

Table 6.11 Do the letters become fuzzy or blurry when you read?

Responses	No. Participants	Percentage
Yes	4	9%
No	41	91%
Total	45	100%

Letters appearing blurring is a common effect of dyslexia (NHS, 2021). As can be seen from Table 6.11, the participated dyslexic students were asked that “Do the letters become fuzzy or blurry when you read”, it was found that most of the participants (91%≈ n=41) responded negatively “No”. The results of this question indicated that the application is excellent and suitable at avoiding this issue, with participants in the post-experiment questionnaire showing that they saw the letters clearly and readily distinguished them using the mobile application.

4. Items that participants liked in the application:

Table 6.12 What features did you most like in the application?

Items that participants liked	Responses		Percentage of students
	No. Participants	Percentage	
Pictures/Sounds	31	30%	69%
Colours and patterns (Layout)	22	21%	49%
Easiness of using	22	21%	49%
Types of games	15	15%	33%
Verbal encouragement	14	14%	31%
Total	**103**	**100%**	**N/A**

Note: Multiple choices available.

As Table 6.12 shows, most of the dyslexic students (n=31) who participated in the post questionnaire (69%) responded that they liked displayed pictures and words pronunciation while using the application. This choice represents the most common choice enjoyed by participants. Hence, this response represents 30% of the total responses (103 responses). In addition, the participants preferred the mobile application layout (i.e., colours and font size) and Easiness of using the mobile application (49%≈ n=22) of the sample. The types of chosen games used in the mobile application were in third place, where it was preferred by 33% of the participants. The last preferred item is verbal encouragement after the participants answered the question correctly (31%≈n=14). The most common characteristics that interest and engage the students with dyslexia are displayed pictures and sounds for corresponding a word, layout in terms of graphic design, and attractive colours with suitable fonts—simple menu with few sub-menus, types of designed games, and verbal encouragement as seen in Figure 6.6 the total percentage of each item that participants like. Thus, these primary benefits of using the application rather than traditional book-based learning are available.

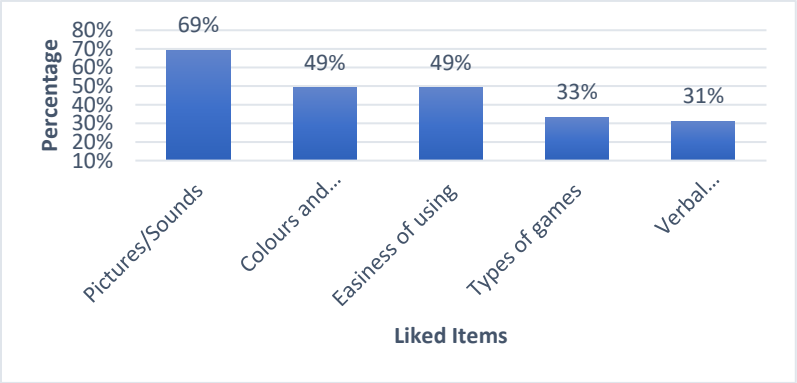

Figure 6.6 represents the total percentage of each item that participants like.

5. The Easiest game to use in the application:

Table 6.13 Which game in the mobile application was easy to use?

Easiest game of the application	Responses		Percentage of students
	No. Participants	Percentage	
1st game (Matching Up)	21	40%	47%
2nd game (Words Construction)	15	29%	33%
3rd game (Letter`s Bank)	9	17%	20%
4th game (Listening Words)	7	13%	16%
Total	52	100 %	N/A

Note: Multiple choices available.

As presented in Table 6.13, most of the dyslexic students who participated in the post questionnaire (47%≈ n=21) indicated that they enjoyed the reading with the first game (Matching Up) and stated that it was the easiest game when we're playing. This response represents slightly less than half of the answers (40% of the total responses). The second game (Word Construction) was the second place the participants considered easy game (33%≈ n=15%). Then, the third game (Letters` Bank) was easy to use and preferred by (20%≈ n=9). The fourth game (Listening Words) was the last preferred game in terms of easiness (16%≈ n=7). It can be seen from Figure 6.7 the percentage of each game considered easy by participants. This is as expected as the games were designed to become more challenging from the first game to the next ones as they progress through the levels. These results suggest that the progression of difficulty in the application is good.

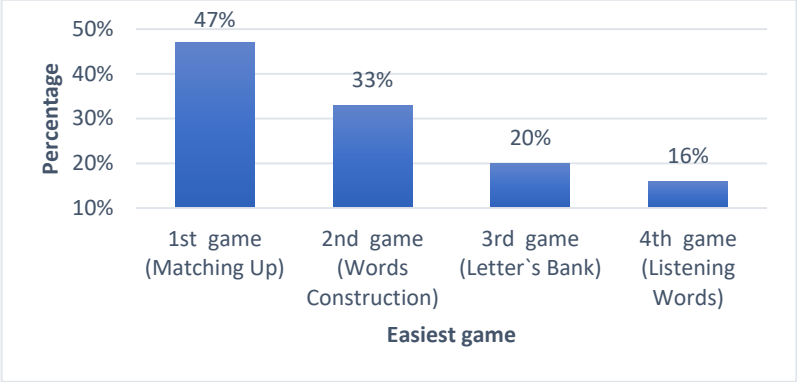

Figure 6.7 represents the total percentage of each game considered easy by participants.

However, all of the dyslexic students who participated in the post-experiment questionnaire (n=45) were asked, "Which game/s in the mobile application was difficult to use". They had no comments regarding this question nor the question: "What feature did you most dislike in the mobile application"?. This shows that although the difficulty progresses through the applications, there weren't any specific issues that caused the students to dislike the games, which positively influences their reading. This can lead to the conclusion that participants had no unique problems navigating through the games in terms of both usability and playability.

In addition, all of the dyslexic students who participated in the post-experiment questionnaire (n=45) responded positively "yes" when they were asked, "Did the pictures and read-aloud reading help improve understanding of the words/texts". This finding indicates a higher level of acceptance for the application's features among the participants; since they agreed that using pictures and read-aloud reading help students recognize the target word clearly and correctly. The visual and auditory features are most recommended to better understand the words/texts.

Moreover, all participants in the post-experiment questionnaire (n=45) responded positively "yes" when they were asked, "Does the way the words are presented attract you to focus on them?". Thus, the results showed that participants had a very positive impression of the design of the way the words were presented in the application.

The fonts size and colours used to display words in the application have an attractive design that can increase the possibility of being readable as they are unobtrusive and provide students a good contrast while reading, which leads them to fast recognizability.

6. Attitudes towards the use of games in the application in enhancing reading:

Table 6.14 How do you feel about using games in the application in enhancing reading?

Responses	No. Participants	Percentage
Satisfied	37	82%
Not satisfied	8	18%
Total	45	100%

From the responses in Table 6.14, it was found that most of the participants (82%, n=37) were satisfied, while a few of them were not (18%≈ n=8). This result indicates that participants in the post-experiment positively influence the usage of the games in enhancing reading. This asserts that the participants were engaged, concentrated, and motivated while using the application. They felt comfortable and productive while using the application as they located their difficulties. Overall, the results indicated a high level of students` satisfaction with the application generally.

Regarding the respondent's dissatisfaction with this statement was due to their preference to read through hardcopy instead of softcopy as they replied to the next question.

7. A trade-off between the learning from the traditional way using textbooks and the HCI mobile application (games-based):

Table 6.15 Would you prefer reading from softcopy or hardcopy books?

Preferences	No. Participants	Percentage
Softcopy (applications- Games)	37	82%
Hardcopy (School textbooks)	8	18%
Total	45	100%

As presented in Table 6.15, most of the participants in the post questionnaire (82%≈ n=37) favoured the games-based approach. It is believed that reading through applications makes them learn better with repeatability, has availability anytime, accessibility anywhere, and is considered a supportive tool for their difficulties.

It is easy to get back to the material in case of missing information. In contrast, only eight preferred reading from school textbooks (18%). These eight students were already unsatisfied with using the mobile application as they replied to the previous question.

It is possible that parents might encourage their children to use traditional reading (i.e., books) for learning as they have full motivation and engagement by practicing and discussing with each other, and quite often are not very keen on gameplaying as they do not see this as learning. Some children may take on their parents' point of view and can be reluctant to engage with game-based learning.

This result indicates that the majority of the participants in the post-experiment questionnaire had positive attitudes towards reading and learning through the proposed mobile application.

In the post-experiment questionnaire, the surveyed participants asked, “Do you find the design of choices (i.e., fonts, colours, … etc.) making reading easier?”. The results indicate that all participants (n=45) felt that their reading skills improved while playing the games. The design choices such as colours and labels play a critical role in how the application looks and interacts and in how the students feel when interacting with it. Thus, these designs helped students concentrate on the words, making them more engaged and easier to read.

Based on the students` feedback/ comments on the post-experiment questionnaire, it is worth mentioning that most students were satisfied while reading through the mobile application, which helped them provide better engagement, motivation, and interaction.

Therefore, based on the positive results from the post-questionnaire, **Hypothesis H4** is confirmed, which illustrates that the mobile application was experienced as engaging and usable and offered a good level of satisfaction. These results directly answered the second research question, which stated, “To what extent would the dyslexic students be satisfied and engaged after using the application?”.

6.6.4 Post-Experiment Questionnaire Findings – Teachers

This section discussed the teachers' point of view when they were surveyed. Their responses were qualitatively analyzed.

1. Attitudes of the teachers towards the usefulness of the proposed game-based mobile application:

The participating teachers were asked “Do you think the application is useful for dyslexic students? Justify?”. All of the participating teachers (n=6) answered “Yes”. They positively interacted with the proposed mobile application, they stated that (Teacher 1) *“ it is more flexible and makes them learn depending on their reading ability”*.

(Teacher 2) “*it is available any time, and it can be repeated multiple times and help them learn at their own speed depending on their performance.”*

In addition, all of the teachers (n=6) agreed that the proposed mobile application is a reliable tool that helps to enhance students’ reading skills in particular. One of them stated that (Teacher 3) *“Dyslexic students would become more involved and able to comprehend knowledge better and faster while reading and learning via the mobile application”.*

2. Improving understanding of the words/texts provided by the game-based mobile application:

The participating teachers were asked, "Did the pictures and read-aloud featured help improve understanding of the words/texts? Explain". All of the teachers (n=6) replied, “Yes”. Two teachers suggested:

(Teacher 1) “*Pictures and the read-aloud features draw the students' interest while reading”*.

(Teacher 2) “*Providing auditory-visual tools in the proposed mobile application that assist students in identifying words more quickly and improve their reading skills*”.

3. Teachers' points of view regarding the most positive aspect of the game-based mobile application that make the students more satisfied and engaged:

The participating teachers were asked, "What is the most positive aspect of the application". Their responses to this questions as follow:

(Teacher 1) *“The application has audio-visual means that increase students' concentration”*.

(Teacher 2) “*It has compelling features such as nice pictures, clear and engaging sounds, bright fonts, and colours.*”

(Teacher 3) *"It is also considered easy-to-use, the displayed report helped them show their progress and performance would motivate them, the verbal encouragement instills self-confidence in the students"*.

(Teacher 4) *"The game-based mobile application's theme is attractive and piques students' attention"*.

(Teacher 5) *"The navigation easily between games makes the application's use easier to such a dyslexic student, and the simplicity and clarity that the application has"*.

(Teacher 6) *"It is generally considered suitable for practicing, repeatability, flexibility, accessibility, and availability to assist in solving many issues related to teaching support for dyslexia in Saudi Arabia"*.

In general, they believed that the mobile application would make the reading process easier due to the students' enthusiasm towards the mobile application. In addition, applying games approach with learning will support the educational process, especially for dyslexic students. The dyslexic students would engage and interact with games in general. They need entertaining methods such as providing cartoonish images that would help them while reading. Therefore, this could be a valuable way to improve students' reading skills with dyslexia.

At the end of the questionnaire, the teachers were asked whether they would add anything to improve the proposed mobile application. The participating teachers were engaged with this question and approved that they were happy with the applied changes after the first study. There were no serious technical issues while using. In general, they mentioned that the proposed mobile application would be a helping tool for dyslexic students in the future.

6.7 Students Data from the Game-based Mobile Application

This section will discuss the analysis of students` findings obtained from the application. This analysis aims to determine which age group improved the most; thus, this analysis finds observable differences in ages rather than statistical differences.

The application consists of four different games, and forty-five dyslexic students from three age groups (i.e., eight to ten years old) participated in the study. The participants' total scores of each game were stored in a database for further analysis.

1. Student Performance at the First Game:

This game aims to differentiate similar letters in shapes as there are 22 similar letters in the Arabic language. It is considered an introduction to the proposed game-based mobile application; so, the students with dyslexia would become more aware of it and pique the participants' attention and concentration. The first game composes five questions.

Table 6.16 Descriptive analysis of the students' performance in the first game.

Age	No. Participants	Total Scores	Mean	Percentage	Std.
8 years	15	60	4	80%	0.85
9 years	15	62	4.13	83%	0.83
10 years	15	64	4.27	85%	0.88

Std.= Standard Deviation.

As presented in Table 6.16, the ten-year-old participants have scored the highest percentage in the first game (85%, Total= 64, Mean=4.27, Std=0.88). Followed by participants at age nine years old (83%, Total=62, Mean=4.13, Std= 0.83), while students at age eight years old have the lowest scores in the first game (80%, Total=60, Mean=4, Std=0.85). As expected and in-line with the first study the first game results showed that participants aged ten have a better base reading performance compared to others as seen in Figure 6.8.

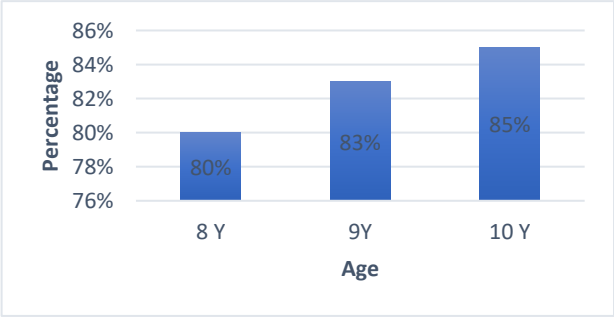

Figure 6.8 Participants' scores in the 1st game.

8. Student` Performance at the Second Game:

The second game has ten questions. Also, this game aims to help dyslexic students differentiate between those similar letters.

Table 6.17 Descriptive analysis of the student's performance in the second game.

Age	No. Participants	Total Scores	Mean	Percentage	Std.
8 years	15	115	7.67	77%	0.82
9 years	15	120	8	80%	1.73
10 years	15	132	8.8	88%	1.93

Std.= Standard Deviation.

As Table 6.17 shows, students at age ten years old have the highest scores (88%, Total=132, Mean=8.8, Std=1.93), followed by students at age nine years (80%, Total=120, Mean=8, Std=1.73), while students at age eight years have the lowest scores in the second game (77%, Total=115, Mean=7.67, Std= 0.82). It was expected that the participants who were eight years old would do less well in the results for reading performance as seen in Figure 6.9, and this is likely due to a lack of vocabulary.

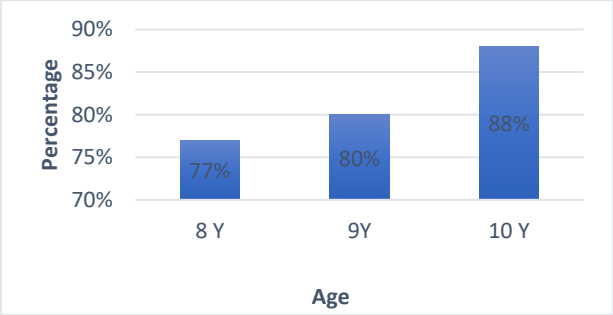

Figure 6.9 Participants' scores in the 2nd game.

9. Students` performance at the Third Game:

The third game contains ten questions. The aim of this game is to help students avoid omitting and adding the letters in a word.

Table 6.18 Descriptive analysis of the student's performance in the third game.

Age	No. Participants	Total Scores	Mean	Percentage	Std.
8 years	15	123	8.2	82%	1.52
9 years	15	130	8.67	87%	1.29
10 years	15	137	9.13	90%	1.06

Std.= Standard Deviation.

As Table 6.18 shows, students at age ten years have scored the highest when compared to others (90% ,Total= 137, Mean= 9.13, Std=1.06), followed by students at age nine years (87%,Total= 130, Mean= 8.67, Std= 1.29), while students at age eight years have scored the lowest (82% ,Total= 123, Mean= 8.2, Std= 1.52). Interestingly, the ten-year-old's performance increased concerning the second and third games as seen in Figure 6.10. This means that the levels of the games are gradually getting hard, and that`s why the students who are eight and nine years old found it more challenging. Thus, this implies that the games work well for the range of students.

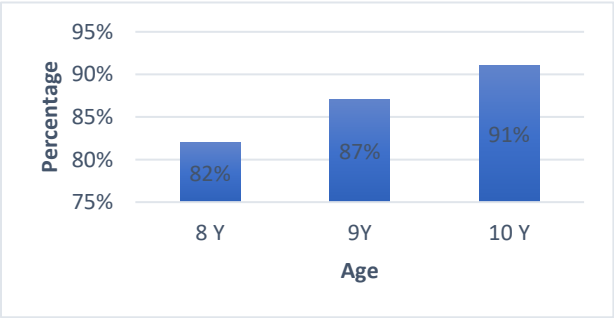

Figure 6.10 Participants' scores in the 3rd game..

10. Students` Performance at the Fourth Game:

The fourth game composes ten questions. This game aims to help students avoid transposing the letters into a word.

Table 6.19 Descriptive analysis of the student's performance in the fourth game.

Age	No. Participants	Total Scores	Mean	Percentage	Std.
8 years	15	128	8.53	85%	1.19
9 years	15	136	9	90%	1.07
10 years	15	140	9.33	93%	0.82

Std.= Standard Deviation.

As Table 6.19 shows, participants at age ten years have the highest scores when compared to others (93%, Total=140, Mean=9.33, Std=0.82), followed by participants at age nine years old (90%, Total=136, Mean=9, Std= 1.07), while the participants at age eight years have scored the lowest (85%, Total=128, Mean=8.53, Std=1.19).

Overall, the majority of results are as expected, with older participants doing better reading performance on average than younger participants as seen in Figure 6.11. However, the good results (all results between 77% and 93%) suggest that the application is at the right level, i.e., no group was failing badly, and no group achieved 100%.

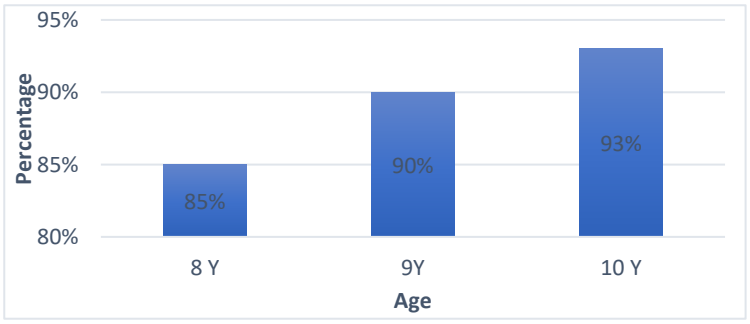

Figure 6.11 Participants' scores in the 4th game.

6.8 Summary

This chapter describes the results of the second study, and the obtained results were analyzed quantitatively and qualitatively. This study was conducted remotely because of Covid-19; however, the experiment was implemented very easily. The research hypotheses were tested statically, and the research questions were answered. The students were able to respond to the pre and post-questionnaires, pre and post-tests, and they interacted with the games.

According to the teachers` perspective, their results as they replied to the post questionnaire showed that the mobile application was suitable for dyslexic students in Saudi Arabia. Using the technology helped them a lot, and they were engaged and motivated more while playing (Learning) via the mobile application.

Chapter 7: Discussion

7.1 Introduction

The proposed game-based mobile application has been designed to assist dyslexic students at primary schools in Saudi Arabia. It has aimed to enhance dyslexic students' reading skills and increase their engagement in reading. Two empirical studies (the first and the second studies explained in Chapters 5 and 6) were conducted based on the proposed mobile application. The main aim of these conducted experiments was to develop the best mobile application that can be beneficial for dyslexic students in Saudi Arabia. Hence, the game-based mobile application at the first study was designed based on the recommendations from the literature review as well as the teachers who dealt with dyslexic students. Whereas the game-based mobile application at the second study was designed based on the feedback from a post-experiment questionnaire of the participants and observations of the researcher when the first study was carried out. The effectiveness of the proposed mobile application was investigated in terms of students` reading performance and satisfaction. Both studies have a very deep insight when compared with the previous studies. Both studies focused on differences in reading ability among students with dyslexia who are aged from eight to ten years old. The results from both studies have confirmed that using a game-based mobile application would help to enhance dyslexic students' reading skills. Adding to that, it represents a high level of satisfaction. This chapter will thoroughly discuss the analyzed results of both experiments, which were presented in chapters 5 and 6.

To the best of the researcher knowledge, this research is distinctive and more insightful compared with the majority of the previous work such as (Aldabaybah & Jusoh, 2018; Benmarrakchi et al., 2017; Ouherrou et al., 2018; Hamid et al., 2015; Srivastava and Haider, 2020) who have focused on technology and theoretical frameworks instead of evaluating the effectiveness of the intervention in the academic environment. Their evaluations have been considered based on teachers` perceptions and questionnaires, or they used a small number of participants (Aldabaybah & Jusoh, 2018; Benmarrakchi et al., 2017; El Kah & Lakhouaja, 2018; Ouherrou et al., 2018).

7.2 Discussion of the First Study Results

The first study was mainly conducted to test the application functionalities and assess the methodology. The application functionalities were tested in terms of their usability. Acquiring the results were from questionnaires for both students and teachers, observation, and extracted data from the application. The structure of the first study ran effectively; the students managed to use the application, and the data were collected. The experiment was completed successfully; fifteen dyslexic students participated (five students for each age). There were no substantial issues with the application` functions, although a few simple problems were detected and resolved (Chapter 6 section 6.3). According to their findings, they made good progress in their reading and provided feedback in the post-experiment questionnaire.

7.2.1 Pre- Questionnaire Results

The findings of the pre-experiment questionnaire (section 5.6.1) illustrated that all dyslexic students had access to electronic devices, with 86.7% of them using their own electronic devices at home. Also, all the participants (100%) had access to mobiles which is the most common device. This finding suggests a very good level of familarity and engagement with electronic devices, which supports the idea that a mobile device based application would be effective; as the majority of the participants (93%) used their electronic devices to watch YouTube, and (87%) of them used their electronic devices for playing games. Most of the participants (73%) spent more than 3 hours a day using electronic devices. A little more than half of the participants (60%) enjoy reading words or sentences, and all the participants (100%) preferred to read words with expressed pictures and a read-aloud feature as supporting tools. It can be concluded that the participants had a solid understanding of how to use games in general, which backed up the aim for the suggested mobile application, which included four different games. In addition, not all the students were the same in terms of their engagement with reading. As a result, as supposed by this research, there was a strong motive for the mobile application to be developed with suitable characteristics to help them improve their reading skills by using the application with all supported features.

7.2.2 Post- Questionnaire Results

The purpose of using a post-experiment questionnaire was to assess the effectiveness of the application usability and students` satisfaction with reading utilizing the application (section 5.6.2). This was evaluated by open and closed-ended questions to determine their use of the application and assess to what extent the application assisted the students in reading skills without encountering any issues. The results illustrated that most of the participants (87%) were satisfied regarding the use of the application in enhancing reading, especially over its types of games and ease of use. Only (13%) of students were not satisfied with the application due to their preferences in reading by using the traditional way (i.e., school textbooks). All participants (100%) were engaged and happy in reading using the application. They believed that reading by application is useful; they found it easy to read and suitable to their needs. Also, all the participants (100%) were satisfied with the features applied in the application, such as (the way of displaying words, using images, sounds, etc.). They were helped in improving their understanding of the words/texts. The majority of participants (87%) preferred reading by the games-based approach rather than school textbooks. These results indicate that the students enjoyed reading using the application and did not have difficulty. The above students` results are similar to those reported by (Ouherrou et al., 2018; Alghabban et al., 2017; Alghabban et al., 2021). Most of the participants (73%) were able to distinguish between similar letter (which is the issue they already struggle with) when they were playing the games, but 93% of students stated that the letters were not fuzzy or blurry, which can be a key interface issue with dyslexia. Thus, the application is good at avoiding these issues based on their scores after completing all games provided in the application. They saw the letters clearly and easily distinguished them through the mobile application.

7.2.3 Students Results from the Game-based Mobile Application

Regarding the increase in students' reading levels, they were divided into three groups (i.e., 8 Years, 9 Years, 10 Years) to find the observed differences between ages and which group improved reading the most. The results were evaluated using descriptive analysis. The application consists of four different games. The first game was composed of five questions. It was considered an induction to the mobile application, and the rest of the games were composed of ten questions.

The results illustrated that, as it is noticeable in Figure 7.1, the students who were ten years old had the highest percentage in the first game (84%), second game (92%), and fourth game (94%). However, their overall scores in the third game were affected (76%) because two students lost their concentration while reading, and this result was evident, as discussed in the observation (chapter 5 section 5.8).

The nine-year-old group has the highest percentage only in the third game (84%). While the group eight years old had the lowest percentage in all the games (72%**,** 64%, 80%, and 70%), respectively.

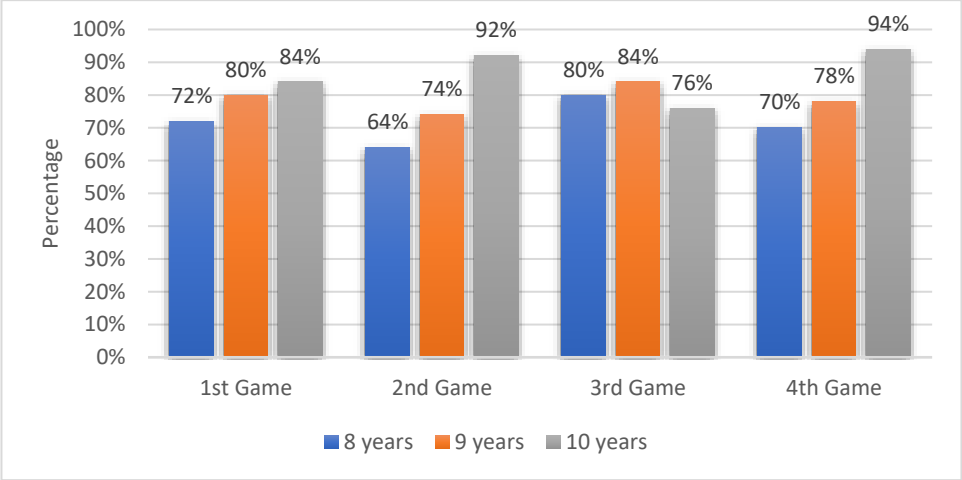

Figure 7.1 The progress in reading for each group of students in all games.

It can be concluded that the ten-year-old had better reading ability and their reading skills improved more than other groups. The majority of results are as expected, with older students outperforming younger students on average due to their high background in vocabulary. However, the good results (all scores between 64% and 94%) imply that the application is at the proper level, i.e., no group scored 100%, and no group performed badly.

7.2.4 Observation Results

The aim of the observation is to analyze the participants` interactions with the application regarding their improvements, engagement, and satisfaction during the experiment (section 5.8). The researcher observed students' behaviours and focused on their facial expressions during observation as this played an important role in giving more explanation during the experiment such as satisfaction if they smile or not satisfied if they grimace (Barrett L., 2019).

The results displayed that most participants were delighted with how the application encouraged them to engage more in reading. This result is in proportion to the findings of (Alghabban et al., 2021).

The students were happy with the convenient features they found in the application, such as being full of engaging pictures and quiet sounds that helped them recognize the word quickly. This result aligns with the results found by (Skiada et al., 2014). However, a small number of the participants faced minor issues while reading. As a result, and to ensure that the students gained from the proposed application and improved their reading performance, their views obtained from observation and post-questionnaire were taken into consideration, and the found issues were addressed before carrying out the second study (Chapter 6 Section 6.3).

7.2.5 Post- Questionnaire Results – Teachers

The post-questionnaire for teachers aimed to evaluate the teachers' opinions of the application (section 5.6.3). Four teachers participated in this questionnaire. The overall results from the questionnaire answers were that all of the teachers were happy with the application and believed that students would become more involved while reading via the mobile application as it was easy to use. They agreed that the applied features in the application would aid the students to be more concentrated while reading, and this would be likely to improve their reading levels. However, they suggested modifications to the application; thus, their opinions were considered and addressed before conducting the second study. This outcome aligns with (Burac & Cruz, 2020), where the teachers were happy and satisfied with developing a mobile application.

It can be concluded that the teachers' replies implied that once the entertainment in terms of using games while reading was combined with learning, this would be an effective way to help the students engage with reading which would show progress in their ability in the reading performance.

7.2.6 First Study Limitations

The results from the first study prove that there were suggestive of a positive impact of the proposed mobile application. However, some problems limited the experiment's success in terms of sample size. The main obstacle was that the first study was conducted while the spread of the COVID-19 pandemic.

Thus, students were poorly affected by constraints and school closures caused by the COVID-19, and it was challenging to manage these changes, which was the most crucial change turning the learning remotely.

As a result, the experiment was conducted in a short period of only one month in February 2021 with only fifteen dyslexic students. Moreover, it lacked a pre and post-test to assess learning quantitatively. In general, the first study showed promise prospects and indicated that the application worked properly.

7.2.7 Summary of the First Study

Even though the students were strongly affected due to Covid-19, leading to the small number of participants, the first study results strongly implied that the proposed mobile application positively affected reading performance. It was clear from the students' responses to the post-questionnaire and their performance levels in the application that all groups benefited from the application. The application was developed according to student and teacher feedback and observation to remove the problems discovered in the first study before running the second study.

7.3 Discussion of the Second Study Results

The second study was considered an extension of the first study, with the feedback obtained from both the students and teachers in the first study applied to innovative the application. The primary purpose of the second study was to conduct a more detailed quantitative and qualitative analysis to investigate how well the developed application will improve reading performance for dyslexic students at primary schools in Saudi Arabia and confirm that the proposed application is proportionate with the research hypotheses. Additionally, the research hypotheses and research questions presented in the first chapter are answered in this study.

The second study's key methodological improvement is a pre and post-test to measure each student's reading performance before and after using the application. The study was performed successfully, with no severe problems, and the application functionalities appeared enhanced due to the adjustments made according to the feedback from the participants in the first study. In contrast to the first study, the sample size for the second study was much larger, with forty-five students divided into three groups in terms of ages (i.e., 8 Years, 9 Years, 10 Years), with each group having fifteen students.

These results produced validation regarding the students' satisfaction and engagement and their improved reading performance with using the application.

7.3.1 Pre- Questionnaire Results

The pre-experiment questionnaire findings demonstrated that all dyslexic students had experienced using electronic devices (Section 6.6.1). This is partially likely to result from the prevalence of COVID-19, leading to the closing of schools and the educational system transferring to be remote. Also, most of the participants (62%) used mobiles, the most frequent device amongst devices. The majority of the participants (71%) used their electronic devices for playing games, and (60%) of them used their electronic devices to watch YouTube. A high percentage (89%) of the participants spent more than three hours a day using electronic devices. This result suggests a good level of ability and knowledge in using mobile devices and experience with touch interfaces. More than half (71%) of the participants enjoyed reading words or sentences, and all the participants (100%) like to read words with expressed pictures and read-aloud features as supporting tools. It can be seen that the findings of the pre-questionnaire discovered the comprehensiveness background of the participants with a strong knowledge of using games in general, which supported the concept for the proposed mobile application. In addition, the students were not at the same level of involvement with reading. As a result, there was a clear case for an educational application to be developed with appropriate helping tools to improve reading performance.

7.3.2 Hypothesis Discussion

Testing the hypotheses to identify the statistical differences in reading levels between pre and post-tests before and after the experiment using two experimental designs (within-subject and between-subject designs).

The results were statically analyzed in the second study discussed in detail in section 6.6.2. The tests scores (pre and post) for all groups were gathered. To examine the first hypotheses, the Two-Related-Samples Test Wilcoxon Signed-Rank test was used to measure the statistically significant differences between the correctly read answers in pre and post-test scores for the dyslexic students within the same group (i.e., 8 Years, 9 Years, 10 Years, and all groups). The test was conducted for the whole sample and then separately for each age group. The test results showed that the participants` performance in reading at post-test was significantly better than their performance at pre-test.

This means that all students' reading performance improved after using the application. Thus, the Wilcoxon Signed-Rank test gives a significant value. The result from this test was predictable, as mentioned by the first hypothesis that there are substantial improvements in the dyslexic students` reading ability after using the “application” compared to their baseline (pre) reading ability. All groups developed their reading performance after using the proposed mobile application. Thus, the first hypothesis was accepted. This result is in-line with the findings of (Alghabban et al., 2021; Alghabban & Hendley, 2020), who also found that there are significant improvements in the students' reading levels after using the assistive technology (website) according to the scores for both pre-test and post-test for the adaptive group (the researchers in their studies mentioned above divided the participants to two groups adaptive group and control group). Thus, the adaptive group, the dyslexic students who were matched with the learning material provided in the used website. To examine the second and third hypotheses, the Kruskal-Wallis test was used to determine whether or not there are statistically significant differences between groups at the pre-experiment and post-experiment phases. The results of conducting the Kruskal-Wallis at pre-test scores between groups (ages) appeared that there is no statistically significant difference. Thus, this result was not in agreement with the second hypothesis, which stated that there were age differences in students’ reading ability at the pre-test phase. Also, the post-test scores' findings between groups demonstrated no statistically significant difference between groups (ages). This result was also not in agreement with the third hypothesis, which declared that there were age differences in students’ reading ability at the post-test phase. Thus, the above two hypotheses were rejected because the findings were unreliable.

A key reason for this was that the sample size was small and additionally as this study was carried out during the pandemic of Covid-19; the students' educational experience was impacted in terms of learning quality as they were exposed to a variety of learning resources that might not be reliable. Hence, it was observed that dyslexic students in each of the three groups showed similar reading levels based on their scores in the pre-test and post-test. To conclude the results from the above the Kruskal-Wallis tests, it is clear that there were no statically significant differences between the participant's relative scores in both pre and post-tests, which suggests that the game-based mobile application benefited all age groups in the same way and that it worked successfully for all of the intended age groups.

To test the fourth hypothesis, which stated that "The developed mobile application will be experienced as engaging and usable and offering a good level of satisfaction", the following section was discussed, and it was confirmed according to the analysis of post-questionnaire results.

7.3.3 Post- Questionnaire Results

The purpose of using a post-experiment questionnaire was to evaluate the participants' feeling and behaviours and investigate the participants' overall satisfaction and visions with reading using the application (section 6.6.3). They were responses to the open and closed-ended questions to assess the impact of the application in increasing their reading skills. Also, to ensure their use of the application after applying some modifications according to the suggestions from the first study, and assure how well the application enhances the students' reading skills. The findings of the post-questionnaire indicated that a large percentage of the participants (82%) were satisfied with reading through the use of the application in developing their performance levels. It aided them in increasing their reading performance in varying ways (i.e., types of games). This high number highlights students' feelings toward the mobile application. However, a small set of students were dissatisfied (18%) due to their style in reading preferences (i.e., traditional reading through school textbooks). The students were asked directly whether they were happy while reading using a set of games; thus, the result demonstrated that all participants enjoyed and were delighted with reading utilizing the application. They believed that reading by application is beneficial. They thought it encouraged them to interact more and engage with the reading process.

Also, all participants were highly satisfied and motivated with the features applied in the application; the features they particularly liked were displaying words way, using images, sounds, types of games, and verbal encouragement. These features contributed to improving their understanding of the words/texts. The majority of participants (82%) preferred reading by the games-based approach rather than school textbooks. It was clear through students' positive responses; these results suggest that they were involved with reading using the application and had no problems. These findings are in line with the previous research (Ouherrou et al., 2018; Alghabban et al., 2017; Alghabban et al., 2021; Alghabban & Hendley, 2020).

Most of the participants (64%) were able to distinguish between similar letters while playing the games in the application (the similarity of letters is a significant issue facing them) when they were playing the games, and (91%) stated that the letters were not blurry or fuzzy. Based on their results after completing all of the games provided in the application, the proposed application is good at avoiding these issues. Through the mobile application, they were able to easily see and discern the letters clearly and readily distinguish them. According to the above results, the application can be considered a successful tool to enhance students with dyslexia to overcome their reading difficulties. These results confirm the fourth hypothesis, which shows that the application experienced as engaging and usable and offering a good level of satisfaction.

7.3.4 Students Results from the Game-based Mobile Application

The collected data from the application concerned students' progress in reading in terms of the total of the correct answers. They were divided into three groups (i.e., 8 Years, 9 Years, and 10 Years) to determine the remarked differences in ages and which group improved the best in reading. The results were evaluated using descriptive analysis. The application consists of four different games. As the first game was considered an induction to the mobile application, it was composed of five questions, and the rest of the games were composed of ten questions. It is clear in figure 7.2 that the students who were ten years old had the highest level in reading in the first game (85%), second game (88%), the third game (90%), and fourth game (93%).

The nine-year-old group achieved in the first game (83%), second game (80%), the third game (87%), and fourth game (90%). While the lowest level in reading in all games was for the eight years old (80%, 77%, 82%, 85%), respectively.

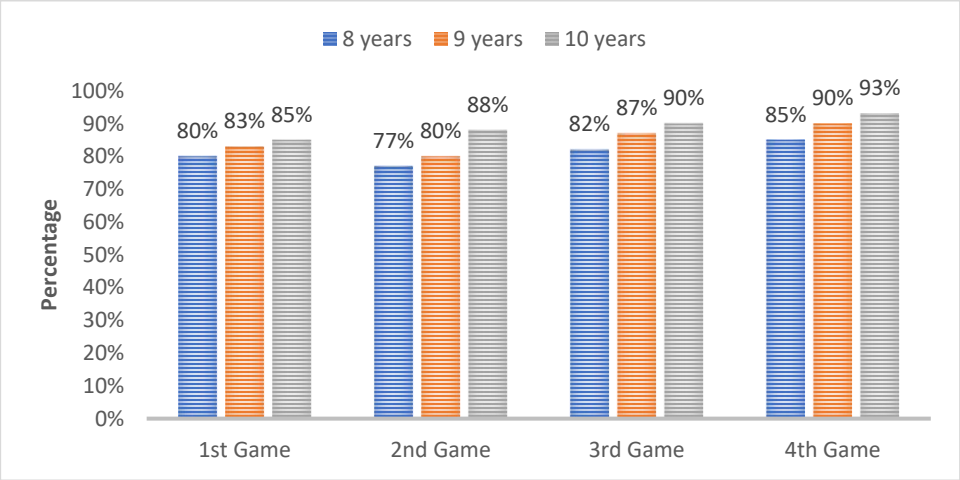

Figure 7.2 The progress in reading for each group of students in all games.

The majority of the findings are as expected, with younger students performing less than older students. It may be concluded that all scores between 77% and 93% indicate that the application is at the appropriate level, which means no group scored 100% and no group failed.

7.3.5 Post- Questionnaire Results – Teachers

The post-questionnaire for teachers aimed to assess the teachers' points of view about using the application as an educational technique to increase the reading ability of dyslexic students. Six teachers participated in this questionnaire. The overall findings had a high level of agreement regarding the students' engagement with the application. All teachers agreed that the application inspired the students to understand their weaknesses and concentrate on reading. This was verified in the experiment as 100% of the students were also very happy and found that the application helped them read more efficiently and found it easy to read and suitable to their needs. The teachers believed that the application accomplished the aim of improving reading as it is favorable. Also, they agreed that the applied features they suggested in the first study would help the students to achieve a higher reading level.

In general, they believed that the mobile application would make the reading process more manageable due to the student's enthusiasm towards the games in the proposed mobile application. Hence, higher motivation levels and engagement direct to a higher level of reading improvement.

These results are consistent with the findings of (Ouherrou et al., 2018). Their results showed that the game is considered a supportive tool to enhance dyslexic children in increasing their learning process successfully.

7.3.6 Summary of the Second Study

Overall, both students and teachers expressed high satisfaction levels with the proposed game-based mobile application in the second study, which indicates how effective it was and how it helped improve students' reading and engagement levels.

7.4 Summary

Overall, the game-based mobile application effectively increased reading performance for dyslexic students. All groups (i.e., 8 Years, 9 Years, 10 Years) showed significantly better reading after using the application, meaning **H1** was accepted.

In addition, although there were measurable differences in performance between age groups these were small and there were no statistically significant differences between age groups in the pre-test and post-test phases, which means that **H2** and **H3** were rejected. The results from mobile application illustrated that in general the older the student the higher the reading abilities as discussed in the literature review (Section 2.2.3). However, even though, there is small differences between groups and the students aged 10 years old did a little bit better, suggesting a gradual increase in ability between the ages, this is not statistically significantly. This suggests that there are no system differences between the three groups (the system does not underperform for a particular age group), thus, this is in line with the results found from testing H2 and H3.

The pre-questionnaire revealed that participants were aware of how to use games in general. Furthermore, not all of the students were equally enthusiastic about reading. The post questionnaire findings demonstrated that most participants were satisfied with the application's ability to improve reading; they were engaged and happy while using it.

They believed reading by application is useful and they found reading easy to read and suited their needs. All the participants were satisfied with the features applied in the application, and this resulted in **H4** being accepted.

The students` results from the application showed that the students who were ten years old had the highest level of reading in all games. In comparison, the lowest reading level in all games was for the eight-year-olds.

Both studies have a profound insight when compared with the previous studies and confirmed that using a game-based mobile application would help enhance dyslexic students' reading skills and that the students had a high level of satisfaction with the system.

Chapter 8: Conclusions and Future Work

The general conclusions and summary of this research are covered in this chapter. The research contributions and assesses the answers to the research questions. Research limitations and future research are also discussed.

8.1 Conclusions and Summary of the Research

HCI interventions have become more convenient and flexible in educational systems, encouraging students to learn continuously (Fage et al., 2018). Using technologies such as mobile-based applications in special education has been shown in this research to have a positive effect, especially for dyslexic students (Madeira et al., 2015). It is critical to students' future attainment to improve their reading skills and provide them with the best possible supportive method. Dyslexic students need to be engaged and satisfied to increase their reading skills (Rello & Ballesteros, 2015). Therefore, this research aimed to show that the proposed game-based mobile application has improved reading skills for dyslexic students and their overall satisfaction at primary schools in Saudi Arabia. Two studies were carried out, and the results have found a high level of satisfaction and engagement, as well as achieving a good reading performance for dyslexic students.

The first study results were explained and discussed concerning testing the efficiency of the application functionality and examining the proposed methodology. Generally, the majority of the students expressed their satisfaction with the mobile application. It is believed that it would be an excellent tool to help them increase their reading abilities. According to the suggestions and feedback of the participants (students and teachers) in the first study, the application was improved for the second study to give better learning support and reduce the problems determined to increase their performance in reading and engagement. The second study results showed that most students were engaged and satisfied with the application, which enhanced their reading performance. Thus, the overall results indicate that the game-based mobile application has a significant effect as a promising tool for helping dyslexic students increase reading performance.

8.1.1 Research Contributions

Three main contributions have been added to this research as the following:

1. **Technical Contributions:**

This research provides a novel educational mobile learning application (as described in Chapter 3) that increases the fluency, comprehension, engagement, and satisfaction levels in the reading of dyslexic children learning Arabic as a first language. This research is distinct from most of the studies carried out in Saudi Arabia due to the fact the presented mobile application is based on games functions to attract students generally. Also, the proposed solution in this research has been implemented based on recommendations retrieved from previous studies, the students, teachers, and the researcher's observations. The features have been used to construct appropriate interactive learning material to meet the dyslexic students` needs and help them increase their reading levels and maintain satisfaction. The implemented mobile application has provided the following:

1. Gathering adequate background regarding the followed strategies in special learning by gathering the best practices from various mediums (i.e., literature review) to provide dyslexic students with dyslexia support in Saudi Arabia with user-friendly learning materials.
2. Identifying appropriate and supportive features that help dyslexic students in reading, such as font type, font color, etc
3. Designing a novel framework by incorporating previously suggested frameworks and developing them.
4. Collecting attractive tools to help ease reading difficulties, such as providing gorgeous images, quiet sounds, and verbal feedback during the learning process
5. Developing a game-based application with four integrated and progressively challenging game-based learning levels to satisfy the dyslexic students in Saudi Arabia and carrying out robust experimentation to assess outcomes.

2. Academic Contributions:

This contribution has two sub-contributions as follow:

2.1 Literature Review

An intensive review has been completed regarding previous studies that focused on HCI interventions to support students with dyslexia. Most of this previous research drew upon the theoretical understanding of dyslexia to derive appropriate interventions; however, the evaluation of the effectiveness of these interventions is often minimal and purely qualitative. Thus, this research builds upon a detailed review of the field to develop a game-based mobile application and associated methodology to overcome their lack of essential evaluation of the intervention.

The provided review delivers a better understanding to researchers in this field of how mobile applications work and their relative success when deployed in the educational sector, specifically when targeted at dyslexic students. Additionally, the used models and methods in the literature have been reviewed and developed that support the work provided in this research. Hence, this contribution will support researchers in this field.

2.2 Methodology

In addition, this research presents several sub-contributions to the methodology which have positively reflected the research. First, the collected data in this research demonstrates a methodology for collection from mixed sources and different public primary schools (i.e., Jeddah, Riyadh, and Aljouf) in Saudi Arabia. Second, this research used a mixed-method for data collection and evaluating the application's effectiveness. This method used several measurements, such as a pre-questionnaire, to investigate the students' experience with the use of electronic devices and background about their reading. A post-questionnaire to collect the participants' experience and feedback and to assess the participants' overall satisfaction and opinions regarding all parts of the application. Additionally, both a pre-test and post-test were used to evaluate the students' performance in reading before using the application and after and draw conclusions on how the application would support dyslexic students.

Thirdly, as the COVID-19 pandemic has created several new challenges, especially in Education, the methodology outlines a COVID-safe environment to provide a robust assessment.

3. Practical Contributions:

This contribution has two sub-contributions as follows:

3.1 Intervention Contributions

Providing HCI interventions via the proposed application has made the reading process easier for the students with dyslexia by providing them with appropriate learning material. It was revealed that most students (87%) in the first study (Chapter 5), and students (82%) in the second study (Chapter 6), were satisfied with reading using the proposed mobile application. This implies that in both studies, the majority of students enjoyed using the application. Results from both studies strongly support improved reading performance. Therefore, these studies' positive results suggest some excellent practices supporting students with dyslexia, which highlights the importance of using mobile applications in the future. Hence, the findings indicate that there is evidence of some good practice.

3.2 Study Contributions

Contributions of pre-questionnaire in understanding students' experiences with the use of electronic devices and their reading background. The results from the pre-questionnaire showed good use and familiarity with electronic devices. This result supports researchers who wish to produce mobile-based e-learning interventions in the future.

8.1.2 Research Questions

As it has been stated in (Chapter 1, Section 1.6) the research has two questions as follows:

1. Will the proposed game-based mobile application improve reading skills for dyslexic students?
2. To what extent will the dyslexic students be satisfied and engaged after using the application?

In order to answer the first research question, three hypotheses were discussed and assessed in (Chapter 6, Section 6.6.2).

Hypotheses 1, which stated that “Students will show significant improvement in their reading ability after using the “application” compared to their baseline (pre) reading ability,” has been proven in the second study statistically (Section 6.6.2.1), which answered the first question. Whereas, remaining hypotheses were rejected due to a small number of participants and the fact that students` exposition of the lack of quality resources learning, which leads to no statistically differences between age groups at pre and post-test stages (Refer to sections 6.6.2.2 and 6.6.2.3).

To answer the second question, hypothesis 4 was evaluated and proven from qualitative and quantitative analysis in the post-experiment questionnaire. This was discussed in detail in sections 6.6.3.1 question 6. The post-questionnaires results showed that 82% of the students were satisfied while experiencing the game-based application, which made the learning environment more attractive to the participants. Hence, the participants were engaged, focused, and motivated while using the application. Overall, the results presented a great level of satisfaction while interacting with the application.

The participants’ responses discussed in (sections 6.6.3.1 under question 5) showed that the proposed application has a quality inline with the potential needs of the students with dyslexia leading to improvement in the educational process. Thus, there weren't any specific issues that caused the students to dislike the games, which positively influenced their learning and fulfilled the requirements of dyslexic students.

Moreover, the teachers were asked about their points of view regarding the students` satisfaction and engagement (Section 6.6.4, question 3). They believed that when mixing entertainment with learning, the students with dyslexia were engaged and interacted with games, which can be an effective way to improve their reading skills.

8.2 Research Limitations

Some of the limitations have been experienced as the following:

1. *Gender issue:*

Due to cultural and religious reasons, Saudi Arabia`s educational system splits male and female students into separate sections in different buildings.

Even though the two studies were conducted remotely, running the experiment with male students was extremely difficult, thus the sample in both studies was female only as (Alghabban & Hendley, 2020) and (Alghabban et al., 2021) have carried out their experiments with females only.

2. *Sample size and timing:*

The sample size of both studies was limited due to the spread of the COVID-19 pandemic. Students were significantly affected by restrictions and school closures caused by the COVID-19 pandemic, leading to not being willing to participate in experiments. Also, the amount of time spent using the application (four games with thirty-five questions in forty-five minutes) was limited due to the students having other teaching classes in parallel.

8.3 Future Work

The following are recommendations for future work in the area of using mobile applications to support dyslexic students.

8.3.1 Recommendation for Teachers

It is believed that the Saudi Ministry of Education should increase the support available to address the dyslexia issues in public schools. Due to limited extra classes (as a supportive way to help them in reading), the teachers should encourage the dyslexic students to access applications as a helpful way that delivers a quality education that is best suited to their difficulties in reading skills. The proposed application can be given to teachers to include as educational material, which will be a positive addition to enhance the reading skill in their classrooms.

8.3.2 Recommendation for researchers

Using mobile applications in education is still a new trend in HCI interventions, particularly in the area of disability support in Arabic teaching. Therefore, many subjects still require investigation, and future work should increase the understanding and knowledge of awareness of dyslexia and use of this to derive appropriate intervention.

Firstly, this research can be improved by including more dyslexic issues such as long vowels and reading sentences. Applying additional analysis of other measurements such as reading rate would be a great step to evaluate students with dyslexia.

Moreover, making a bank of games and a bank of questions so participants are not exposed to the same experience would lead to more stable verifications increasing the number of games and the number of questions in each.
Applying these recommendations to the current application and including different genders may help in trusting such new technologies when examining the progress of dyslexic students.

Secondly, investigating new learning technologies such as augmented reality or applying artificial intelligence solutions makes the learning environment more productive and attracts students with dyslexia.

8.3.3 Recommendation for Policy Makers

The application has shown positive results gained from the students which can be introduced by policymakers (i.e., teachers and school managers) to consider that the mobile applications' could be adopted by special needs education, especially for dyslexic students, and this could potentially improve their reading performance as found by this particular study.

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Appendices

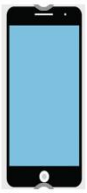
Appendix A: Experiments Materials (Questionnaires and Tests)

Appendix A.1: Pre- Experiment Questionnaire – Surdents

1. Do you use electronic devices at home?

Yes No

2. What type do you use?



Mobile

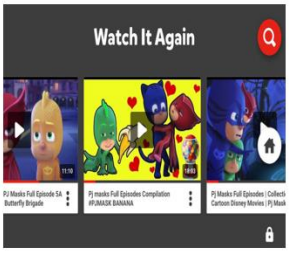
iPad

Laptop/Computer

playStation

3. What do you use it for?

Communication with friends/family



Watching YouTube

Playing games

4. How often do you use it per day?

Once Twice Three times More than three times

5. Do you enjoy reading words or sentences?

Yes No

6. Do you prefer read the word with expressed picture and a loud reading ?

Yes No

Appendix A.2 : Post- Experiment Questionnaire – Students

1. Do you think learning reading through applications will be useful?

Yes No

2. Did you feel happy when you were playing the games?

Yes No

3. Do these types of games make the reading easy?

Yes No

4. Were you able to distinguish between similar letters while playing the games in the application?

Yes No

5. Do the letters become fuzzy or blurry when you read?

Yes No

6. What features did you most like in the application?

7. Which game in the mobile application was easy to use?

8. Which game/s in the mobile application was difficult to use?

9. What feature did you most dislike in the mobile application?

10. Did the pictures and read-aloud reading help improve understanding of the words/texts?

Yes No

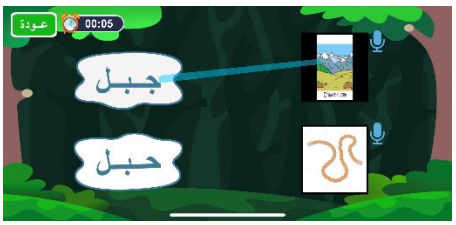
11. Does the way the words are presented attract you to focus on them?

Yes No

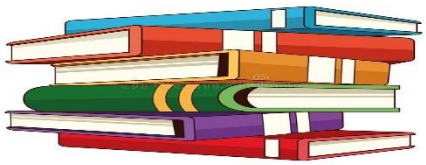
12. How do you feel about using games in the application in enhancing reading?


Satisfied Unsatisfied

13. Would you prefer reading from softcopy or hardcopy books?



Softcopy (Application- Games)



Hardcopy (School Textbooks)

14. Do you find the design of choices (i.e., fonts, colours, … etc.) making reading easier?

Yes No

Appendix A.3 : Post- Experiment Questionnaire – Teachers

1. Do you think the application is useful for dyslexic students? Justify?

2. Do you think using the application helps to improve the students reading? Justify?

3. Did the pictures and read-aloud featured help improve understanding of the words/texts? Explain.

4. What is the most positive aspect of the application?

5. Do you think the application will make the reading process more easier? Explain.

6. Is there anything you would add to the application ?

Appendix A.4 : Pre- Experiment Test and Post- Experiment Test

Read the following words:

إقرأ الكلمات التالية:

راعـي	قـطار	إنـسان	خروف	مرض
ولد	طريـق	مسـاء	أعـمال	دواء

Appendix B: Ethical Approval

Certificate of Approval	
Reference Number	ER/RA480/1
Title Of Project	Developing a mobile learning application for increasing reading skill of dyslexic students
Principal Investigator (PI):	Paul Newbury
Student	Randa Allafi
Collaborators	
Duration Of Approval	3 months
Expected Start Date	22-Feb-2021
Date Of Approval	11-Feb-2021
Approval Expiry Date	22-May-2021
Approved By	Karen Long
Name of Authorised Signatory	Lauren Shukru
Date	11-Feb-2021

Certificate of Approval	
Reference Number	ER/RA480/2
Title Of Project	Developing a mobile learning application for increasing reading skill of dyslexic students
Principal Investigator (PI):	Paul Newbury
Student	Randa Allafi
Collaborators	
Duration Of Approval	2 months
Expected Start Date	03-Apr-2021
Date Of Approval	10-Mar-2021
Approval Expiry Date	03-Jun-2021
Approved By	Karen Long
Name of Authorised Signatory	Lauren Shukru
Date	10-Mar-2021

Appendix B.1 : Consent Form – Schools Managers

UNIVERSITY OF SUSSEX

HEAD TEACHER'S CONSENT SHEET

Researchers are required to abide by ethical guidelines when working in schools. These cover topics such as gaining appropriate consent, permitting children to withdraw from the study, and keeping data confidential. We would be grateful if you could check and sign the following sheet to show that you approve of the research procedures for this study.

PROJECT NAME

Developing a mobile learning application to increase reading skills for dyslexic students.

APPROVED BY

University of Sussex Sciences & Technology Cross-Schools Research Ethics Committee (crecscitec@sussex.ac.uk)

NAME OF RESEARCHER VISITING THE SCHOOL

Randa Allafi (r.allafi@sussex.ac.uk)

NAME OF PROJECT SUPERVISORS

Dr. Paul Newbury (P.Newbury@sussex.ac.uk) and Dr. Phil Watten (P.L.Watten@sussex.ac.uk).

PERIOD OF VISITS

Spring Term 2021

CLASSES/YEAR GROUPS VISITED

Year 3 , Year 4, and Year 5

PROJECT DESCRIPTION

We wish to invite your teachers and students to participate in a research study to interact with the mobile learning application to support dyslexic students in reading skills at primary schools in Saudi Arabia.

PROCEDURE

The research will take place during the term. The study aims to develop a mobile application for increasing reading skill of dyslexic students at the primary schools in Saudi Arabia. This will focus on children aged between 8 and 10 years old and it will use questionnaires with the teachers after the study and use questionnaires for the students briefly before the study to get an idea of how much

they use devices and after the experiment. A pre-test will be used before using the application. The reason behind this is to test the targeted students' ability of reading. The pre-test includes ten random words taking from the student's curriculum. After that, each participant would be asked to read the words one by one; hence, this would take 10 minutes approximately. Also, a post-test will be used after using the application to test the participants' performance after using the application. This post-test is identical from the pre-test, including the number of words, and the researcher will ask the child to read the words. This will take 10 minutes.

This project will examine whether the proposed educational application helps dyslexic students improve their reading skills. Also, it will examine how mobile learning effectively supports children with a range of learning preferences. It is aimed to run the study with 45 children and five teachers.

CONSENT

Teachers will be sent an information letter with details of the study and a consent form to be signed to participate in the study. Parents/careers will be sent an information letter with details of the study and a permission form to be signed and returned for their child(ren) to participate in the study. Teachers should be given at least one week to read and respond to the letter. Children will be asked for verbal consent to participate in the study after receiving an initial briefing on the nature of the study and the procedures involved. Teachers and students, will also be given the option to withdraw from the study at any point.

UNIVERSITY OF SUSSEX

Please sign below to confirm that you:

- Understand the requirements of teachers who take part in the research
- Understand the requirements of children who take part in the research
- Have received detailed descriptions of the methods and materials to be used
- Give approval for the research to take place at your school.

Name of school: _____

Name of [School Manager]: _____

Signature: _____

Date: _____

Appendix B.2: Recruitment letter – Teachers

Teacher Recruitment letter

I am a PhD student in the School of Engineering and Informatics at the University of Sussex. I am researching a mobile application aimed at helping dyslexic students learn to read. This project aims to develop a mobile learning application for increasing the reading skills of dyslexic students in primary schools in Saudi Arabia.

This study will be completed as part of the Arabic language subject of third to fifth-year primary schools. You are receiving this letter as a teacher who is teaching these students. I am looking for participants and would be very grateful if you would be willing to participate in my study. If you agree to do so, you will have the chance to learn more about the study before making any decision. You would be under no obligation to take part. It is entirely up to you whether to participate in this research study.

It is of great value to have you participating for this research; you will have the chance to be familiar with a new educational tool. Then, you will complete a short questionnaire after the experiment. The data produced from your participation will be kept confidential. Your name will not be used nor associated with the data in papers, dissertations, or any printed or non-printed volumes related to this study. The result of this study will be used in my thesis for a PhD degree and publication purposes and can be accessed through the university archived theses library and/or published sources.

My research is supervised by Dr. Paul Newbury and Dr. Phil Watten and they can be contacted on: P.Newbury@sussex.ac.uk and P.L.Watten@sussex.ac.uk respectively. The study has been approved by the Sciences and Technology Cross-Schools Research Ethics Committee. If you have any ethical concerns, please contact the ethics chair (crecscitec@sussex.ac.uk)

Thank you and Best Regards,

Mrs. Randa Saad Allafi
School of Engineering and Informatics
Department of Informatics
University of Sussex
R.allafi@sussex.ac.uk

Appendix B.3: Information Sheet - Teachers

UNIVERSITY OF SUSSEX

TEACHER INFORMATION SHEET

PROJECT NAME

Developing a mobile learning application for increasing the reading skills of dyslexic students.

INVITATION TO TAKE PART

You are being invited to take part in a research study. Before you decide whether to take part, it is essential for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully.

WHAT IS THE PURPOSE OF THE STUDY?

This project will examine how the proposed educational application helps dyslexic students improve their reading skills. Also, it will examine how mobile learning effectively supports children with a range of learning preferences.

WHY HAVE I BEEN INVITED TO PARTICIPATE?

As a teacher who teaches the Arabic subject in primary schools in Saudi Arabia. it is great value to have you participating for the purpose of this research.

DO I HAVE TO TAKE PART?

It is up to you to decide whether to take part. If you do decide to take part, you will be given this information sheet to keep and be asked to sign a consent form. If you decide to take part, you are still free to withdraw at any time up until the results are analyzed (01/12/2021) and without giving a reason.

WHAT WILL HAPPEN TO ME IF I TAKE PART?

If you decide to participate in this study, you will complete a questionnaire after the experiment to get your feedback about using the application as a supporting tool.

WHAT ARE THE POSSIBLE DISADVANTAGES AND RISKS OF TAKING PART? (WHERE APPROPRIATE)

You will only be required to complete a short questionnaire after the students using the system. This will pose no additional risk to your safety.

WHAT ARE THE POSSIBLE BENEFITS OF TAKING PART?

Taking part in this study will help to learn a new way to teach students with dyslexia, thus supporting practical and interactive learning.

WILL MY INFORMATION IN THIS STUDY BE KEPT CONFIDENTIAL?

The data you produce during this study will be kept confidential and your name will not be used nor associated with the data in papers, dissertation, thesis, reports, or any printed or non-printed volumes associated with this study.

WHAT SHOULD I DO IF I WANT TO TAKE PART?

If you wish to take part in this research, please contact Randa Allafi either telling her in person or emailing her at R.allafi@sussex.ac.uk

WHAT WILL HAPPEN TO THE RESULTS OF THE RESEARCH STUDY?

The result of this research will be used in thesis for PhD degree and for publication purposes. They can be accessed through the university archived theses and/or published sources.

WHO IS ORGANISING AND FUNDING THE RESEARCH?

I am conducting the research as a student at University of Sussex . The organizers of this research are Mrs Randa Allafi, Dr Paul Newbury, Dr Phil Watten.

CONTACT FOR FURTHER INFORMATION

For further information on this research, you can contact: Dr. Paul Newbury and Dr. Phil Watten and they can be contacted on: P.Newbury@sussex.ac.uk and P.L.Watten@sussex.ac.uk respectively.

The researcher : Randa Allafi
R.allafi@sussex.ac.uk
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er 1
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INSURANCE

The University of Sussex has insurance in place to cover its legal liabilities in respect of this study.

THANK YOU FOR TAKING TIME IN READING THIS INFORMATION SHEET

DATE

09/03/2020

Appendix B.4: Consent Form – Teachers

UNIVERSITY OF SUSSEX

TEACHERS CONSENT FORM FOR PROJECT

Title of Project:

Developing a mobile learning application for increasing reading skill of dyslexic students.

Name of Researcher and School:

Randa Saad Allafi . School of Engineering and Informatics. C-REC Ref no: ER/RA480/2

	Please tick box **Yes**	**NO**
• I consent to the use of anonymized quotes in publications from the research	☐	☐
• I consent to complete the questionnaire after the experiment	☐	☐
• I understand that any information I provide is confidential, and that no information that I disclose will lead to the identification of any individual in the reports on the project, either by the researcher or by any other party	☐	☐

- I have read the information sheet, had the opportunity to ask questions and I understand the principles, procedures and possible risks involved. ☐ ☐

- I consent to the processing of my personal information and data for the purposes of this research study. I understand that such information will be treated as strictly confidential and handled in accordance with the General Data Protection Regulation (GDPR) 2016. ☐ ☐

- I understand that my participation is voluntary, that I can choose not to participate in part or all the project, and that I can withdraw at any stage of the project without being penalized or disadvantaged in any way nor do I have to give reasons for this. ☐ ☐

- I understand I can request without penalty that my data be withdrawn and deleted even after testing is complete, any time up until the results analysis is complete (01/12/2021). ☐ ☐

- I consent to my data being deposited in the UK Data Archive for re-use in future research and analysis. I understand that it will be fully anonymized before deposit. ☐ ☐

- I agree to take part in the above University of Sussex research project ☐ ☐

Name:

Date:

Type your signature if submitting electronically:

Appendix B.5: Recruitment letter – Parents

Parent/guardian Recruitment letter

I am a PhD student in the School of Engineering and Informatics at the University of Sussex. I am researching a mobile learning system aimed at helping dyslexic pupils learn to read. This project aims to develop a mobile learning application for increasing the reading skills of dyslexic students at primary schools in Saudi Arabia.

This study will be completed as part of the Arabic language subject of third to fifth-year primary schools in Saudi Arabia. You are receiving this letter as your child is a dyslexic student taking this module. I am looking for participants and would be very grateful if your child would be willing to take part in my study. If you agree to do so, you will have the chance to learn more about the study before making any decision. Your child would be under no obligation to take part, and this will have no impact on your child's marks, assessments, or future studies. It is entirely up to you to allow your child to participate in this research study.

It is of great value to have your child participating for this research; your child will be given a short questionnaire to complete before the experiment. After that, the session will begin with a pre-test before using the application. The reason behind this is to test the targeted students' ability to read. The pre-test includes ten random words taken from the student's curriculum. After that, each participant would be asked to read the words one by one; hence, this would take 10 minutes approximately. Following this, the mobile application would be installed in their devices either from the App Store or Google play (with the participants' guardians). Then each child will be observed by the researcher and the teacher as well via Microsoft Teams, and as a parent, you must be present during that. After that, a post-test will be distributed to test the participants' performance after using the application. This post-test is identical to the pre-test, including the number of words, and the researcher will ask the child to read the words. This will take 10 minutes.

After that, once the children use the application, they will complete a short questionnaire after the experiment. Your child will have the chance to be familiar with a new educational tool with the help of your child's teacher or me. The data produced from your child's participation will be kept confidential. Your child name will not be used nor associated with the data in papers, dissertations, or any printed or non-printed volumes associated with this study. I will not record any video or audio during the observation. The result of this study will be used in my thesis for a PhD degree and publication purposes and can be accessed through the university archived theses library and/or published sources.

My research is supervised by Dr. Paul Newbury and Dr. Phil Watten and they can be contacted on: P.Newbury@sussex.ac.uk and P.L.Watten@sussex.ac.uk respectively. The study has been approved by the Sciences and Technology Cross-Schools Research Ethics Committee. If you have any ethical concerns, please contact the ethics chair (crecscitec@sussex.ac.uk)

Thank you and Best Regards,

Mrs. Randa Saad Allafi
School of Engineering and Informatics
Department of Informatics
University of Sussex
R.allafi@sussex.ac.uk

Appendix B.6: Information Sheet – Parents

UNIVERSITY OF SUSSEX

PARENT/GUARDIAN INFORMATION SHEET

PROJECT NAME

Developing a mobile learning application for increasing the reading skills of dyslexic students.

INVITATION TO TAKE PART

Your child is being invited to take part in a research study. Before you decide whether to take part, you need to understand why the research is being done and what it will involve. Please take time to read the following information carefully.

WHAT IS THE PURPOSE OF THE STUDY?

This project will examine the proposed educational application that helps dyslexic students improve their reading skills. Also, it will examine the use of mobile learning to support children with a range of learning preferences effectively.

WHY HAVE WE BEEN INVITED TO PARTICIPATE?

As a parent, your child is a dyslexic student in primary schools in Saudi Arabia. Moreover, we expect to test 45 children from year third to fifth of School. It is of great value to have your child participating in the purpose of this research.

DO WE HAVE TO TAKE PART?

It is up to you to decide whether to take part. If you decide to take part, you will be given this information sheet to keep and be asked to sign a consent form. If you decide to take part, your child is still free to withdraw at any time up until the results are analyzed (01/12/2020) and without giving a reason. To take part your child will have to download an application. Choosing for your child to either participate or not participate in the study will have no impact on your child's marks, assessments, or future studies.

WHAT WILL HAPPEN TO US IF WE TAKE PART?

It is aimed to run the study with 45 children and five teachers. Children will then complete a short questionnaire online before beginning the practical session. After that, the session will start with a pre-test before using the application. The reason behind this is to test the targeted students' reading ability. The pre-test includes ten random words taken from the student's curriculum. After that, each participant would be asked to read the words one by one; hence, this would take 10 minutes approximately. Then the system will be accessible via the smartphone or tablets, and then children start playing the games by interacting with pictures, words, and audio. Following the session, each

child will be observed by the researcher and the teacher via Microsoft Teams, and as a parent, you must be present, and you should remain with your child during the session. Later, a post-test will be distributed to test the participants' performance after using the application. This post-test is identical to the pre-test. Then, the children complete a short questionnaire to obtain their perspectives on using the application. You may review the mobile application content and questionnaire questions before deciding whether to participate.

WHAT ARE THE POSSIBLE DISADVANTAGES AND RISKS OF TAKING PART? (WHERE APPROPRIATE)

During the session, students will read words and listen to the audios provided in the application to answer the questions. Then, your child will interact with the smartphone and learning materials. This will pose no additional risk to your child's safety.

WHAT ARE THE POSSIBLE BENEFITS OF TAKING PART?

This study will help your child enhance her reading skills and help the teacher learn a new way to teach students with dyslexia, thus supporting practical and interactive learning.

WILL OUR INFORMATION IN THIS STUDY BE KEPT CONFIDENTIAL?

The data your child produces during this study will be kept confidential. Your child's name will not be used nor associated with the data in papers, dissertations, thesis, reports, or any printed or non-printed volumes related to this study.

WHAT WILL HAPPEN TO THE RESULTS OF THE RESEARCH STUDY?

This research will be used in the thesis for PhD degree and publication purposes. They can be accessed through the university archived thesis and/or published sources.

WHO IS ORGANISING AND FUNDING THE RESEARCH?

I am conducting the research as a student at University of Sussex . The organizers of this research are Mrs. Randa Allafi, Dr Paul Newbury, Dr Phil Watten.

CONTACT FOR FURTHER INFORMATION

For further information on this research, you can contact: Dr. Paul Newbury and Dr. Phil Watten and they can be contacted on: P.Newbury@sussex.ac.uk and P.L.Watten@sussex.ac.uk respectively. The researcher: Randa Allafi ra480@sussex.ac.uk

INSURANCE

The University of Sussex has insurance in place to cover its legal liabilities in respect of this study.

THANK YOU FOR TAKING THE TIME IN READING THIS INFORMATION SHEET

DATE

09/03/2020

Appendix B.7: Consent Form – Parents

PARENT/GUARDIAN CONSENT FORM FOR PROJECT

Title of Project:
Developing a mobile learning application for increasing the reading skills of dyslexic students.

Name of Researcher and School:

Randa Saad Allafi. School of Engineering and Informatics C-REC Ref no: ER/ /RA480/1

Parent Consent for their child

	Please tick box Yes	No
I agree to my child completing the questionnaire	☐	☐
I agree to my child will be observed via MS Teams	☐	☐
I understand that my child participation is voluntary, that my child can choose not to participate in part or all the project and that my child can withdraw at any stage of project without being penalized or disadvantaged in any way nor do we have to give reasons for this	☐	☐
I understand I can request without penalty that my child's data be withdrawn and deleted even after testing is complete, any time up until the results analysis is complete (01/12/2021).	☐	☐
I consent to my child data being deposited in the UK data Archive for re-use in future research and analysis. I understand that it will be fully anonymized before deposit.	☐	☐

I agree that my child take part in the above University of Sussex research project. ☐ ☐

Name of Child ----------

Name of Parent or Guardian ----------

Age of child ----------

Date ----------