Design Model for Developing Virtual Reality Based Systems for Dyslexia

By

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THESIS ACCEPTANCE CERTIFICATE

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DEDICATION

I dedicate this thesis to my FAMILY and TEACHERS for their tremendous support, cooperation and encouragement

ACKNOWLEDGEMENTS

I am very grateful to ALLAH SWT (the most merciful and beneficial) for his countless blessings upon me. With His blessings, I was able to complete my research work.

I am also thankful to my father for his efforts and support. He always stood by my side during my hard times while I was in the phase of completing my work.

ACRONYMS

Individualized Reading Enhancing Application for Dyslexia	IREAD
Non-Native Language Learning Teaching	NLLT
Mobile Game-Based Learning	mGBL
Game-Inspired Designs	GBIs
Virtual Reality Environments	VRE
User-Centered Design	UCD
Immersive Virtual Reality	iVR
Virtual reality Neuroscience Questionnaire	VRNQ
Meaningful Immersive Virtual Reality Learning	MiVR-L
Virtual Reality Everyday Assessment Lab	VR-EAL
Virtual Reality Induced Symptoms and Effects	VRISE
Psychological, Cognitive and Behavioral Sciences	PC&B
British Ability Scales	BAS
Three Dimension	3D
Two Dimension	2D
Visual-Spatial Potential of Dyslexics	D-Potensi
Reading Learning Disabilities	RLD
Active and Student-Centered Learning	ASCL
User Interface	UI
System Usability Scale	SUS
Augmented Reality	AR
Virtual and Augmented Reality	VAR
Head-Mounted Display	HMD
Machine Learning	ML
Developmental Dyslexia	DD

Tangible Interactions	TI
Specifications	Specs
Consonant-Vowel	CV
Tangible Interactions in Three Dimension	3DT
Artificial Intelligence	AI
Application	App

ABSTRACT

Virtual Reality (VR is a computer-generated simulated environment that may be similar to or different from the real world), has given a paradigm shift to the technological world. From the world of just images and 2d objects, we have now entered into a whole new virtual world that is more interactive and intuitive. Virtual reality has proven to be the best education tool as it provides a virtual interactive environment and in-depth knowledge of the subject being presented. In our previous research work, we reviewed the role of VR in education and learning for people with disabilities. The current research aims to explore the accomplishments of virtual reality technology for the progression of dyslexics. Dyslexia is a learning disorder that effects an individual's reading, spelling, phonological skills and working memory. We have proposed a User-Centered design and development process model (UCDDPM) that also includes design guidelines to develop VR-based accessible applications for dyslexics. Existing dyslexia-specific mobile games have been evaluated using evaluation matrices for dyslexics. "Alphalexiv" is a webVR-based learning game we aim to develop by implementing the proposed guidelines and UCDDPM. A prototype has been developed in this thesis. The prototype has been evaluated using online accessibility tools for dyslexics. The research has concluded that VR-based applications when developed using proposed guidelines and UCDDPM play a vital role in the betterment of dyslexics, enhancing attention, readability and working memory. Further large-scale studies based on the proposed methodologies are suggested to benefit dyslexics on a widespread scale.

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Chapter 1

INTRODUCTION

The success of a country depends upon the literacy rate of that country which defines the percentage of the population able to read and write. These abilities are crucial for performing basic daily routine activities [26]. Therefore, the government of a country needs to show special attention towards the literacy of its people. When literacy is a concern, people having learning disorders must be considered and should be a special concern of educational institutes. The most common learning disorder that effects the reading, spelling, comprehension and phonological skills of a person is known as “Dyslexia”. The term dyslexia is derived from the Greek words “dys” and “lexia”. The word “dys” means poor, abnormal, or inadequate and the word “lexia” means language or words, therefore it is a learning disorder [2]. Dyslexia is neurobiological in nature effecting cognitive functions of the brain. It effects the executive functions of the brain i.e. short-term memory for verbal information the process which plays a vital role in reading and spelling. Developmental dyslexia is commonly described as a difficulty in attaining fundamental phonological skills i.e. accurate and fluent reading, spelling, word comprehension and writing. Dyslexia may cause range of multiple cognitive functional deficits that include attention, working memory, planning and information organization.

European Erasmus+ program (A program by European Union for the support of training, education, sports and youth in Europe) reported in a study that Dyslexia is a growing disability that effects adults, as well as children and the estimated prevalence of dyslexia in Europe is 8-20%, whereas 2-4% of the population is seriously suffered. The report also identified that this disability is causing high youth unemployment, un-complete vocational training and functional illiteracy. Dyslexia in adulthood put a person into a frustrated, underachieved and often unemployed lifestyle. Therefore, it is necessary to develop teaching techniques that leverage dyslexics to enhance their learning abilities.

Information and communication technologies (ICT) have developed solutions for dyslexic to leverage them in learning. ICT includes PC, mobile phones, iPad, tablets and virtual reality [3]. The coronavirus disease 2019 (COVID-19) pandemic has given a boost to ICT-based e-learning programs in recent years. Virtual Reality has shown its positive implications in the education domain through integrated virtual simulation technologies during this pandemic [4].

Several pieces of research have also shown a positive impact of using Virtual Reality for the improvement of cognitive abilities of students with special educational needs (SENs) by implementing a constructionist learning approach [52]. VR-based interventions for Psychological, Cognitive & Behavioral (PC&B) sciences have shown distinctive advantages [11]. Kalyvioti K. et al. conducted a literature review-based survey to analyze the effect of using virtual reality for dyslexia and suggested that virtual reality is presenting unique features to people with dyslexia [46].

As virtual reality for dyslexia is in its infancy and requires further research and advancements in the particular domain therefore we have conducted a literature review-based survey to identify the issues and challenges being faced by developers while developing VR-based applications for dyslexics. The results of the conducted survey depicted that although VR-based interventions and assessment techniques have shown positive improvement with respect to dyslexics; still, they are not producing high-grade results due to the lack of design guidelines and the absence of a design and development process model to develop VR-based systems/applications for dyslexics.

It has been identified through our survey that VR is showing promising results for the dyslexia-specific domain. VR-based applications are being developed for the following rationale:

1) Assessment: For early detection of dyslexia in preschool students.
2) Training: For demonstration of dyslexics' undergoing issues to teachers, parents and medical staff
3) Intervention: For improvement of dyslexics' learning capabilities

This indicates that Virtual Reality applications are worth developing for dyslexics. Hence their potential could be enhanced by following an established set of design guidelines as well as a development process model to develop these applications.

1.1 Problem Statement

Although Virtual Reality is producing worthy results generally in education field and specifically for dyslexics. Research studies have revealed the issues faced by developers in adopting strategies while developing such systems. For this reason, the significance of current research is the proposed leveraging features of VR for dyslexics.

"Virtual Reality based systems have provided promising results for the betterment of dyslexics, still this research discipline is in its infancy. Therefore, it's need of time to have firm design guidelines and a design and development process model to further achieve best results in this discipline"

1.2 Objectives

The goal of this research is focused on the following aspects:

- To Review the paper 'guidelines for web accessibility of dyslexia' to find out whether these guidelines be suitable in the case of virtual reality for dyslexia.
- To Identify the traits of VR that are most suitable for developing systems for dyslexic children.
- To evaluate existing mobile-based applications to explore their potential and limitations that a virtual reality based application could enhance.
- To propose a comprehensive set of design guidelines that will provide assistance to researchers about how virtual reality based systems are helpful for dealing with the issues of dyslexic children.
- To propose a User-Centered design and development process model for developing effective and efficient systems for dyslexics.
- To develop a prototype following the guidelines and proposed model to evaluate the authentication of the presented methodologies.

1.3 Relevance to National Needs

The decision to approach Virtual reality for dyslexic users is motivated by three reasons relating to its social relevance:

1.3.1 Dyslexia is frequent and universal

Dyslexia is a growing disorder effecting 5-10 % of the population. It effects the basic learning skills and results in a low literacy rate, unemployment, frustration and fatigue in learning.

1.3.2 Virtual Reality as future technology

Virtual Reality is the future technology, as the world is planning to step into a whole new world called the metaverse. At this stage, we must be aware of this technology and its uses in different fields of life so we may not leave behind in this era of technology.

1.3.3 It contributes to the special schools

Using these guidelines special systems could be developed and deployed in schools or institutes for facilitating the children undergoing dyslexia.

1.4 Advantages

- Helpful for children dealing with dyslexia.
- Useful for the developers to understand the disorder and it's in depth details, beneficial features of VR technology for developing special systems for learning disorders and having a guide to follow while developing such systems.
- Also effective for students (without dyslexia) for learning, as basic phonology, reading and spelling learning apps could be used by non-dyslexics as well.
- For awareness of teachers and parents about the difficulties faced by the child.

1.5 Area of Application

- E-learning
- VR-Based training
- Special Schools
- UI/UX
- Parenting
- Teaching
- Entertainment

1.6 Thesis Outline

Chapter 1: In this chapter, we have described introduction, research objectives, advantages and areas of application of current research.

Chapter 2: This chapter consist of brief introduction of dyslexia and virtual reality along with leveraging features of VR for dyslexia.

Chapter 3: This chapter comprises a literature review based survey to identify key challenges faced by researchers and developers when working with VR-based application.

Chapter 4: This chapter provides evaluation methodology and results of the existing mobile applications.

Chapter 5: This chapter comprises our proposed set of design guidelines and the User-centered design and development process model proposed in our research.

Chapter 6: In this chapter the prototype developed using proposed design guidelines and model have been presented along with its evaluation methodology and results.

Chapter 7: This chapter presents discussion, conclusion and future work.

Chapter 2

DYSLEXIA AND VR

2.1 Overview

In this chapter, we have briefly explained dyslexia as a learning disorder, how it effects the life of people, Virtual Reality as a technology, why we have chosen virtual reality for dyslexia? and also described our literature review-based survey and its results.

2.2 Dyslexia

Dyslexia is a Reading Learning Disorder (RLD) that effects the fluency in ready, spelling, comprehension and phonological skills of a child [48]. Dyslexia does not affect the intelligence of an individual as there are many famous and genius personalities that lived with dyslexia e.g. Albert Einstein, Steve Jobs, Thomas Edison etc.

2.2.1 Dyslexics Deficits

We have briefly described some of the deficits of dyslexics in this subsection to demonstrate the problems or issues encountered by these individuals and to provide an understanding of the challenges that are up fronted by them. Researchers in [65] [41] have described these issues briefly. Table 2.1 shortly describes these issues.

2.2.2 Cognitive Functional disorder

Dyslexia not only effects the linguistics related skills like reading, spelling, comprehension and phonological skills but it also has its impact upon some other cognitive functions. Following are all the neurological issues faced by dyslexics (researchers have discovered so far) [54] [18].

- Linguistics
- Working memory
- Planning, Organization and Task monitoring
- Inhibition
- Set shifting
- Attention
- Perceptual-visual development
- Perceptual auditory development

Table 2.1:Deficits faced by dyslexics

Deficit	Explanation
Letter reversal	Letter may seem flipped or reversed e.g. ‘d’ as ‘p’ or ‘b’ or ‘q’.
Mirrored Words	Words and letters may seemed mirrored to them e.g. ‘p’ seems ‘q’ and “brown” as “nword”.
Disorder letters	Confused understanding accurate order of letters in a word e.g. “dog” as “gdo”.
Bad witting	Dyslexia directly effects reading skills but indirectly it also effect writing (improper writing is a result of the mispronounced letters/word or incorrect reading).
Letter confusion	Confused between similar looking letters e.g. small case ‘f’ and ‘t’.
Slow reading	The above problems make them read slow and inaccurate.
Spelling	Disorder of phonological skills effects vocabulary acquisition and spellings.
Phonemic Awareness	Lack of Phonemic Awareness occurs in dyslexics and results in incorrect sound pronunciation.
Orthography	Difficult to differentiate between orthographically similar words, e.g. “Drive” and “Derive”.
Typography	May alternate between font case e.g. “eliminate” to “EliMinate”
Derivation	May face difficulty in derivational words (forming new words by combining two words), e.g. “night” + “mare”= “nightmare”
Foreign language	It’s difficult for them to learn a foreign language

- Semantic, Syntactic and lexical
- Motor coordination: Laterality and Directionality

Figure 2.1 demonstrates the brain cognitive functions have been effected by dyslexia.

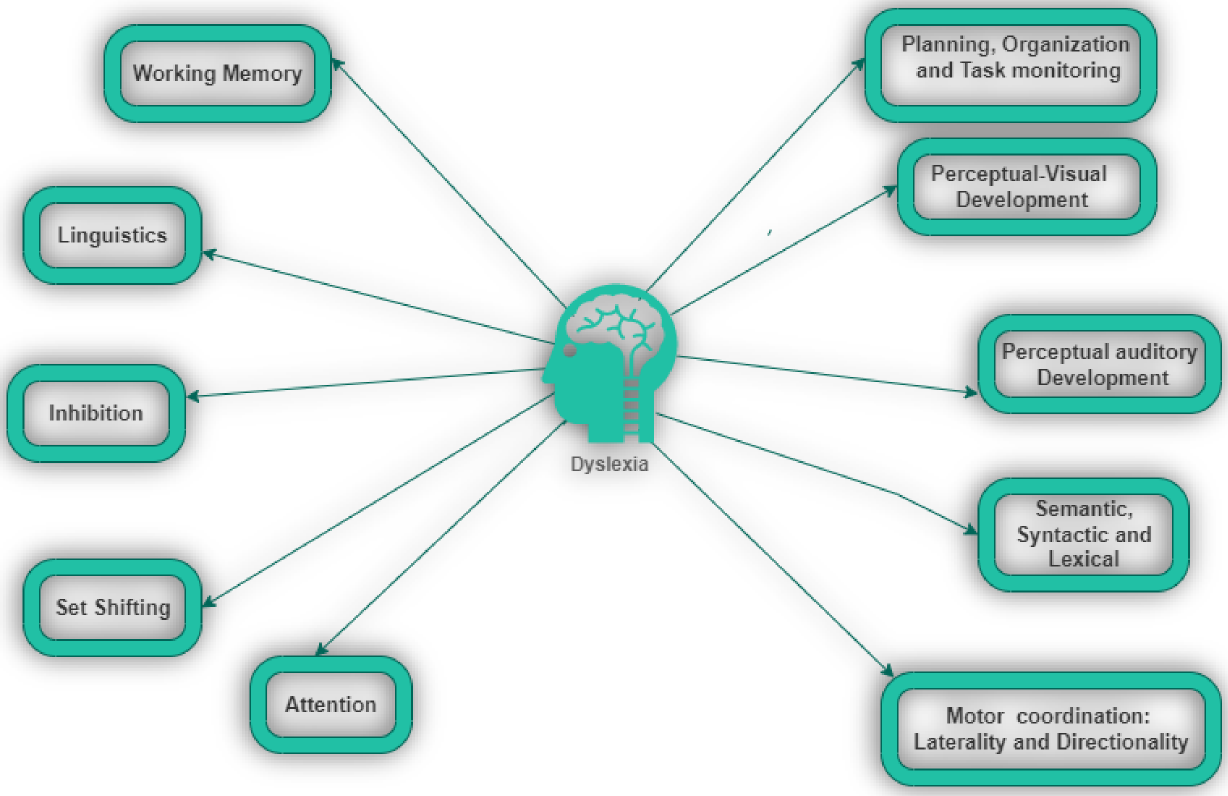

Figure 2.1: Cognitive functions affected by dyslexia

2.2.3 All Dyslexics Are Different

Dyslexics symptoms vary from person to person and different at different age groups. Signs of preschool children may include slow learning, late speaking, difficult to learn and remember rhymes, difficulty in learning letters, naming etc. School going children symptoms include difficulty in reading, decoding, memorizing spellings, weekdays, months, sequences and selection of correct words etc. Teens and adults shows lack of fluency while reading, mispronunciation of words, trouble memorizing lessons etc. Every person is differently effected by dyslexia. It is not a must that every dyslexic face all of these difficulties. The symptoms vary from mild to severe.

2.2.4 Comorbidities

Dyslexia also come with comorbidities (means other learning disorders existing in a person along with dyslexia). These learning disorders are described below.

- Dysgraphia (Disorder related to writing)

- Dyscalculia (Disorder that effect mathematical learning)
- Autism (effects interaction and communication skills along with learning behaviors)
- ADHD (Attention deficit hyperactivity disorder)
- Dyspraxia (Disorder that effects movement and co-ordination)

2.2.5 Dyslexics as Picture Thinker

Dyslexics are different from others as their brain works differently from non-dyslexics. Researchers have suggested that dyslexics are picture thinkers and have high imaginative powers [26]. According to Ron Davis himself a Dyslexic, Dyslexics are picture-thinkers, their mental modal dependents upon sensory imagery except words, sentences, or self-talk (internal dialogue in mind). For the reason that this thinking method is subliminal-much faster than a person could be aware to, most of the dyslexics are not even aware of their distinctive thinking method [63]. They are good at hands-on activities, strategizing, real-world problem solving and creative endeavors. They may hesitate working with word-based linear, sequential problems and poor at little-by-little reasoning strategies.

2.3 Virtual Reality

VR will change the lifestyles of people in the near future when people no longer have to be physically present at any place to show their presence; they will do so by the use of VR technologies while sitting at their home places and making their avatars presenting them at a specific/particular location. In the current era, VR is playing an essential role in on-campus education, special education (for people with disabilities i.e. visual or hearing impaired) and e-learning [7]. VR technology is also playing a vital role in Science, Technology, Engineering and Mathematics (STEM) fields [8]. Still, below described reasons hindered its widespread usage, a) lack of technical skill, b) user acceptance and c) weak design and development strategies. We have now entered an era when technologies supporting the development and deployment of VR have been advanced [9]. It’s time for software designers and developers to take advantage of this advancement and should pay special attention towards the design and developmental methodologies of VR-based applications. This research study aims to discover the design and development methodologies of existing VR-based applications in general and specifically VR-based applications for dyslexics. We have shortly described virtual reality history, VR technology, software and hardware support available to develop VR-based applications.

2.3.1 Brief history

"Sensorama" was the first machine, a multi-sensory simulator invented in 1957 by Morton Heilig [5]. This was the initial approach towards developing a virtual world that has all the features of a virtual environment VE (colored prerecorded film, binaural sound augmentation, wind, scent and vibration experiences) still, it was not interactive. Ivan Sutherland presented a virtual reality solution in 1965. An artificial world with interactive graphics, forced feedback, taste, smell and sound, He introduced a head-mounted display (HMD) that he termed as "window into a virtual world". Jaron Lanier was the first person who coined the term "Virtual Reality" in 1980 [6]. He is known as the founder of VPL research who started developing Gear including goggles (for visual experience) and gloves (for hand haptics) that were required to experience actual VR. Later on, multiple definitions of virtual reality have been proposed by different researchers, C. Cruz-Neira [51] defined virtual reality as follows:

"VR refers to immersive, interactive, multisensory, viewer-centered, three dimensional computer generated environments and the combination of technologies required to build these environments."

We can group the VR systems accordingly to the level of immersion they offer to the user. VR systems could be grouped according to the depth of immersion they offer their users. There exist three basic types of virtual reality that are:

1)Non-immersive, 2) Semi-immersive and 3) Fully immersive. In Figure 2.2 we have briefly described these types of VR.

2.3.2 Software Requirements

VR development software is required to develop three dimension, an immersive and interactive environment. These days' different software development tool kits (according to multiple requirements i.e. game development and VR for browsers and VR for collaborative online meetings) are available in the market to help VR developers in creating virtual environments. We have described some of the most in-use software in table 2.2. Two types of software have been described in the table.

1) Desktop (use to develop native experiences, especially for windows) and

2) WebVR (use to develop web experiences that can be enjoyed using web browsers like Google Chrome and Mozilla Firefox).

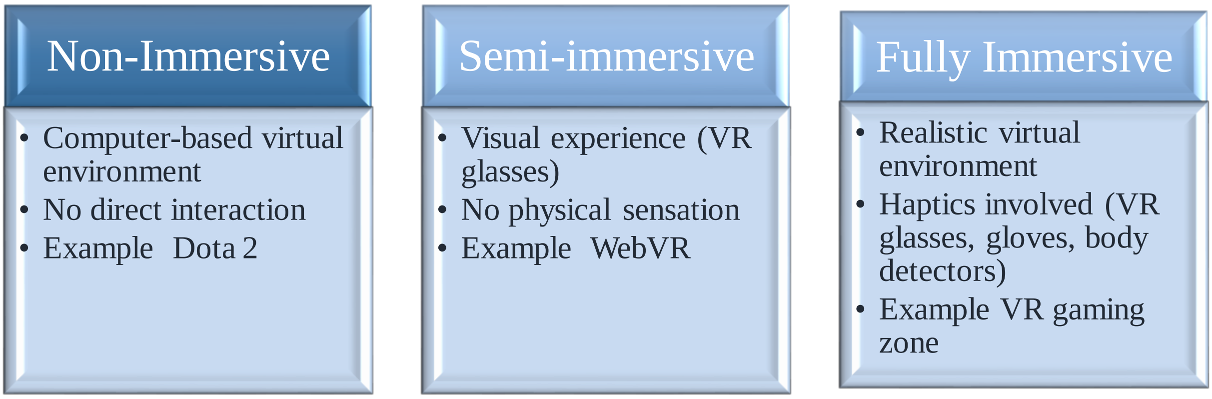

Figure 2.2:Types of VR

Table 2.2: List of Software applications to develop VR-based systems

Software Name	Description	Link
	Desktop Tools	
Unity 3D	A game engine, based on C# and JavaScript, 3D assets are also available for quick development, easy to export to other platforms and support almost all main HMDs.	Unity 3D
Unreal Engine (UE$_4$)	A game engine having VR integration with an asset store and huge documentation. A modern editing environment that could be exported to some of the known platforms.	Unreal Engine
	WebVR Tools	
Three.js	A JavaScript library developed on top of WebGL (an API based upon OpenGL, used to allow interaction with 3D experiences on webpages). The use of JavaScript makes it easy to use.	Three.js
A-Frame	An Open-Source project by Mozilla (An Entity-Component System). A framework built on Three.js and WebGL; use with HTML and CSS to develop VR experiences.	A-Frame
React VR	A framework to develop web-based VR experiences, built on APIs like WebGL and WebVR along with a declarative approach of React Native.	React-VR

2.3.3 Hardware Requirements

VR hardware is required to make a VR application fully immersive, interactive and to give a real-world like experience. We have some basic and most required hardware in this subsection.

2.3.3.1 Head-mounted Display (HMD)

A display device for VREs, put on the head that covers the vision of an individual. It has a display unit (optics) in front of each eye (in binocular HMD) and a single display (in monocular HMD). There is no screen in front of the user just a projection on special optics.

2.3.3.2 PC or mobile device

The mobile device is used to display the VR environment in those devices that do not have optics display and use mobile to display the environment in front of the user's eye.

PC has to connect with an HMD device to project the VR environment onto the device. PC is also a requirement for the development of high-resolution VR applications.

2.3.3.3 Haptic Gloves

Wearable gloves are used to interact with the environment and allow realistic touch and feedback from the environment. They have embedded sensors to create a sense of touch.
Table 2.3 describes some major HMDs along with PC/ mobile specifications.

Table 2.3: Description of major HMDs

HMD	Description	PC/ Mobile Specs
Google Cardboard	A cheap handheld device to experience Virtual Reality	Android 4.1 or above iOS 8 or above
Valve Index	It has an IPS display and supports "lighthouse" 2.0 tracking system, also has accelerator and controllers	Memory: 8GB Display: DisplayPort 1.2 OS: Windows 10, linux, SteamOS
HTC Vive Cosmos Elite	It provides a wide field of view, with laser tracking system. Allows "room-scale" movement as user can freely move around in the room and not has to stuck at a particular area.	Memory: 8GB Display: DisplayPort 1.2 OS: Windows 10
Oculus Quest 2	Allows six degree of freedom (6DOF) position tracking. Also has accelerator, game controller, gesture control and adjustable IPD.	Memory: 8GB + OS: Windows 10
Pimax Vision 8KX	It has two 4K displays (one per eye). Has accelerator and controllers.	Memory: 8GB Display: DisplayPort 1.2 OS: Windows 10
Samsung HMD Odyssey	It has position tracking, accelerator, game controller, gesture control and adjustable IPD.	Memory: 8GB Display: DisplayPort 1.2 OS: Windows 10

2.4 Why VR for dyslexia

We have preferred virtual reality over other ICT methodologies due to the reason that it offers unique features to benefit dyslexics overcome their deficits, these features have not been offered by other ICTs. Some of the feature that leverage dyslexics enhance their capabilities are described in table 2.4.

Table 2.4: Features of VR leveraging dyslexics

Sr. no.	VR feature	Description
1.	**Embed compensatory strategies**	VR environments allows the efficient use of compensatory strategies (methods of information processing which allow users to attain their objectives through multiple means, as story making (connecting a story to something so that it may stick/stay in mind) and grouping of items regarding common aspects).
2.	**Multisensory stimuli**	Involving haptics along with audio/visual stimuli helps dyslexics enhancing multisensory learning.
3.	**Virtual world**	Dyslexics are picture thinkers and possesses high imagination power that will leverage by virtual environment.
4.	**Immersion**	Being present in and environment that is safe of any damage allows the user to indulge in the environment without any hesitation.
5.	**Focus**	Dyslexics have attention issues that could be overcome by the use of HMDs as they exclude visual distraction by covering whole vision.
6.	**Enjoyment**	Studies have shown that children who use VR enjoy this type of learning and demanded to have more learning experiences like that.

Researchers have also expressed Evidence based virtual environments (VEs) that embed compensatory strategies i.e. cueing could change motor-behavior and enhance exercise strength as well as being motivating and engaging [52]. VR could also enhance the capability of a person to process and understand visual information (cognitive visuospatial ability). VR ability to change the environment as required (change of inner objects' properties, quantity and locations) is also supportive for dyslexics. These VR features help dyslexics superior visuospatial strengths when present in a virtual environment [53].

2.5 Summary

In this chapter we have briefly described dyslexia as a disorder, deficits faced by dyslexics and comorbidities that comes with dyslexia. We have also the feature

Chapter 3

A SYSTEMATIC LITERATURE REVIEW-BASED SURVEY

3.1 Our Survey Methodology

We have conducted a literature review-based survey to identify the existing gaps in developing VR-based applications for dyslexics. For our survey, we first explored highly cited peer-reviewed journal papers relevant to our research criteria, from the year 2010 to 2022. We explored papers from reputable digital libraries that are ACM, Springer, IEEE Xplore, Elsevier and Google Scholar. The research criteria for our survey and corresponding paper regarding each criterion are listed in table 3.1. Figure 3.1 describes our survey methodology carried to conduct the survey. The goal to carry out this survey was to investigate the challenges faced by designers and developers during the development of VR-based applications for dyslexia. We identified a lack of guidelines and developmental methodologies for developing the specified application as a result of our survey.

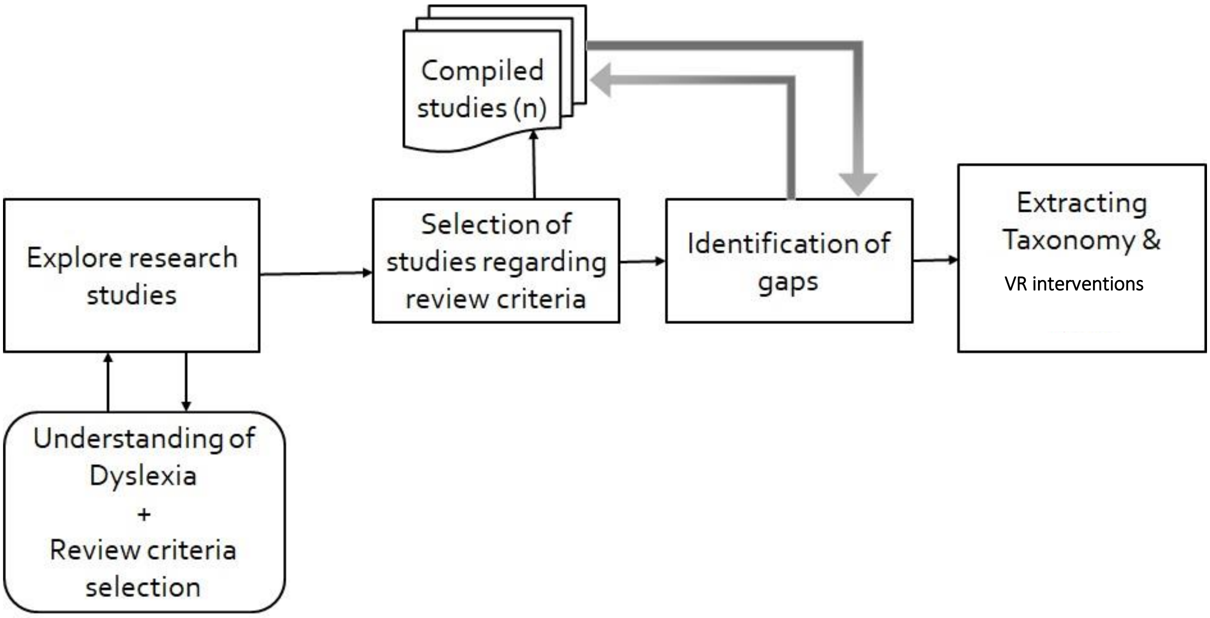

Figure 3.1: Survey methodology

3.2 Literature Survey

This section comprises the literature review of the papers we have selected in order to identify the key challenges faced by software engineers while working on VR-based systems for dyslexics. Every subsection is labeled with its corresponding review criteria for ease of understanding and to enhance readability.

Table 3.1: Research criteria for the survey and corresponding research studies

Sr. No.	Research criterion	Research studies
1.	**VR in Education**	[10], [12], [13], [14], [15], [17], [20], [21], [22], [31], [33], [38]
2.	**VR for Dyslexia**	[36], [37], [43], [44], [46], [47], [48], [49], [50]
3.	**Other technologies for Dyslexia**	[18], [23], [24], [25], [26], [27], [28], [34], [39], [40]
4.	**Text presentation and reasoning strategies for dyslexia**	[29], [30], [41], [42], [45]
5.	**VR design methodologies**	[11], [16], [19], [32], [35]

3.3 VR for education

Virtual reality for education has been in practice for years and has manifested its potential and strengths in the field of education, learning and training. In this subsection, we have described some research work already done in the specific field that aims to examine and inquire the influence and potential of VR in education field and have also proposed some promising VR-based interventions in the specified field.

The research concerning those features of VR that strengthen learning is in its early stages [31]. Veronica S. Pantelidis in his study lists down some examples of the research conducted to explore the use of virtual reality in education and training [14]. Justifications for the use of virtual reality have been described. The authors have also discussed the precedence and drawbacks of using VR along with recommendations about the conditions where VR could be used and where it could not. To identify whether VR could be used for a particular education and training program a model has also been proposed by the authors. Michela Ott et al. [17] also conducted a scientific literature based survey regarding the advantages and effectiveness of using Immersive Virtual Reality (iVR) for Education in the years (2013-14). Authors have highlighted the use of VR in general and specifically iVR for adult training in particular conditions. They have also suggested a limited use of VR for children under 10 years of age as its use can effect the physical and cognitive development. The effectiveness of using VR for disabilities most importantly for individuals with intellectual impairments have also been discussed. The authors concluded by providing motivations to use VR for education.

Sang Min Ko et. al. [33] presented usability guidelines for AR-based smartphone applications, AR-based system's design principles, handheld mobile device's interface guidelines and tangible user interface's usability guidelines. An alphabet learning book has been created by researchers using AR technology [12]. The proposed book has two sections. The first one is known as the Alphabet Introduction and the second is called as Exercise section. 15 children were selected to use the specified app with the book, according to most of the children they enjoyed learning using the AR book. Similarly, "*House of Languages*" is a VR-based application developed by Estonian game company Fox3D with the purpose to teach foreign language vocabulary acquisition (Spanish, English, Russian and German). The application has presented an innovative strategy for vocabulary acquisition by enabling the user to interact with a VR-based virtual environment that consists of mini-games like puzzles and word guessing. House of languages is specially developed to configure with Samsung Galaxy smartphone and headgear. Alfadil M. has conducted research to explore the effect of the above-mentioned application on vocabulary acquisition in intermediate school students [10]. The author divided the 64 male students sample into controlled and experimental groups each comprise 32 students. A brief instructional tutorial regarding the headset and the application (functionalities and usage) has been provided by the author for a basic understanding of the students about the system usage. Research results have depicted a high success rate of VR-based learning in contrast to traditional learning strategies. Jorge Buele et al. [13] in his paper proposed a VR-based system to strengthen the linguistic ability of dyslexic children. The system comprises three games (each game has three levels of difficulty). Each game is specially designed for the rehabilitation of specified children as it combines auditory messages along with visuals to compliment them (with the purpose to provide an immersive experience and linguistic training). The system has been evaluated (using SUS usability test) by a sample of 8 infants. The results have shown that the proposed system was user-friendly, intuitive and provided ease of use. Blanka Klimova et al. [38] in his study reviewed VR's role for non-Native Language Learning and Teaching (NLLT). The author claimed that VR technologies have proven to be effective for NLLT but it still has not been adopted at a large scale because of the following reasons:

- teachers lacking in technical skills
- high cost
- small-scale research in NLLT

The authors concluded that VR offers many facilities to second language learners, for example, learner's autonomy development, achievement of beneficial learning results, or customized approach to learning therefore more attention should be drawn to this technology for beneficial learning outcomes.

The use of gestures or motions with illustrations has exhibited greater learning attainment and retention in contrast to traditional text and audio/visual strategies. VR could provide a meaningful platform for kinesthetic language learning, such as learning that is based upon physical activities. Such a study has been conducted to propose a kinesthetic learning-based language education system using VR [15]. Researchers present a system called Words in Motion, that is a VR-based system for language learning to boost and support the connection or relation among the pairs of actions and words. The system does so by perceiving the movement made by students and then displaying the related name of the action being performed in the target language. 57 students were involved in the study. A positive correlation has been explored among the times the pair of action and words was executed and the times the word was memorized by the individuals, supporting the idea of using VR having embedded kinesthetic elements for language learning.

"Active and Student-Centered Learning" (ASCL) is the most relevant and interactive way of learning in the field of engineering for understanding basic science concepts. Active learning comprises anything about the course which every student in the class session has to perform rather than just taking notes of what they are listening to or watching in the class session. Virtual and augmented reality VAR have shown their potential in the field of ASCL. Cukierman Uriel et al. [20] have conducted a study to develop and test VAR systems for engineering students to improve their basic sciences concepts in freshmen courses. The development process comprises three stages; in the first stage, the members have to analyze the topics or units that will be covered in the development of the system, the second stage is the development part of the system itself third and the last stage is the evaluation phase of development. Similarly, Alexandre Cardoso et al. [21] developed a VR-based educational software for physics. The software is composed of twenty-six physics experiments and have explored the positive effect of the system on learning. Agnes Fong and Sonia W.L. Cheung have also studied the impact of VR-based learning [22]. The authors have evaluated two VR-based undergraduate courses, ‘Pharmacology and Therapeutics’ and ‘Understanding Ecotourism’ on the basis of student experiences. Students have appreciated the idea of using VR in the field of education as it broadens the knowledge and in-depth perspective of the relevant topic.

3.4 VR for Dyslexia

The following literature has been reviewed to explore the work done in the field of VR for dyslexia.

Nada Khalil et al. in their study have presented a method of combining entertainment along with education to deliver an effective strategy of teaching [50]. The application developed as a result of the presented methodology teaches the alphabet to students by tracing Arabic letters in three modes (starting, intermediate and ultimate) along with letter pronunciation. This application is a VR-based application and has a friendly VRE. System evaluation has shown promising results not only for dyslexics but also for non-dyslexic children. Researchers have conducted a study to explore VR game training effects on children with reading learning disabilities (RLD) [48]. The fundamental intention of the research was to analyze the effect of VR-based training on reading capabilities (pace, accurateness and comprehension), motor balance, coordination and visual attention in the specified children. The research was carried out by comparison of two groups (controlled and experimental) of children having RLD. The development of game was carried out using two commercial games "BeatSaber" and "GrafoTami". The results showed a positive effect of the training among the experimental group and suggested a need for a large-scale study to enhance the results in reading performance. A Wii-based game has also been developed by Elisa Pedroli et al. [43] to demonstrate that VR based action video games could be more beneficial for upgrading dyslexics' reading conditions. Results of the study have shown that a cue-based VRE may serve as a significant tool for enhancing focus issues. The authors have also mentioned that the effects are not immediate and declared a need for a prolonged protocol in the future.

The aim of the study conducted by Katerina Kalyvioti et al. [47] was to identify the memory difficulties faced by dyslexic children. VR based specialized tasks were designed to identify the issues in undergraduate dyslexic students. The results showed that both dyslexic and non-dyslexic users performed approximately similarly during the tasks. Considering the results of the study and students' attitudes it could easily be concluded that VR may serve as an intervention and assessment tool to achieve significant results in dyslexics.

Lack of knowledge among nurses about learning disabilities (i.e. dyslexia) could have disastrous consequences upon the patients. Therefore, it is necessary to educate them about the deficits and issues these people are facing in their lives to make a better understanding of patients' mental and emotional conditions. Keeping this in mind Lorna Saunder et al. [44] deployed "Shareville" into the postgraduate and undergraduate nursing education programs at their university to overcome the mentioned issue. Birmingham City University has developed Shareville, a virtual environment that allows the students to understand the condition of people with learning disabilities using problem-based and realistic scenarios. To test the performance of the implemented system both students and staff members were evaluated for their experiences. A positive inclination towards the system was recognized among the students and reported that the presented scenarios were immersive and real, enhancing their in-depth knowledge regarding learning disabilities and have allowed them to make decisions during challenging situations (in a virtual environment) before their real practice in the field. The attitude of the lecturers was also positive towards the system (find out during interviews) and they also were in favor of collaborative teaching and blended learning to enhance the knowledge of nurses.

Authors in [37] developed a non-immersive VRE to determine the visual-spatial strengths of dyslexics that is known as D-Potensi. The authors have adopted Sutcliffe's [36] VR development methodology that comprises four stages which are as follows:

- VR type selection
- interaction devices and modalities selection
- creation and modeling of 3D objects
- creation of terrains

The design of the application focused on two basic features which are dyslexic's characteristics and the goal-directed principles of Sutcliffe methodology. The evaluation of the presented application has declared that the selection of mentioned features was not enough for developing such an application there are other features like position, orientation and movement, that should be focused on to develop a VR environment for dyslexics. Elizabeth A. et al. also conducted a study to assess the visuospatial abilities of dyslexics [49]. The authors tested the Visuospatial ability by implementing the Design Recall and the Pattern Construction subtests of the British Ability Scales (2nd edition; BAS-11) along with a virtual environment test. Results have shown that dyslexics may possess good visuospatial capabilities regarding some pseudo-real-life evaluations of spatial strengths. Researchers in [46] have conducted a review to analyze the effectiveness of using VR for the betterment of people with dyslexia. The findings of the paper suggest that VR could be an effective tool in diverse areas of intervention and therapeutics. Scientific literature in the field of VR for dyslexia has the following focus areas of study

(a)memory performance, (b) non-verbal problem skills, (c) visuospatial skills and (d) awareness increase.

VR features provides a novel composition of effective and innovative patient/human-centered systems and should be implemented on a higher scale to benefit both dyslexic children and adults. Reviewed literature not only identifies the strength of VR for dyslexics but also provides some guidelines for parents, teachers and practitioners.

3.5 Technologies other than VR for dyslexia

Many 2D (computer-based applications other than VR) applications have been designed for the betterment of dyslexics, a few of them we have described below to identify the promising effects of using information technology for enhancing the capabilities of dyslexic students.

Serious games allow the users to learn in an entertaining, fun-based and especially attractive manner. Game-inspired designs (GBIs) such as gamification and serious games have widespread use to enhance users' involvement in monotonous tasks [24]. Therefore, a design model and design rules for the development of serious games for dyslexics have been presented by [34] to upgrade the learning capabilities of children with dyslexia. Jaramillo-Alcázar et al. [18] proposed an approach to develop accessible serious games specially designed for dyslexic children. The authors presented a set of guidelines for developing accessible serious games and have also developed that kind of a game using an existing methodology for developing such games. The proposed game aims to enhance the following abilities of the children:
attention, sequencing, working memory, visual discrimination, semantic awareness, cognitive flexibility, phonological awareness, spatial location, auditory discrimination, etc.
The proposed game helped children to improve their neurocognitive abilities and primary learning skills. DIESEL-X is another computer game developed for the detection of DD in preschool children [25]. The game comprises three different modules to evaluate three basic skills (that are defected by dyslexia) of the user to analyze the presence of developing dyslexia among the users. Mr. Read is also developed to help dyslexic children enhance their reading skills by using sight words strategy in the application [26]. The application implements sight words in three forms for reading that are short stories, rhymes and song lyrics. Authors have used the mobile game-based learning (mGBL) Engineering Model for application development as this model provides learning content-based design and development, encourages storyboarding (which is the basic criteria of the application being developed) and allows the developers to customize the design and development phases according to the requirements of the project under development. Individualized Reading Enhancing Application for Dyslexia (IREAD) [27] is a mobile based application to aid dyslexics. It utilizes text-to-speech mechanism to improve the reading proficiency of dyslexics and proved to be an effective and efficient application for users after the evaluation.

Online learning has gained fame during the last decade, but the accessibility of these learning platforms has not gained as much focus as it was required to attain. The attention towards the accessibility of applications for dyslexics is deficient in contrast to other user groups such as blind, hearing impaired, etc. [28]. Loren Pang et al. [23] presented a review regarding the accessibility requirements of online learning for dyslexic users. Nine articles were examined by the authors and have identified that besides the strength and widespread usage of online learning existing guidelines for these systems are not sufficient for all the users i.e. dyslexics. The authors prescribe the need for specific design guidelines to develop accessible online learning platforms that are equally beneficial at all levels. Martina Da Rold et al. conducted a research study to identify "good practices" to use technology for interventions and guidance for developmental dyslexia (DD) in children and adolescents [39]. A Delphi method was used to conduct this study; 18 participants were selected for the study. It included speech-and-language pathologists, child neuropsychiatrists and psychologists. All the members were out of the most famous and reputed DD experts of the country. The study comprises three successive rounds. During the first round open-ended questions and multiple choice questions were asked to the experts to gather their general opinion, in the second round solidarity was judged on a sequence of manifestos based on previous replies and the cut-off of 75% agreement on each manifesto was fulfilled after rounds. The results of the study identified a positive attitude by all the members towards ICT-based intervention strategies for developmental dyslexia.

Siti Nurliana Jamali et al. [40] in their paper provided the Tangible Interactions (TI) design principles that could be adopted for the learning model for children with dyslexia. The guidelines comprise four elements that are:

- TI system needs/requirements
- styles of presentation
- learning conditions
- and learning types

A prototype has also been developed based on the proposed guidelines. Disleksia Belajar is a 3DT prototype that is a tangible application to help dyslexics in learning the Malay language in phonology skills, spelling and reading. The prototype has five modules that are

1. identification of letters (vowels and consonants)
2. teaches spellings of the consonant-vowel in two syllables (CV+CV)
3. teaches syllables of vowels, consonants, diphthongs and digraph words
4. matching letter with the associated pictures
5. listening to the reading of a paragraph with minimal length

This prototype could serve as a supportive and interactive tool for dyslexics for learning the Malay language.

3.6 Text presentation and reasoning strategies for dyslexia

We have reviewed some of the papers regarding basic recommendations about text presentation for dyslexia and the strengths and weaknesses of dyslexics.

Miniukovich et al. [29] provided 61 readability principles attained as a result of conducting a series of workshops in company with dyslexics and domain experts. Presented Guidelines include text simplicity, navigation and visual appearance-related topics. Miniukovich et al. in [30] also summarized 39 text presentation and readability related guidelines. In another study conducted by [41], a set of text customization (as presentation of the text effects the reading speed of dyslexics) related recommendations have been presented. These guidelines are proposed to enhance text presentation on computer screens to increase the accessibility of computer-based applications for dyslexics. The parameters that were focused upon in the study are as follows:

- text font and background color combination
- font size
- character and column width
- paragraph and line spacing

Based upon the conducted study authors have proposed text presentation recommendations to enhance readability for dyslexics. Authors have also suggested that there are other factors effecting the readability of text like text content.

Alison M. Bacon et al. [42] have conducted three experiments to identify the thought that reasoning strategies adopted by dyslexics and non-dyslexics individuals differ from each other. The conducted experiments supported the idea of this difference. the actual difference lies in the relative importance of visual processes. Non-dyslexic individuals are able to make a simple argument/decision on the basis of an object's linear ordering on the other hand dyslexic individuals utilize visual information to understand the problem and to make an explicit comparison within objects. This identifies the vital role of semantic and visual processes for reasoning among dyslexics. The authors conclude this reasoning strategy plays a fundamental role, offsetting verbal memory and phonology deficits. In another study, researchers described the visual attention deficit among dyslexics [45]. Oculomotor patterns observed during reading were abnormal (frequent saccades having a minimal amplitude, long fixations, greater number of saccades to the left (retro-saccades) and bad binocular coordination in between and after the saccades) among dyslexic children. Conclusions drawn from the results identify a deficit regarding the processing of visual information and an immature connection between vergence and saccade systems. The authors have also discussed different methodologies that could be beneficial for dyslexics to improve their conditions and have concluded that dyslexics' reading capability could be enhanced with the help of the methodologies discussed in the paper.

3.7 VR design Methodologies

Literature regarding the design issues of VR and proposed methodologies to design and develop VR systems have been discussed in this section.

VR clinical interventions have a positive impact on the psychological treatment of individuals [32]. VR has shown its potential in the field of health specifically psychological, cognitive and behavioral (PC&B) science for decades, still, researchers are facing issues regarding the design process of embedding physical therapies into VR to achieve user satisfaction. Luma Tabbaa and Chee Siang Ang et al. have investigated the design requirements, facilities and issues in designing effective and efficient PC&B-VR interventions [11]. They have examined four user-centered PC&B-VR's interventions design processes and investigated the process of adapting therapies into VR to meet user needs, examined the design components for significant experiences and also explored the healthcare field's knowledge contribution to the design process. The researchers have also identified future directions for PC&B-VR intervention design. The authors in [35] have presented guidelines to develop VR and Augmented Reality based training and education software to meet the following requirements:

- learning, training and teaching technologies
- information representation and exchange
- data and devices

These guidelines comprise conceptualization, architecture for information modeling, functional components based upon international ISO standards and implementation components for virtual training and education.

Fully immersive VR has proved to be an efficient tool for research purposes. The widespread usage of this technology has been hindered by VR-induced symptoms and effects (VRISE) and the absence of a high level of VR development skill set. Panagiotis Kourtesis et al. [19]

presented developmental guidelines for immersive VR (iVR) systems specially developed for neuropsychology and cognitive neuroscience. The guidelines are in the form of a description of the developmental stages of VR Everyday Assessment Lab (VR-EAL), the first neuropsychological battery in immersive VR. Techniques to evaluate cognitive function (based on real storylines) have been discussed. The utilities of various software have also been described to guide cognitive scientists over issues caused by VRISE and to enhance the VR-based system's quality. Three variants of VR-EAL have also been evaluated by implementing a VR neuroscience questionnaire (VRNQ) technique to a sample of twenty-five participants. The authors concluded by supporting the effectiveness of VR-based clinical software in the absence of VRISE during a VR session of 60-minutes.

A framework for iVR learning environments has been proposed by Mulders et al. [16]. The proposed framework is based upon the Cognitive Theory of Multimedia Learning (which is a proven and widespread theory), its usage concerning instructional design goals and key features of iVR that makes this technology unique. The meaningful iVR Learning (MiVR-L) framework constitutes six recommendations to be considered when designing iVR systems, proposed recommendations are as follows.

- Give Learning more priority than immersion
- Provide interactions relevant to learning
- Divide complex tasks into smaller units
- Immersive learning guidance
- Build on prior knowledge
- Present constructive learning tasks

3.8 Summary

By reviewing the scientific literature, it has been concluded that VR applications developed for dyslexics have a limited amount of research, thus it represents that the VR development specific to this domain is in its infancy. The survey has also identified that the applications being developed in this domain may not be achieving that highest potential that they are able to attain. This may be caused due to the unique nature and distinctive features of VR technology for the reason that to the best of our knowledge there are no design guidelines and model presented by any researcher, particularly for this domain. Developing VR applications for a specific disorder (without any guidelines) may lead to an inaccurate development of the system as the developer may make a mistake in perceiving the system or the disorder. Therefore, a comprehensive set of design guidelines and system development process model is the need at the time to avoid confusion and to attain the highest improvements in dyslexics' capabilities.

Chapter 4

EVALUATION OF EXISTING APPLICATIONS

4.1 Overview

In this chapter, we have evaluated some of the existing mobile-based applications specifically developed for dyslexic people to help them read and learn. Applications have been evaluated against requirement matrices for dyslexia. Evaluation has been carried out to identify the contributions of specific applications and to what extent they are fulfilling the requirements.

4.2 Evaluation Methodology

Laura Lenz [57] evaluation approach has been used to evaluate the applications. Laura Lenz et al. in their paper have described a set of evaluation requirements for a VR-based system in the case of Dyscalculic students. Ana Manzano León et al. [58] also described some evaluation matrices for dyslexia-friendly mobile applications. Dyslexia and Dyscalculia, both are learning disorders and effects the cognitive abilities of a person therefore we have mapped the requirements of these two studies as our application evaluation methodology. We have briefly described each application in this section.

4.3 Augmentally

Augmentally is a reading aid app developed for dyslexic people that allows the user to scan printed documents and customize text formatting (font family, background color and line height) as required.

The drawbacks of this app are:

1) It only allows switching between white and yellow background colors.
2) Allows only portrait scanning of a document and does not support landscape page scanning as shown in Figure 4.1.
3) If the document has multiple sections, it will clutter the page thus decreasing the readability of the document. This issue has been illustrated in Figure 4.1.

4.4 Dyslexia Reader

This app helps dyslexics in reading, it uses a special large font that enhances the readability. It has been developed by Russian developers and allows the user to copy the text (into the specified area) he/she wants to read, the font of copied text will be changed

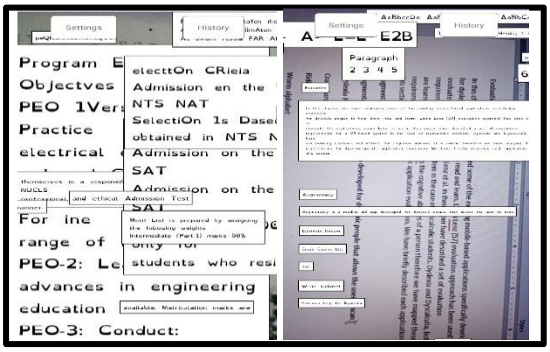

Figure 4.1: Interface of Augmentally, showing cluttered information that is unable to read.

into the particular app font. This app allows the user to change font size according to his/her ease. The user could copy and share this text with others as well. Figure 4.2 represents the interface of the Dyslexia Reader.

Drawbacks of this app are:

1) It has no user tutorial which makes it difficult for a user to understand its use.
2) Some of the icons are not self-explanatory.

Figure 4.2: Interface of Dyslexia Reader App

4.5 Crazy Cursive Lite

This is a writing aid app that teaches the children to write the basic alphabet, helps them to learn writing of hundred basic words and allows the user to type a word of his/her choice to learn its writing. All the alphabet and words are written in dotted form the user has to trace over the dots. The user can trace the letter or word using his/her finger. Figure 4.3 shows the interface of Crazy Cursive Lite.

Drawbacks of this app are:

1) Tracing over the dots is slightly difficult.

2) Tracing tutorial is fast in speed which makes it difficult to understand the tracing pattern.

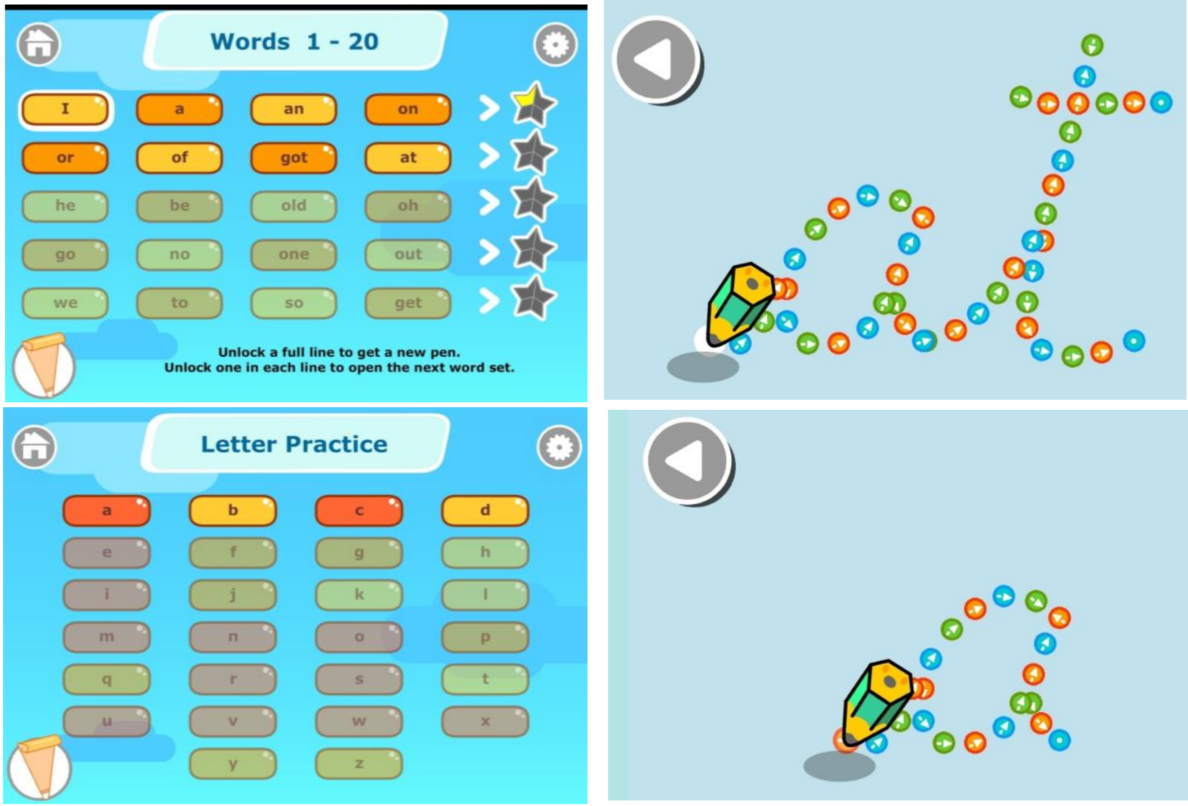

Figure 4.3: Interface of Crazy Cursive Lite

4.6 Ridit

This app is designed to make reading easy for dyslexics. It allows the user to either scan a document or paste the copied text into the specified block. The user can then customize the text presentation (font size, color and family, background color and speed) to his/her preference. The app uses a word-by-word strategy that is; right after the user has done scanning or pasting the text, the text is displayed as single word in the form of word after word like a running video. The user can set the speed of the displaying words. The interface of Ridit is shown in figure 4.4.

Drawbacks of this app are:

1) The Tutorial provided is very brief according to dyslexic students.
2) Does not scan a document properly as it crops some of the words from the sides of the image taken.

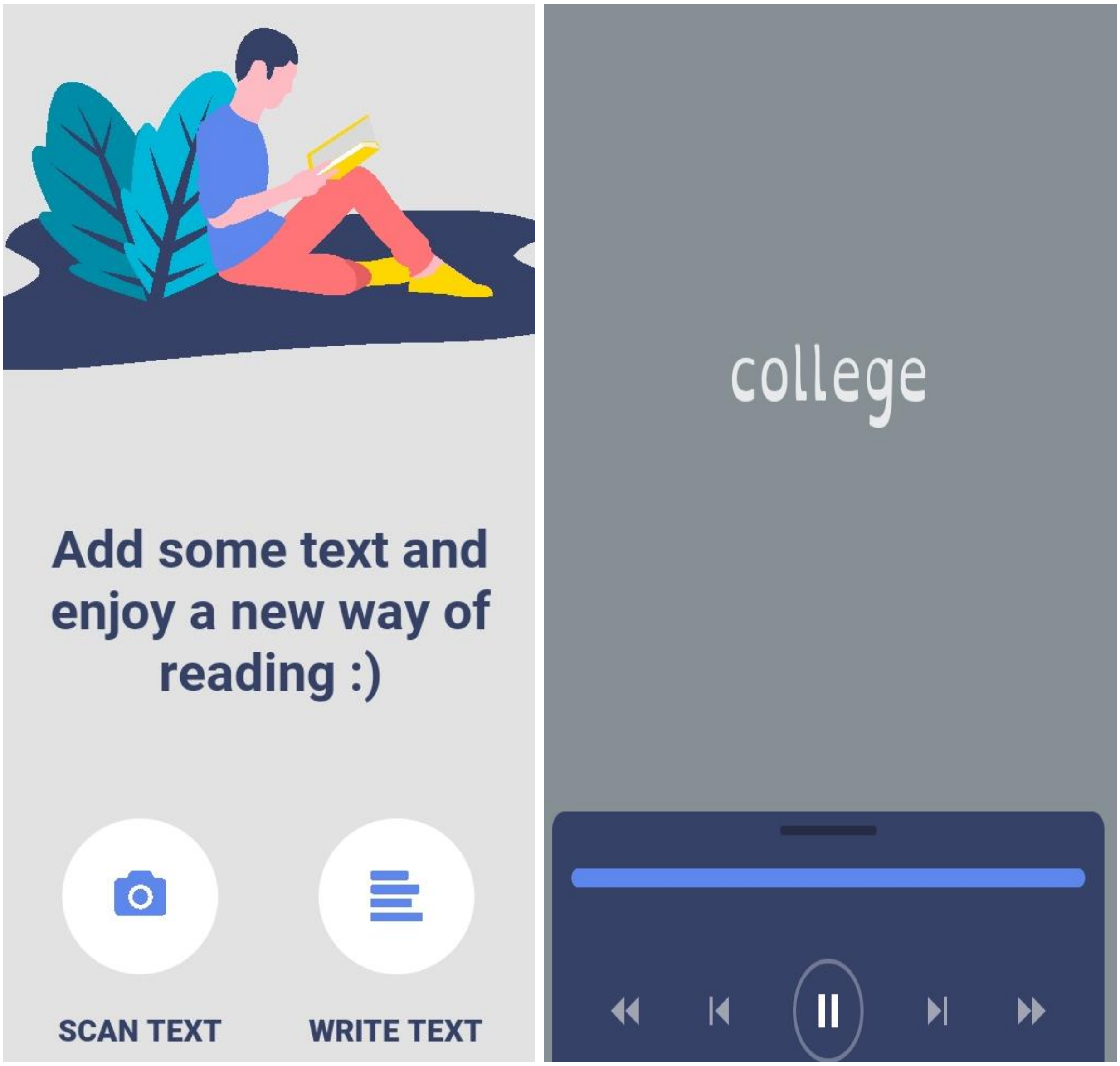

Figure 4.4: Interface of Ridit

4.7 Worm alphabet

This app is developed to learn capital and small alphabet. A Small letter is given and the student has to select the corresponding capital letter from a list of capital letters. The interface of the app is shown in Figure 4.5.

Drawbacks of this app are:

1) No tutorial for the explanation about how to use the app.

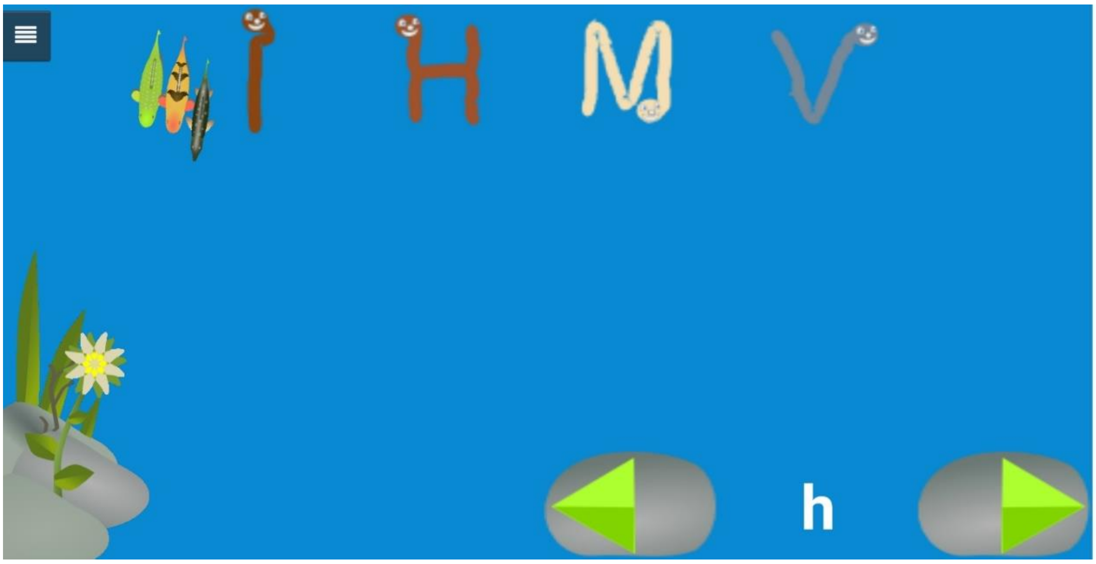

Figure 4.5: Interface of Worm alphabet

4.8 Percivals help for Dyslexia

This is a spelling aid app for dyslexic students. This app is developed by a school teacher in the United Kingdom. The app is specially designed for dyslexics considering their special requirements. The app allows the customization of background color, word color and color of highlighted letters (spelling letters in a story). There is a professor (cartoon character) guiding the students to proceed in the app and teaching the letters to the child. For each word, there are some cartoon characters associated which help the child remind the spelling as every word has a story attached to it and story words start with the spelling letters of the word. An example of this application interface is shown in fig 4.6.

Drawbacks of this app are:

2) It is little difficult to understand the professor's wording/ accent (cartoon character to teach spellings).

There are in total twelve requirement matrices for the evaluation of the apps specially designed for dyslexics. The evaluation requirement matrices have been described in Table 4.1.

Figure 4.6: Interface of Percivals help of Dyslexia

Table 4.1: Requirements matrices for evaluation

Sr. No.	Matrix	Description
1.	**Visual stimulus**	Visualization of the lesson being taught.
2.	**Audible stimulus**	Audio elements to complement visualization
3.	**Fixed color scheme**	Should follow the same pattern between different modes
4.	**Reward**	On successful completion of each task, a reward must be granted
5.	**Repetition**	Things already taught must be repeated in later stages for interconnectivity and revision.
6.	**Translate into forms**	Some objects or elements should be associated with the alphabet and words
7.	**Separated similar words**	For dyslexics some alphabets may seem similar to each other, they must be properly separated
8.	**Difficulty level**	Apps must be designed in a way that their difficulty level gradually increases
9.	**Clear objectives**	Tutorial (audio/visual) to teach users about the objective of the application
10.	**Supportive messages**	Users must get supportive messages to know about the environment and his/her progress
11.	**Error feedback**	An error must be properly conveyed to the user
12.	**Fun learning**	Lessons must be taught in a friendly environment

4.9 Evaluation Results

Each application has been evaluated against the evaluation requirement matrices. Evaluation results have been described in table 4.2. Yes, indicates the presence of the required matrix and No indicates its absence. Figure 4.7 illustrates the results in graphical form.

Table 4.2: Evaluation results of Mobile applications

	Applications					
Requirements	**Augmentally**	**Dyslexia Reader**	**Crazy Cursive Lite**	**Ridit**	**Worm alphabet**	**Percivals help for Dyslexia**
Visual stimulus	No	No	Yes	Yes	Yes	Yes
Audible stimulus	No	No	Yes	No	Yes	Yes
Fixed color scheme	Yes	Yes	Yes	Yes	Yes	Yes
Error feedback	No	No	Yes	No	Yes	Yes
Separated similar words	No	No	Yes	No	No	No
Translate into forms	No	No	No	No	No	Yes
Rewards	No	No	No	No	Yes	Yes
Repetition	No	No	Yes	No	Yes	No
Clear objectives	Yes	No	Yes	Yes	No	Yes
Difficulty level	No	No	Yes	No	No	No
Fun learning	Yes	No	Yes	Yes	No	Yes
Total	**3**	**1**	**9**	**4**	**6**	**8**

4.10 Summary

We have evaluated existing mobile application on the basis of matrices required to achieve improvement in learning and reading capabilities of dyslexics. App developers are creating dyslexia-friendly apps to help dyslexics improve readability for adults and teach alphabet, phonology, spelling and writing to preschool children. Evaluation results have shown existence of weaknesses in the specified apps that hindered their potential in improving the state of dyslexics hence limiting their use. The results also represent that this limited fulfillment of requirements is due to the absence of multimodal stimuli required to enhance multisensory learning which is a fundamental requisite of dyslexics. VR-based applications could be a suitable solution to this limitation if these applications would be designed and developed on the basis of a specialized design and development approach. Therefore, there exists a need for app development on the basis of dyslexia-related guidelines to enhance the state of dyslexics and also for increasing the usage of such applications.

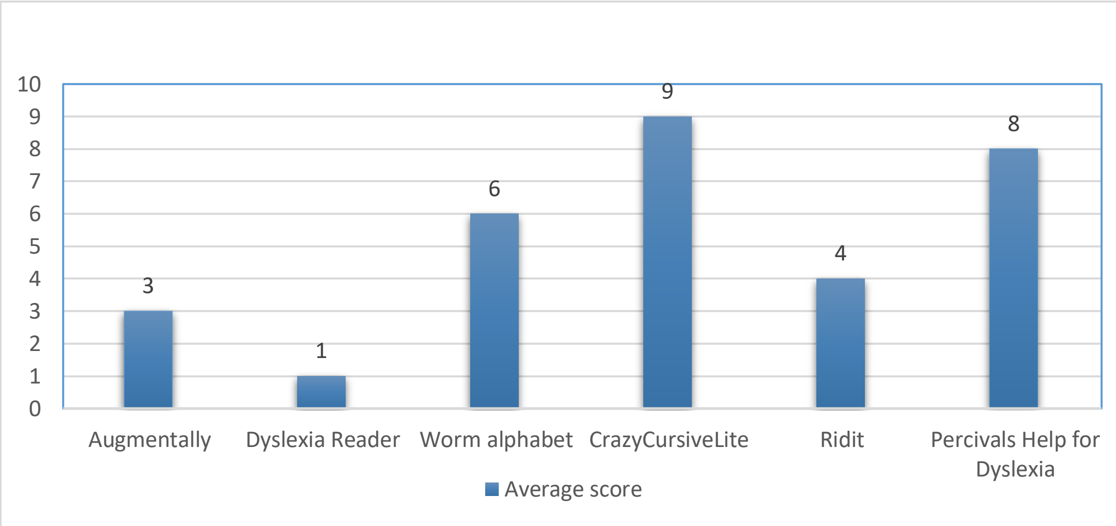

Figure 4.7: Graphical representation of evaluation results

Chapter **5**

PROPOSED DESIGN GUIDELINES AND MODEL

5.1 Introduction

In this chapter, we have presented our findings based on conducted survey. Taxonomy of VR-based applications for dyslexia that has been extracted from our survey is presented along with intervention strategies for different cognitive functions effected by dyslexia. For resolving the design challenges faced by researchers and developers, we have presented our proposed design guidelines and User-Centered design and development process model (UCDDPM). The activities at each phase of UCDDPM have been discussed in detail.

5.2 Taxonomy

VR could be used in different ways when it comes to dyslexics. A taxonomy has been proposed to classify multiple categories or contexts in which one could use VR to support dyslexics. Following taxonomy could be helpful to recognize the opportunities dyslexics are enjoying/acquiring from VR and serves as a guide for developers to identify the context of their study for dyslexics. Table 5.1 describes the presented taxonomy.

1. Early screening
2. Awareness
3. Intervention
4. Assessment
5. Education
    a. Edutainment
    b. E-Learning
    c. Real life training
6. Entertainment

5.3 VR-based Interventions

We have described Cognitive functions effected by dyslexia and their consequences on the performance of dyslexics along with techniques that could be implemented in VR to help the target overcome their deficits [54]. Table 5.2 briefly describes these cognitive functions and corresponding interventions.

Table 5.1: Taxonomy categories description

Sr. No.	Category type		Description
1	**Early screening**		To test children at an early stage for being dyslexics or not
2	**Awareness**		To educate teachers, parents and medical practitioners about the issues and deficits of dyslexics
3	**Intervention**		Developing new techniques to help dyslexics overcome their cognitive issues
4	**Assessment**		To assess/ determine the deficits and strengths of dyslexics e.g. working memory, visual-spatial strengths, etc.
5	**Education**	**Edutainment**	Merging entertainment and education i.e. learning based games
		E-Learning	Remote learning using metaverse properties
		Real-life training	To create real-world simulations for training purposes i.e. car driving simulation
6	**Entertainment**		To entertain people with dyslexia i.e. serious games

Table 5.2: VR-based interventions

Cognitive issue	Deficits caused by cognitive imbalance	Intervention in VR
Linguistics	Phonological awareness, poor reading, difficult to decode phenomes etc.	Marungko approach, E.S. Claveria's technique could be implemented using VR to enhance the benefits of these techniques.
Working Memory	Reading comprehension, reasoning, learning, decision-making and problem-solving	Digital working memory trainings with gamified elements embedded in VR could be helpful.
Planning, Organization and Task monitoring	Struggles with handling information, difficult to set priorities, to make a plan	A virtual environment where people have given small tasks to achieve, assistance in making schedules and decisions could be helpful. Remotely organizing and managing different task within metaverse environment.
Inhibition	Interrupt conversations, making it difficult to maintain a fluid conversation, frequent mistakes in speak and making answer to questions	**VR based Neuro technology (**cognitive stimulation technologies), that consist of EEG equipment, to record per individual activities of brain and to adapt according to each person. Games like Lumosity, Elevate brain Training could also be developed to help dyslexics.
Set Shifting	Ability of unconscious shifting of attention between two tasks is effected	Gamed based trainings which force the person to take immediate decisions at run time (decision making resembles real world decisions) from simple to advance level.
Attention	Fatigue, distractions, lack of focus	For attention enhancement VR-based paragraph comprehension could be designed. VR-based drawing reproduction task could also be developed.
Perceptual-visual development	Difficult to connect letters with sounds; difficulty in understanding visual information, whether, shapes, objects, or letters	Hidden pictures, puzzles, patterning, matching and sorting games developed using VR in a new way could be beneficial to dyslexics.
Perceptual auditory development	Trouble processing phonemes (basic language's sounds), letter's sounds and groups of letter that result in a slow reading and difficulty to recognize different voices	Special training course could be designed (with special therapists involved to explain the helpful exercises). In real world noise in sounds cause difficulty in listening, VR based environment can overcome this issue by using these training programs at quite places.
Semantic, Syntactic and lexical	Oral reading with semantic errors, Struggle to understand plot and narrative of a study	Picture cards could be used to help cope up these issues. Where along with a picture its semantics have also been explained and also have given real world existence example in VR.
Motor coordination: Laterality and Directionality	unclear speech, Poor writing, etc.	Special VR based action games can help enhance motor balance and coordination. Specifically motor tasks, that involve hands (VR with hand haptics involved) and multiple cognitive activities, could be effective for such issues.

5.4 Guidelines for developing VR based systems for dyslexia

We have proposed design guidelines to guide developers and researchers in developing VR-based application for dyslexia.

5.4.1 Guidelines related to "Typography"

Following are some basic guidelines regarding typography that would be helpful for writing instruction manuals or tutorials in VR.

5.4.1.1 Text

- **Font family: Font style** recommended for dyslexics are **Roman** and **Sans-Sarif** while **typefaces** useful for dyslexics are **Arial, Courier, CMU, Helvetica** or **Verdana**
- **Font size:** Recommended font size is **18, 22 and 26**
- **Others:**
  - Avoid all **uppercase letters** (UPPERCASE TEXT IS DIFFICULT TO READ) as it reduces the readability of the text
  - Avoid ***Italic* and underline** text to prevent the text to get crowded.
  - To emphasize a text make it **bold**

5.4.1.2 Color Contrast

- Use a **black colored text on white colored background is not suggested** for dyslexics as it makes **high contrast**, as they are mostly sensitive to the brightness and this may cause reducing reading ability. Therefore, high color contrast is not recommended for dyslexics
- **Black/Cream** is a recommended color pair; British Dyslexia Association (BDA) is using this color contrast for their Web site.
- W3C algorithm recommend to avoid **color difference less than 500** and **brightness difference less than 125**.

5.4.1.3 Paragraph

- **Letter/word spacing:** Recommended character spacing is 0, +7 to +14
- **Line spacing:** According to a study line spacing has no effect upon reading for dyslexics so standard line space 1.5 is recommended
- **Paragraph spacing:** There must be a single line space between the paragraphs
- **Paragraph alignment:** Paragraphs must align left as it is most readable then justified which adds irregular spaces between words
- **Paragraph length:** Write short and **concise paragraphs** (to the point not long stories as dyslexics have issue with working memory so it is difficult for them to understand lengthy text).

- **Ideas per paragraph:** Narrate **one idea** in a paragraph to avoid confusions and cognitive load.

5.4.1.4 Writing style

- **Simplicity:** Use of Complex language is a key issue for the target group, therefore simple language should be used for instance use of usual, consistent and precise words could help enhancing readability of dyslexic individuals.
- **Clarity:** Avoid using abbreviations if required then provide glossary for all the technical terms
- **Graphical use:** Use graphics i.e. flow charts and tables where possible to make the more readable
- **Bullets/ Numbering:** It is preferable to use bullets or numbers for lists,
- **Avoid double negatives:** Double negatives means two negative words in a single sentence avoid this approach as it is considered as bad practice also make people confused
- **Active voice:** Is preferable to use active voice
- **Write for "screen reader":** Avoid using short form of words e.g. No. for Number, Sr. for Serial and St. for street to make it easy for screen reader to understand the text properly. Use simple and easy to understand language.
- **Headings:** Use heading to separate different pieces of information this will make it easy for the user to figure out main section and sub sections of the written text
- **Summary:** Provide brief summary at the end of lengthy texts in the form of points or steps to follow

5.4.2 Overlays

Children with dyslexia seem to avail much better results when they use colored overlays, than their non-dyslexic peers; therefore, usage of colored overlays should be allowed to them, to make them comfortable while reading using colored overlay of their own choice hence enhancing their reading ability.

5.4.3 Screen Readers

VR based applications should allow screen reader compatibility or embed a built in screen reader feature in their applications to make it easy for the reader to switch to screen reader if they are not able to read and understand the text. If possible it is preferable to allow user to change typography settings according to his/her comfort and ease that will make the text more readable for the reader.

5.5 Guidelines based on "VR Environment"

- User sessions duration should be a fundamental concern. These sessions must not exceed a limit of 20-30 minutes due to the fact that user start losing concentration after this specific period of time.
- User Interface (UI) components must be located at a convenient gap from the viewer.
- Every individual has distinct experiences and mindset about the world therefore particular instructions must be given e.g. indicating direction by an action or arrow sign would be much obvious than just saying “move ahead” that may not convey its actual meaning.
- Avoid tiring interactions/gestures (those actions that user could not perform after a particular period of time).
- Consider the movement of hands when designing (human hands have arch movement in place of straight lines).
- Consider both standing and sitting posture while designing because standing get tiring over time.
- Comfort must also be kept in view when established the interactive components in a scenario. Use of usual and consistent interactions and gesture that are easy on the hands and body should be adopted to avoid user frustration.
- Abrupt changes in the VR scene must be avoided e.g. sudden brightness change could result in user confusion. A sudden shift from dark to bright scenario could cause eye strain. Therefore, it is suggested to apply changes in VR space steadily.
- To design a VR scene space scale must be carefully allocated. Just like real world where too small, or too large spaces make individuals uncomfortable. Too large VR space may result in the user to lost somewhere contrary to that a too small space make the user to feel confined.
- Enhance the sense of presence in an environment but it should not be on cost of learning, learning must be first priority
- Give audio/visual instructions (simple, clear, unambiguous and loud guides) regarding further steps to be performed in the activity after regular intervals to remind them about the task or activity's steps.

- Since VR consists of a multimodal interaction developer must specify the type of interactions used in the applications and corresponding devices to obtain the input for having that interaction.
- Important notifications must be conveyed through audio/visual elements to enhance usability and avoid confusion.
- While performing any activity try to give audio or visual rewards upon completing the task that keeps the person motivated (that is something must require in the case of dyslexics)
- Bad graphics (blur environment) is pathetic to use emphasize on using good quality graphics
- The use of sound/ vibration effect on screen is recommended as VR still lack tactile feedbacks, for providing a reaction whenever a user touch any object.
- Give instruction manuals or tutorials before starting the experience of virtual world which will guide the user about the steps he could take or what are the tasks he/she could perform in the given application.
- Systems designed for dyslexics should follow a user-centric design approach and must involve the agents, e.g. dyslexic patients, teachers and medical practitioners to develop a deep understanding of the needs and requirements of the system design.
- Create straight forward interactions rather hidden actions to perform as they cause cognitive load/stress to the user
- According to McHale and Cermak handwriting/typing may also cause fatigue to dyslexics as it requires vocabulary/spelling of a word to type therefore avoid unnecessary use of typing-based inputs.

We have come up with a fundamental set of comprehensive guidelines/ principles to design VR-based applications for dyslexia these guidelines would be beneficial while designing such applications [64].

5.6 Proposed User-Centered Design and Development Process Model (UCDDPM)

Mostly VR design and interaction techniques are based on an example application [62], burdening the designers to extract a generalized form of provided guidelines according to their particular domain and intended application to be developed [61]. Yang Chen and fellow researchers have organized a Delphi study for the purpose to examine design guidelines to use

User-centered Design (UCD) in gamification development [59]. They have also mentioned the principles of ISO (ISO 9241-210, 2010) standard, which proposes six basic key guidelines that ensure a user-centered design project. The guidelines are as follows:

1. The basic component of the design is explicit knowledge about the user, tasks and environment.
2. User involvement is mandatory all through the design and development.
3. User-centered evaluation is mandatory to derive and refine the design.
4. Follow the iterative process.
5. The whole user experience is addressed by the design.
6. The design team should be multidisciplinary skilled.

Researchers in [55] have implemented Charles & McDonough's illustration of the PACT (People, Aesthetics, Context, Technology) framework [60], which is able to demonstrate the integration of important PACT elements into a well-defined design and development process. Researchers have added an extension to it by adding a behavioral change component in the explained framework for designing and developing a special game for upper arm stroke rehabilitation. Design principles and guidelines to develop VR base applications for physical disabilities have also been presented by the researchers. These guidelines are beneficial in the design and development of VR base- applications. Aan Jelli Priana, Herman Tolle and Ismiarta Aknuranda have also used UCD by ISO 13407:1999: along with experience design to develop a mobile application for stroke patients [56]. We have used all these guidelines and frameworks as a guide/ base to propose our design model for developing VR-based applications for dyslexics.

The proposed design and development model (for the development of VR-based systems for dyslexics) has been described below. The model consists of nine phases which are as follows:

5.6.1 Selection

In the first phase category or area of study has to be selected from the given taxonomy to clarify the purpose of the proposed system. After selecting the study area, one must identify the targeted type of dyslexia for which the system will be developed. This phase will be beneficial to identify the goal of the system researchers are planning to develop for the betterment of dyslexics (whether it is educational training, a game, or a mix of education and entertainment).

5.6.2 Team establishment

This phase is important to identify the people who are going to help in the project. End users and domain experts have to be identified in this phase, like people with dyslexia, teachers and clinicians. The best practice is to recruit dyslexic patients, an expert (representatives of the users), developers, designers, research groups and project managers. This team should work collaboratively and make decisions in every phase of the design and development process and manage the project.

5.6.3 Requirement analysis

This phase comprises three sub-phases that are Requirement gathering, requirement categorization and Requirement prioritization.

The first step is crucial to obtain data from the user regarding the needs, concerns and preconditions of the user. On the basis of obtained data, important decisions will be drawn i.e. identification of system objectives, interface requirements, system design, technical aspects (computing specification), user's particular issues, cost estimation, the feasibility of the project, demographic information, some special hardware requirements for VR, risk management, background knowledge, etc. Requirements could be gathered by interviews, questionnaires, etc. and represented through user stories, high-level visual graphics, rich pictures and through similar methods.

The second step is to identify the different categories of obtained requirements e.g. GUI, design, technical, hardware requirements, etc.

The third step is to allocate priority to the obtained requirements to specify those requirements which are the most crucial for the user and should be designed early in the design and development phase.

5.6.4 Software and hardware selection

It is crucial to decide about the assets, tools and technology to be used during the design and development process of the system. The software which will be used to develop the system e.g. A-frame, unity, or other in case of VR. VR also has specific hardware requirements so the selection of appropriate hardware (HTC Vive, Oculus Rift) is crucial for the success of a system. Project management tools, web hosting platform in the case of WebVR and other similar tools required to design and develop systems should be selected earlier.

5.6.5 Design

Design is the fundamental component of the system as the system will be the functional representation of the design, therefore it is important to dive deep into the design phase of the system. In some aspects, VR design will be different from conventional system design therefore its crucial to create the design with the appropriate involvement of users and all the other team members and the design process should follow agile development "sprint" (on the basis of prioritized requirements) and multi cycles of "design + evaluation" would be beneficial for a successful design. We have embedded the activities of a User-centered design by ISO 13407:1999 in our model.

1. Understand and define user context
2. Determine the needs of users and organizations
3. Present the resulting design solution (brainstorming, paper prototype, PowerPoint and rapid building of functional prototype)
4. Evaluation

The appropriate design process may follow the steps given below:

1: Brainstorming

2: Paper prototype

3: PowerPoint design documents

4: Rapid building of functional prototype

These steps have proven to be constructive for the design process and may vary according to system requirements.

5.6.6 New Recruitment

After the establishment of full-scale design, there may be a need for further recruitment as VR-based systems are critical in nature and thus require a broad range of talent for development and testing. Highly skilled people (with multiple skills) must be hired at this stage to develop a fully functional system with increased usability.

5.6.7 Development

The system should be developed according to the proposed and accepted design. Effective prototyping results in an iterative release manner (developing independent subsystems on the basis of the prioritized functionality in the requirement analysis phase)

5.6.8 Testing

Every subsystem released during the development phase must be tested and evaluated by the users to fix issues if any. During the testing phase parallel development of the next subsystem could be carried out to save time.

5.6.9 Maintenance

After full deployment of the system, there exists a need for sustainability and maintenance of the system, therefore project development team must provide support to users to entertain their queries, requirement change, other enhancements, or help in the use of the system.

Figure 5.1 describes the model proposed in our research.

5.7 Summary

Proposed design guidelines and model is a pioneering step toward proposing model in the specified domain as to the best of our knowledge there is no such model available in the literature to develop VR-based applications for dyslexics.

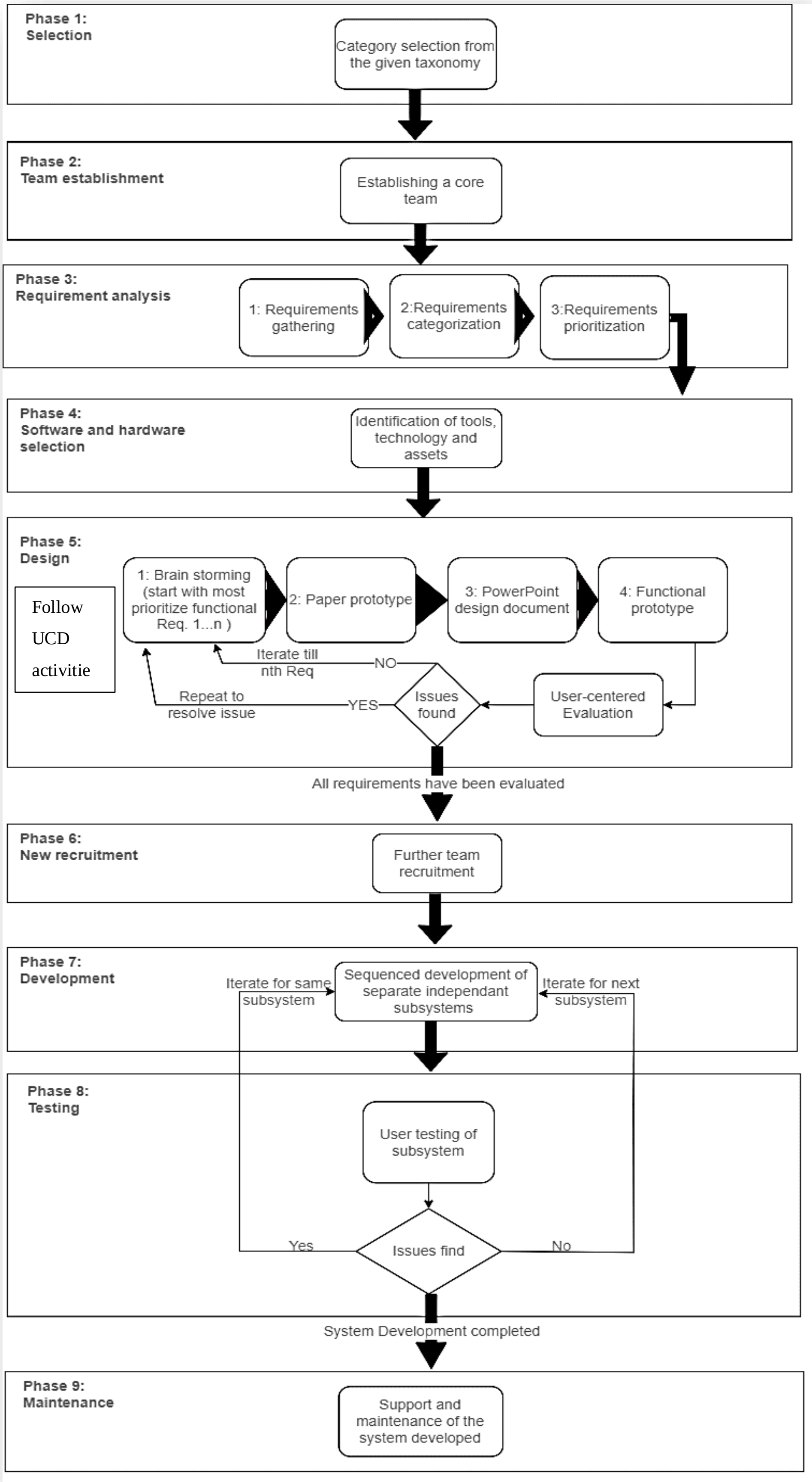

Figure 5.1: UCDDPM

Chapter 6

PROTOTYPE DEVELOPMENT AND EVALUATION

6.1 Overview

We have developed a VR-based prototype following the design guidelines and model. Step-by-step development of the prototype has been explained in this section along with evaluation criteria and results.

6.2 Prototype Development

We have developed a prototype using the proposed guidelines and model to identify the authentication of our proposed solution to the challenges upfront by the developers and researchers. Steps for developing our prototype named as "Alphalexiv" have been explained briefly.

6.2.1 Category Selection

At the first phase we have selected the category in which we desired to work for dyslexics, selected the desired age group to work for and also selected the area of intervention. All the selected fields are described in table 6.1.

Table 6.1: Description of selected fields

Field Name	Selected Field
Category	Edutainment (entertainment + education)
Age group	Preschool students
Area of intervention	Spelling, Phonological awareness, Memory

6.2.2 Team Establishment

We have finalized our team in this phase. The team comprise domain specialists (To add expert domain opinion we have reviewed research papers from neuropsychology domain (specific to dyslexia)), end users (case studies of dyslexics have been reviewed to attain their requirements), VR specialists (to learn VR programming using online learning material). Due to time limitations we were not able to make actual participant a part of our team.

6.2.3 Requirement Analysis

This phase is subcategorized into three phases.

1) Requirement gathering (gathered the specifications of the system, extracting user needs from the case studies).
2) Requirement categorization (categorized the requirements into functional and non-functional requirements)
3) Requirement prioritization (Prioritized the requirements)

6.2.3.1 Requirement gathering

Following requirements have been gathered in this phase.

1.1) Interface icons and labels must be similar with the regular standards e.g. “Tutorial” instead of “Description”.

1.2) Alphabet should be placed at particular distance to avoid confusions.

1.3) Similar looking alphabet should not be placed closer to each other.

1.4) Every item should have different color i.e. shapes and alphabet.

1.5) Generate error message if the user clicks a wrong object.

1.6) Provide user tutorial or user guide.

1.7) Provide names of objects in both audio and text format.

1.8) On clicking the hidden object, when find, application should give reward.

1.9) To enhance memory design a hide and seek game.

1.10) By clicking the shapes their names will be taught via audio

1.11) Clicking the alphabet would lead to its particular page (specifically designed to learn that specific alphabet) e.g. clicking ‘A’ will lead to world of ‘A’.

1.12) Users: teachers and students

1.13) PC/Laptop with windows 7/8/10

6.2.3.2 Requirement categorization

Table 6.2 describes the categorization of the requirements.

6.2.3.3 Requirements Prioritization

Requirements have been prioritize based upon the functionality.

1) Development of “Alphabet environment” with just initial four letters to evaluate the functionality and then to add other letters.

2) Developing only the world of ‘A’ so that its functionality will be tested by the user and then similar functionality will be added to other alphabet worlds.

3) Designing and developing only first level of hide and seek to evaluate its functionality.

4) Table 6.3 explains the prioritization of requirements as critical, high, medium and low.

Table 6.2: Categorization of requirements

Category	Requirements
Dyslexia specific	R1-R10
Technical	R11, R12
System	R5-R10
Interface	R1-R4
Functional	1.5, 1.6, 1.7
Non-functional	1.1, 1.2, 1.3, 1.4

Table 6.3: Prioritization of requirements

Priority	Requirements
Critical	R2, R3,R4,R10
High	R1, R5, R6, R7, R8, R9
Medium	-
low	-

6.2.4 Tool and technology selection

Table 6.4 describes the tools and technologies that have been selected to develop the required prototype.

6.2.5 Design

Design phase comprise following activities.

6.2.5.1 Understand and define user context:

The application will be used by the teachers to guide the child and the child will only use the application under the supervision of the teacher in the classroom.

6.2.5.2 Determine the needs of users and organizations:

We have already determined user needs completely in phase 3.

Table 6.4: Description about selected tools

Selected tool	Description
WebVR	We have chosen this technology as it allows to interact with VR experiences in a browser
A-Frame	Selected A-Frame library as it could be embedded with html and offers fast pace learning
Glitch	This platform offers building WebVR experiences using A-Frame

6.2.5.3 Brain Storming

Brain storming involve mind mapping of ideas in an irregular form. For the development of our VR-based website we have also carried out brainstorming activity that helped us making basic design of our prototype. Figure 6.1 illustrates our brain storming activity.

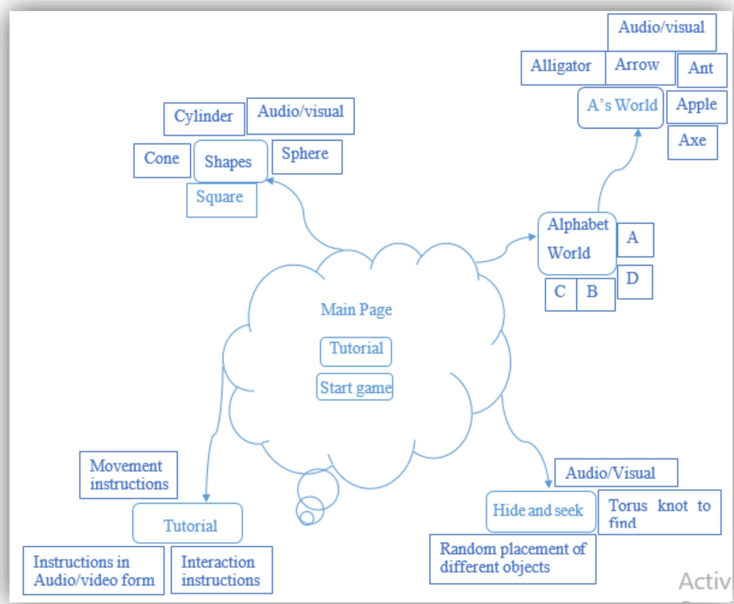

Figure 6.1: Representation of brainstorming activity being performed

6.2.5.4 PowerPoint design document

During this phase we have developed a hierarchical design of the website/application to identify the hierarchy. Figure 6.2 illustrate the hierarchy of the website.

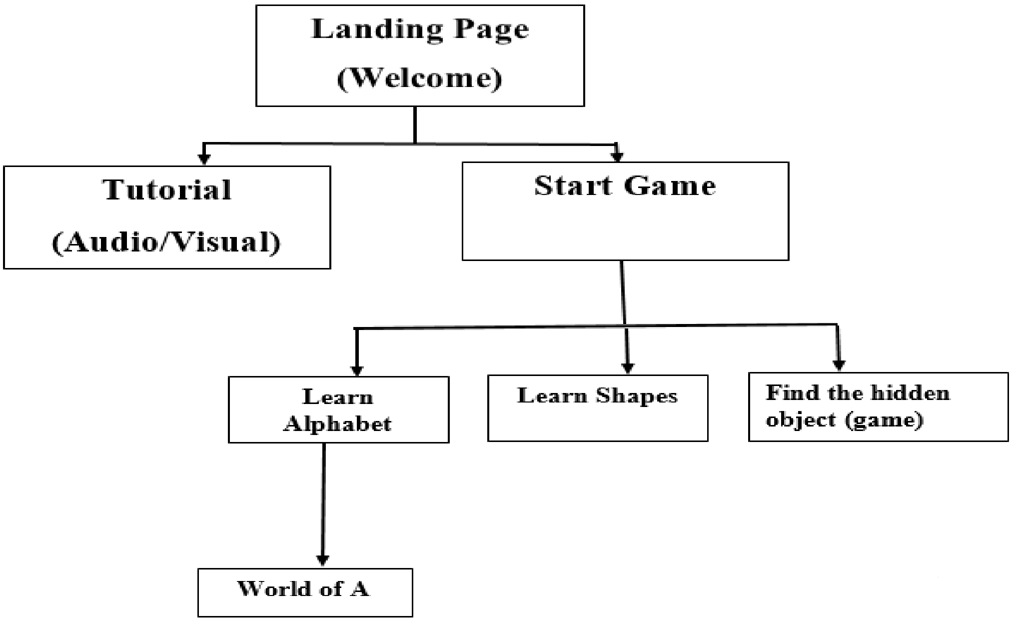

Figure 6.2: Illustration of the hierarchy of the website

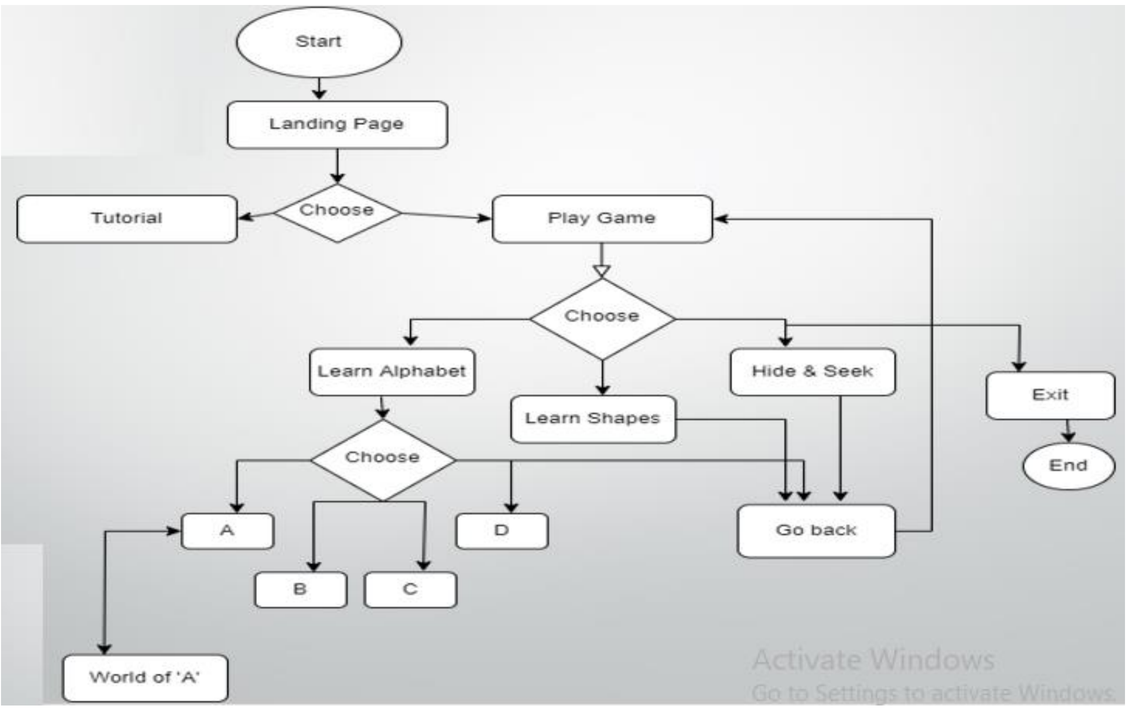

Figure 6.3: Workflow of the prototype

6.2.5.5 Functional prototype

Finally, the first functional prototype comprises seven different environments that are described below.

6.2.5.5.1 Main Page

Landing page is the main page or welcome page of the website that include "Tutorial" and "Start Game" button.

1) Tutorial button leads to Tutorial page
2) Start Game button leads to Game page

6.2.5.5.2 Tutorial page

This page comprises a written tutorial regarding the followings

1) Movement in the environment (right, left, front, back by the use of arrow keys)
2) Description about the buttons where they lead.
3) Description about each environment.

6.2.5.5.3 Game page

This page comprises three buttons that are described below

1) Learn Shapes
2) Learn Alphabet
3) Hide and Seek

6.2.5.5.4 Learn Shapes

This page consists of different shapes to teach. Example of this page has been illustrated in Figure 6.4. The taught shapes are as follows:

1) Cylinder
2) Sphere
3) Square
4) Cone

6.2.5.5.5 Learn Alphabet

This page includes first four alphabets of English in an artistic form. Clicking any alphabet would lead to the environment comprise of all the elements. An example of this environment is represented in Figure 6.5.

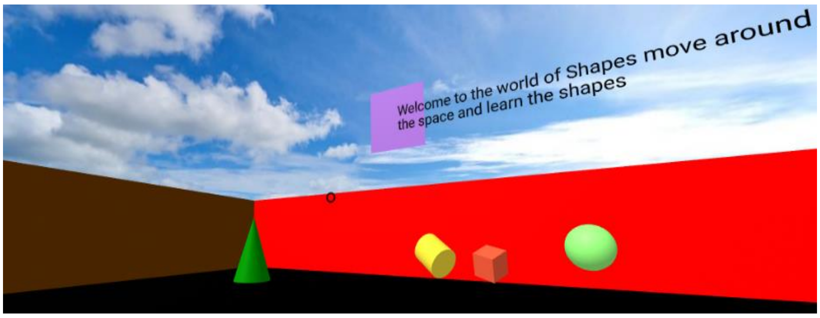

Figure 6.4: Interface of “Learn shape” environment

Figure 6.5: interface of “Learn Alphabet” environment

6.2.5.5.5.1 *A’s World*

This page includes multiple elements whose name start from ‘A’. Clicking on a specific element will pop-up its written name along with pronunciation (in audio). Figure 6.6 illustrate this environment. The elements of this environment are as follows.

1) Alligator
2) Axe
3) Arrow
4) Apple
5) Ant

6.2.5.5.6 Hide and Seek

This page is an environment where random elements are placed and the user has to find a torus knot that is hidden behind the randomly placed elements. Figure 6.7 illustrate this environment.

6.2.5.6 Evaluation

To identify the accuracy of developed prototype we have evaluated for accessibility and for dyslexic’s requirement matrices.

Figure 6.6: Interface of "World of A"

Figure 6.7: Interface for hide and seek

6.2.5.6.1 *Accessibility*

Accessibility refers to ability of a website to incorporate disabled individuals (a website is easy to use by its disabled users like Dyslexics).

Accessibility Guidelines Working Group (AGWG) developed by W3C has proposed WCAG (Web content accessibility guidelines) guidelines. It has following four basic principles.

1) Perceivable
2) Operable
3) Understandable
4) Robust

6.2.5.6.1.1 *WCAG Compliance Levels*

Each guideline principle could be evaluated regarding following levels.

1) A (provide basic accessibility)

2) AA (provide intermediate accessibility)

3) AAA (provide full accessibility)

6.2.5.6.1.2 *Tool used for Evaluation*

The tool used for accessibility testing/evaluation is "A11y" provided by Bureau of Internet Accessibility (BOIA). This tool checks the accessibility against WCAG A/AA check points. The result of accessibility evaluation has been illustrated in Figure 6.8 and 6.9.

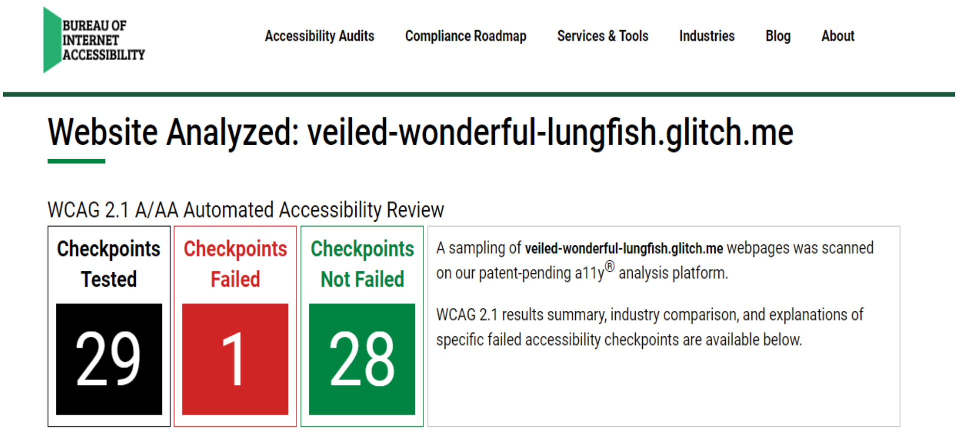

Figure 6.8: Evaluation results from BOIS

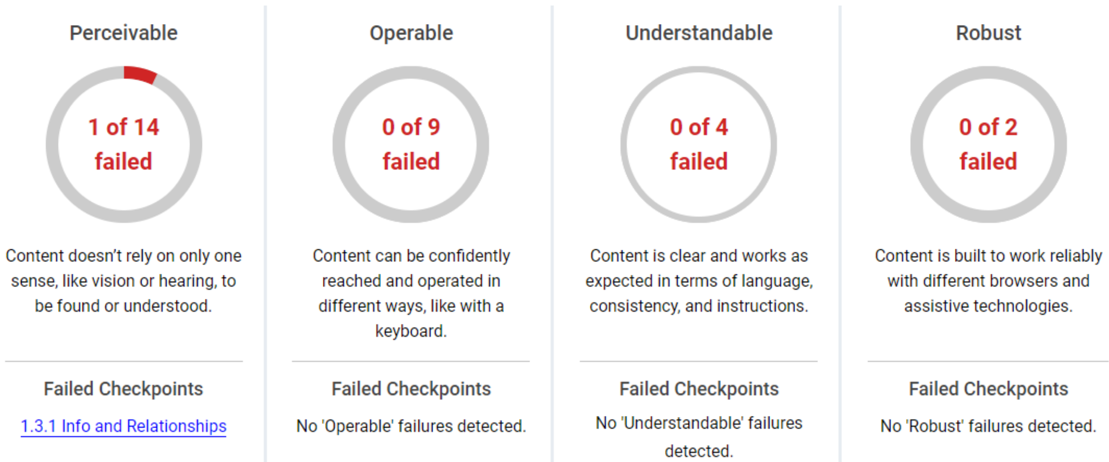

Figure 6.9: Evaluation results regarding design principles

6.2.5.6.2 Requirement Matrices

Each environment has been evaluated against the evaluation requirement matrices. Evaluation results have been described in table 6.4. Yes, indicates the presence of the required matrix and No indicates its absence. Figure 6.10 illustrates the results in graphical form. There are in total twelve requirement matrices for the evaluation of the apps specially designed for dyslexics. The evaluation requirement matrices have been described in table 4.1.

Table 6.5: Evaluation results using requirement matrices

Requirements	Environment				
		Alphabet	**World of 'A'**	**Shapes**	**Hide and Seek**
	Visual stimulus	Yes	Yes	Yes	Yes
	Audible stimulus	Yes	Yes	Yes	Yes
	Fixed color scheme	Yes	Yes	Yes	Yes
	Error feedback	No	No	No	Yes
	Separated similar words	Yes	Yes	Yes	Yes
	Translate into forms	Yes	Yes	Yes	Yes
	Rewards	Yes	Yes	Yes	Yes
	Repetition	Yes	Yes	Yes	Yes
	Clear objectives	Yes	Yes	Yes	Yes
	Difficulty level	Yes	Yes	Yes	Yes
	Fun learning	Yes	Yes	Yes	Yes
	Total	**10**	**10**	**10**	**11**

6.3 Summary

The evaluation results have shown improvement in user-friendly, accessible and effective VR environments.

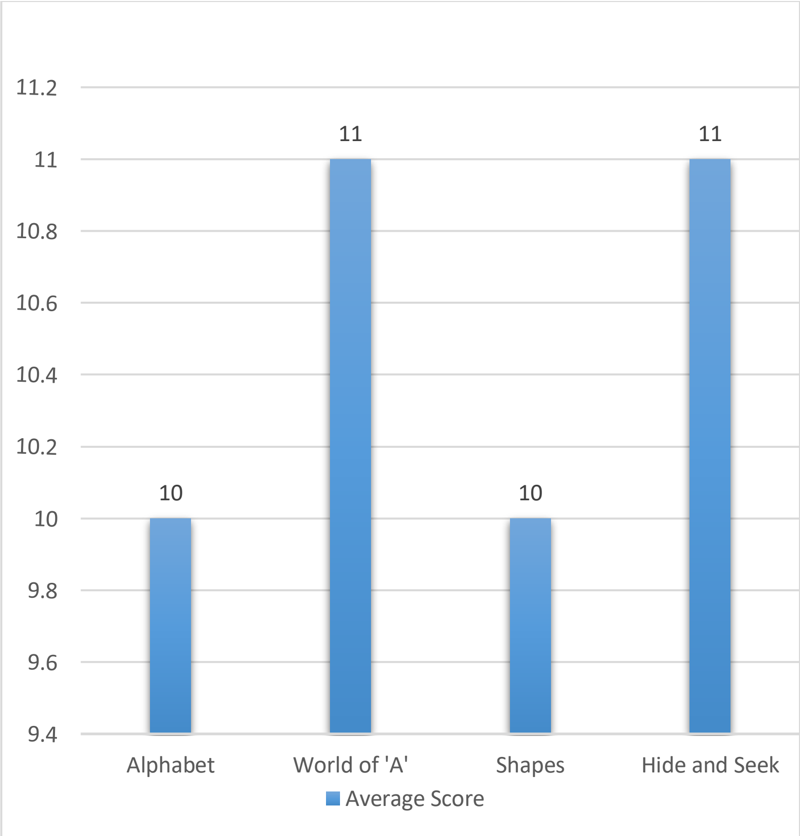

Figure 6.10: Graphical representation of evaluation results

Chapter 7

DISCUSSION, CONCLUSION AND FUTURE WORK

The motivation to carry out this research was to benefit dyslexics by the use of VR as VR is offering distinctive features to its users and these features have proven to be beneficial for education domain. Dyslexia is a Reading Learning Disorder (RLD) that effects fluency in ready, spelling, comprehension and phonological skills of a child [48]. Multiple ICT based applications have been developed by the researchers to assist dyslexics to learn in a distinct, beneficial and effective style. VR-based applications have proved to be the enhanced version of all the other technologies due to its unique features and multisensory approach (audio, visual and haptics (having sense of feel)). Research has proved the domain of VR for dyslexia as a growing and emerging domain but with a steady pace. The reason behind this steady speed may be a lack of design guidelines and a design model to follow while developing such application. Hence this research aims to present an extensive set of design guidelines along with a design model UCDDPM that could be followed in order to develop such applications. We have evaluated existing mobile applications to identify their weakness that could overcome by using VR. The proposed model will help developers and researchers to involve end-users

A VR-based prototype has been developed using WebVR (technology that allows the user to enjoy VR experiences using web browser) following the proposed design guidelines. The prototype has been evaluated in two ways: 1) Accessibility testing of the website to check whether it is compliant with WCAG 2.1 (to evaluate the accessibility of the website for dyslexics), 2) Evaluated against dyslexic's requirement matrices to identify whether the website fulfilling the requirements desired from a VR or mobile application that aim to provide learning experience to users.

The results have shown that the prototype is fulfilling 95% of requirements and compliance based necessities or demands. This limitation of our work is the absence of actual users/participants, as we have examined case studies of students and views of several domain experts to derive user requirements and specifications of the system (due to time constraint). The absence of actual user impacts the results of a research study. This research examined the case studies, therefore further research is required by involving actual dyslexics to capture more accurate results of the proposed guidelines and model. The design and development model is the pioneer of this domain that may require more refinement in the future to enhance its potential for developing applications.

7.1 Conclusion

The current research aims to explore the accomplishments of VR technology for the progression of dyslexics. Dyslexia is a learning disorder that effects people's reading, spelling, phonological skills and working memory. We have proposed guidelines to develop VR-based applications for dyslexics and also presented a User-Centered design and development process model to develop VR-based accessible applications for dyslexics. Existing dyslexia-specific mobile games have been evaluated using evaluation matrices for dyslexics. "Alphalexiv" is a webVR-based learning game (a prototype has been developed in its first phase) developed by implementing the proposed methodologies. The prototype has been evaluated using online accessibility tools for dyslexics. It has been concluded that VR-based applications play a vital role in the betterment of dyslexics enhancing attention, readability and working memory. Further large-scale studies are suggested to benefit dyslexics on a widespread scale.

7.2 Future Work

In the future "Alphalexiv" will be completely developed in the presence of end users (dyslexics) and domain experts to capture more efficient results of proposed model and will also be evaluated by the user themselves.

As dyslexia differently effects each individual a self-learning approach is the requirement of the future. Artificial intelligence (AI) and Machine Learning (ML) approaches could be embedded in VR applications to provide more convenient learning environments. A self-learning environment could be a future direction, an environment that would be able to proficient itself on the basis of specific user needs and performed actions.

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