HAPTIC BASED FRAMEWORK IN SUPPORTING SENSORY-MOTOR FOR NEURODEVELOPMENT OF COGNITIVE SKILLS AMONG DYSLEXIC CHILDREN

SALMAN JAVED

MASTER OF SCIENCE (COMPUTER SCIENCE)

FACULTY OF INFORMATION AND COMMUNICATION TECHNOLOGY

UNIVERSITI TUNKU ABDUL RAHMAN

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APPROVAL SHEET

This thesis entitled "**HAPTIC BASED FRAMEWORK IN SUPPORTING SENSORY-MOTOR FOR NEURODEVELOPMENT OF COGNITIVE SKILLS AMONG DYSLEXIC CHILDREN"** was prepared by SALMAN JAVED and submitted as partial fulfillment of the requirements for the degree of Master of Science in Computer Science at Universiti Tunku Abdul Rahman.

Approved by:

____________________________ Date: 02/07/2024

(Dr. Manoranjitham Muniandy)
Supervisor
Department of Computer Science
Faculty of Information and Communication Technology
Universiti Tunku Abdul Rahman

____________________________ Date: 02/07/2024

(Dr. Lee Chen Kang)
Co-supervisor
Department of Internet Engineering and Computer Science
Lee Kong Chian Faculty of Engineering and Science
Universiti Tunku Abdul Rahman

____________________________ Date: 02/07/2024

(Dr. Husniza Husni)
External Co-supervisor
School of Computing
Universiti Utara Malaysia

FACULTY OF INFORMATION AND COMMUNICATION TECHNOLOGY

UNIVERSITI TUNKU ABDUL RAHMAN

Date: 02/07/2024

SUBMISSION THESIS

It is hereby certified that ***Salman Javed*** (ID No:***22ACM01252***) has completed this thesis* entitled "*Haptic Based Framework in Supporting Sensory-Motor for Neurodevelopment of Cognitive Skills Among Dyslexic Children*" under the supervision of Dr. Manoranjitham Muniandy (Supervisor) from the Department of Computer Science, Faculty of Information and Communication Technology, and Dr. Lee Chen Kang (Co-Supervisor) * from the Department of Internet Engineering and Computer Science, Lee Kong Chian Faculty of Engineering and Science.

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DECLARATION

I Salman Javed hereby declare that the dissertation is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UTAR or other institutions.

(Salman Javed)

Date: 02/07/2024

DEDICATION

I am dedicating this thesis to my family members and my beloved supervisor.

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HAPTIC BASED FRAMEWORK IN SUPPORTING SENSORY-MOTOR FOR NEURODEVELOPMENT OF COGNITIVE SKILLS AMONG DYSLEXIC CHILDREN

By

SALMAN JAVED

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ABSTRACT

HAPTIC BASED FRAMEWORK IN SUPPORTING SENSORY-MOTOR FOR NEURODEVELOPMENT OF COGNITIVE SKILLS AMONG DYSLEXIC CHILDREN

SALMAN JAVED

Dyslexia, a neurodevelopmental disorder affecting word-accurate identification and reading skills, poses significant challenges to cognitive development. Multisensory learning approaches, including tactile and kinesthetic elements, have shown promise in enhancing cognitive skills. However, these elements are often overlooked in traditional practices. Haptic technology, which stimulates motor and somatosensory regions of the brain, has been used in various countries to support dyslexic children but remains underexplored in Malaysia.

This study aims to develop a framework, integrating haptic elements to support sensory-motor skills for the neurodevelopment of cognitive skills among dyslexic children. The HapticLearn 1.0 model has been developed from the framework. The model serves as a guide for IT developers, multimedia designers, educators, and parents in designing accessible learning applications.

Interviews and classroom observations were conducted at Persatuan Dyslexia Malaysia to understand current practices. The HapticLearn 1.0 model was developed and tested with 36 dyslexic children. Pre-test and post-test assessments were conducted to measure improvements in cognitive skills. Expert evaluation was also conducted to assess the model's readability and usefulness.

The experimental group using HapticLearn 1.0 showed significant improvements in remembering and understanding tasks compared to the control group. The pre-test and post-test assessments revealed a 23% improvement in cognitive skills among the experimental group, highlighting the effectiveness of the haptic-based framework. Expert evaluation by 5 IT developers indicated a positive reception of the model, with scores above 80% for relevancy, applicability, readability, understandability, and significance which also highlighted the effectiveness of the framework.

In conclusion, the HapticLearn 1.0 model demonstrates the effectiveness of haptic technology in enhancing cognitive skills among dyslexic children. It serves as a valuable guide for designing haptic-based learning applications and has the potential to improve learning outcomes for dyslexic children in Malaysia and beyond.

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LIST OF ABBREVIATIONS

API	Application Programming Interface
COVID-19	Coronavirus Disease of 2019
DCD	Developmental Coordination Disorder
HCI	Human-Computer Interaction
IT	Information Technology
IQs	Intelligence Quotients (IQs)
LDs	Learning Disorders
PDM	Persatuan Dyslexia Malaysia
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
REM	Remembering
RQs	Research Questions
RRT	Rhythmic Reading Training
SLD	Specific Learning Disability
STS	Superior Temporal Sulcus
DSM-5	Statistical Manual of Mental Disorders fifth edition
3D	Three Dimensional
TD	Typically Developing
UND	Understanding
VTM	Visual Tracking Magnifiers
VAKT	Visual, Auditory, Kinesthetic, Tactile
VR	Virtual Reality

CHAPTER 1

INTRODUCTION

In this chapter, a thorough introduction to the topic of the study is given. The chapter begins with a brief introduction to dyslexia, prevalence issues, cognitive skills, sensory-motor skills, multisensory techniques, and the use of technology such as haptic technology. This is followed by the problems faced by children with dyslexia in the context of accessible learning. The research questions address the suitability of the existing representation of haptic interventions practiced on dyslexic children and how to improve such representation to be more accessible in terms of haptic intervention incorporating motor skills and cognitive skills. The objectives of the study have been devised to investigate the problems faced by children with dyslexia and to formulate and validate the model as a solution to improve the learning platform for this group. This research is motivated by the growing number of children with dyslexia and also to be part of the Malaysian plan to improve multimedia learning among disabled groups. The scope and the significance of the study to the dyslexia society have also been stressed in this section. The chapter ends with an outline of the thesis and operational definition of key terms in the context of this study.

1.1 Background of Study

One of the most prevalent neurodevelopmental disorders in children is specific learning disorder [1, 2]. The Diagnostic and Statistical Manual of

Mental Disorders (DSM-5) fifth edition, which was recently revised, renamed the term "learning disability" as a Specific Learning Disability (SLD), which includes issues with one of four domains: dyslexia (a reading disability), dysgraphia (a writing disability), dyscalculia (a math disability), and dysphasia (a language disability) [3]. Academic progress, self-confidence, psychological anxiety, mental health, and eventually career achievement are all at risk due to SLDs [1].

Dyslexia is one of these conditions that impacts 5% to 10% of children globally [4]. Dyslexia is not rooted in a physical issue like impaired vision; rather, it revolves around the brain's processing of information. The inability of a person with dyslexia to split words into their constituent components during reading, speaking, or writing is a brain processing disorder [5]. Dyslexia has a substantial impact on an individual's literacy skills, which include a variety of abilities required for efficient communication, such as reading, writing, speaking, and listening. The disorder profoundly impairs textual information understanding, resulting in significant obstacles in several aspects crucial to reading ability[6]. These difficulties include difficulties in obtaining a large vocabulary, maintaining fluent reading, efficiently blending words, recognizing and memorizing words, and precisely pronouncing words - all of which are essential components for proficient reading [7]. The processes of reading and writing are interconnected and reliant on each other [8]. Pupils with dyslexia encounter difficulties related to their cognitive abilities, as indicated in Figure 1.1, which significantly impacts their learning process [9].

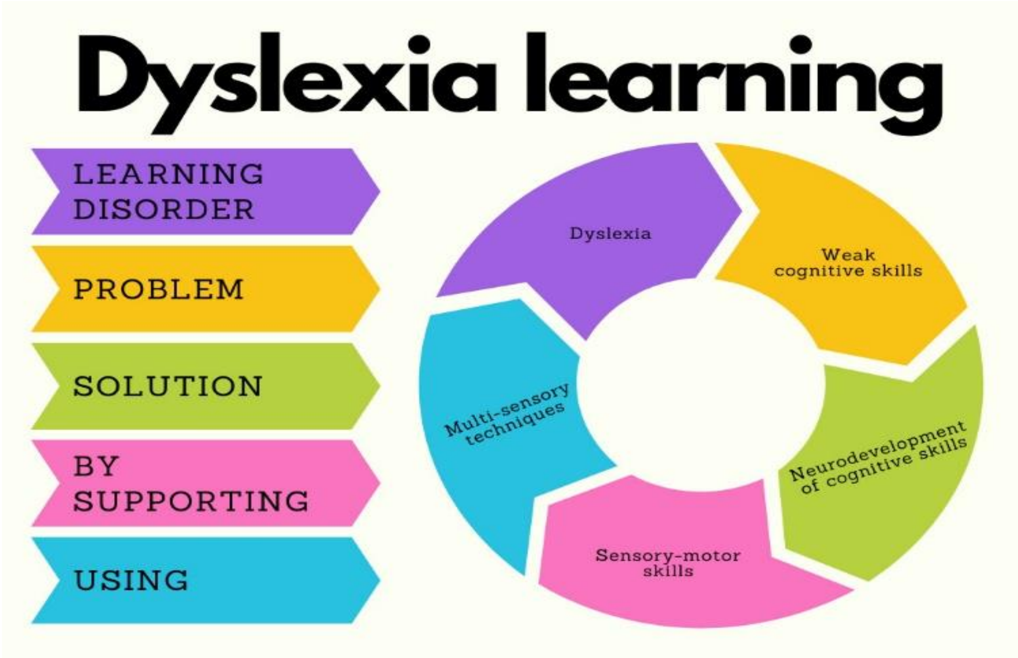


Figure 1.1: Dyslexia Learning Process: [4]

"Cognitive skills" encompass the foundational mental processes involved in acquiring knowledge, manipulating information, and engaging in higher-order reasoning [10]. These cognitive skills, crucial for intelligence development, consist of a diverse set of capabilities such as comprehension, judgment, evaluation, critical thinking, memory retention, attention span, and recall, which synergistically interact [11]. These combined abilities facilitate various cognitive functions, including thinking, reading, learning, remembering, reasoning, and sustaining attention [11]. Because of their strong relationship with information processing, cognitive abilities have a significant impact on learning efficiency and capacity [12].

Strong cognitive abilities are necessary for processing various types of sensory information [12]. To enhance cognitive strength, the coordination of sensory inputs plays a crucial role, where motor skills contribute significantly to cognitive development by enabling interaction with the environment, thus enriching sensory experiences. Information is received by the VAKT sensory systems, and sensory processing involves the perception, organization, as well as interpretation of this [13]. The ability to respond to stimuli with the proper motor and behavioral responses is known as sensory integration.

The term "motor responses" refers to the movement of the body's muscles with the intention to perform specified activities [14]. Using one's ability to do motor movements improves control over brainwaves and improves sensorimotor rhythm [15]. Training therapies frequently incorporate exercises that involve both motor and sensory tasks, with the goal of improving sensory functions [16]. Simultaneous motor training and sensory stimulation may result in improved efficiency [17]. An approach incorporating visual, auditory, tactile, and kinesthetic learning elements is known as multimodality. Utilizing a multimodal approach is advantageous for all children, including those with dyslexia, as it incorporates elements that stimulate many areas of the brain [18]. According to research, using a multi-sensory technique is considered the most successful technique for teaching students with dyslexia due to their heightened inventiveness and strong sensory receptors [19]. By implementing a multi-sensory strategy, as depicted in Figure 1.1, children with learning issues can enhance their learning outcomes in a more efficient manner [19, 20].

In short, the implementation of multisensory instructional methods, including visual, auditory, kinesthetic, and tactile stimulation, improves the speed of learning, enhances information retention, and facilitates the application of newly acquired concepts by dyslexic children [21]. Among the many multisensory instructional techniques, tactile and kinesthetic practices are noteworthy for their emphasis on touch and motor skills, fostering learning through physical engagement and movement. This technique not only incorporates the touch sensation but also progresses to a more comprehensive integration of touch, as learners interact with materials and environments. The tactile, which can convert information from the external physical environment into internal sensations, is among the most complex sensory systems [22]. Information processing and retention by the kinesthetic system is dependent on the instantaneous perception of motion impulses [23]. Despite the importance of the tactile and kinesthetic systems in information processing and retention, it has received less attention compared to the visual and auditory systems. Touch sensation and motor skills can be implemented through haptic technology. "Haptic" is a technology that transmits tactile and kinesthetic information using sensations such as touch, force feedback, and vibration. "Haptic technology" is a technology that can create an experience of touch, force feedback, and vibration. In recent years, there have been noticeable enhancements in the learning environment in countries such as Canada, Dubai, and the US, specifically in relation to tactile and kinesthetic aspects [24, 25].

The majority of these studies utilize Haptic technology to illustrate the sense of touch and bodily movement. Haptic technology is employed to induce stimulation of the motor cortex and somatosensory cortex area in the brain [26]. While haptic-based research has flourished in many nations, the situation in Malaysia is not the same. Malaysia remains strongly oriented towards traditional practices. The field of haptics is in its early stages of development in Malaysia, necessitating further research to establish a systematic strategy for future advancements [4]. This project aims to contribute to the dyslexia society in Malaysia by examining current practices for dyslexic children and enhancing accessible learning through the integration of motor skills and cognitive skills elements using technology.

In order to achieve such learning improvement, the IT designers would need to have good guidance in terms of designing effective learning interventions for children with dyslexia. Therefore, the main objective of this study is to create a conceptual model using haptic components to enhance the sensory-motor abilities necessary for the cognitive development of children with dyslexia. Choosing haptic features can enhance the sensory-motor and cognitive abilities of children diagnosed with dyslexia. In this project, a conceptual model called "HapticLearn 1.0" was created to include essential components that can provide guidance to future IT developers (IT developers refers to multimedia designers, application designers, and systems developers throughout the thesis) in building a learning application that is accessible to children with dyslexia. Special needs educators and parents of children with dyslexia will have access to "HapticLearn 1.0" to assist in guiding the children with dyslexia. They will benefit as secondary users of the program.

1.2 Problem Statement

Currently, the lack of intervention practices for dyslexic children in Malaysia is twofold; (1) lack of utilization of haptics and (2) lack of incorporating motor skills and cognitive skills elements in haptics.

Certainly, in the context of dyslexia, "intervention practices" refer to educational methods and approaches used to support dyslexic children in their learning process. These practices aim to address the specific challenges faced by dyslexic individuals, such as difficulties with reading, writing, and spelling. Interventions can include specialized teaching techniques, assistive technologies, and strategies to help dyslexic children overcome these challenges and succeed academically.

Currently, the lack of intervention practices for dyslexic children in Malaysia is twofold. Traditional methods of teaching and learning are predominant, with minimal integration of haptic technology, which has shown promise in enhancing cognitive skills for dyslexic individuals. A quick research shows that Malaysia has no practice in using haptic technology for dyslexic children. The utilization of haptics is important and relevant because it engages tactile and kinesthetic senses. Apart from that, many teaching and learning centers for dyslexic children in Malaysia seem to be using only traditional methods.

There are several benefits to creating interventions from scratch, especially when it comes to dyslexia. Starting over allows initiatives to be more relevant and successful by allowing them to be customized to the unique needs and contexts of the local people. Additionally, this strategy promotes creativity and the integration of the most recent research findings, which may result in treatments that are more effective and significant. Moreover, creating interventions from the ground up prevents the replication of restrictions or antiquated procedures from interventions created elsewhere. It encourages local stakeholders to feel invested and committed, which promotes sustainability and long-term success. Furthermore, adding novel interventions to the corpus of information about dyslexia can help people with the condition globally, advancing the field and enhancing the learning of dyslexics.

1.2.1 Lack in Intervention Practices

A team of researchers conducted semi-structured interviews with five teachers at PDM (Persatuan Dyslexia Malaysia), which unveiled that teaching materials have an impact on learning style [27]. Highlighting the persistent use of conventional teaching methods among teachers working with dyslexic children, primarily attributed to limited resources in Malaysia. These methods included the cycle motor teaching approach, one-on-one sessions, reliance on black-and-white illustrations, and a notable absence of graphical or visual aids. Notably, some dyslexic children, inclined to lose focus and unable to maintain prolonged attention spans, showed disinterest in these conventional learning styles. Before concluding the interviews, teachers lamented the absence of interactive or visual aids tailored to these children's learning needs. However, upon introducing interactive motion during testing, a significant shift was observed. The children exhibited heightened enthusiasm and enjoyment during lessons, underscoring the effectiveness of image representation. This approach allowed dyslexic children to discern shapes and colors more effectively than through conventional illustrations or graphics. Furthermore, the outcomes gleaned from the teachers' interviews emphasized the direct influence of teaching materials on learning styles, highlighting the diverse impact different materials can have on learning outcomes.

A group of researchers from Malaysia emphasizes to develop the appropriate and relevant teaching aids with the right level of needs at intermediate and advanced levels for children with dyslexia [23]. By creating effective teaching aids for children with dyslexia at intermediate and advanced levels, it's essential to understand their specific learning needs at each stage. These aids should be tailored to bridge foundational gaps at intermediate levels, integrating interactive, multisensory elements, while at advanced levels, they should encourage critical thinking and higher-order cognition. By focusing on individual learning styles and incorporating assistive tools, they aim to empower dyslexic children to learn independently and progress successfully in their educational journey.

1.2.2 Lack of Utilization of Haptics

A group of researchers from Malaysia emphasize that handwriting approaches as a memory support [28]. Handwriting is more than an ordinary method of transcription; it functions as a cognitive aid, reinforcing memory retention through motor skills and tactile engagement. When children physically write by hand, they engage multiple sensory pathways, strengthening the neural connections associated with learning and memory. The utilization of haptics in handwriting is necessary because it adds a crucial layer of sensory feedback and guidance that enhances the learning process, especially for dyslexic children. Haptics, which makes use of motion and touch, can offer kinesthetic and tactile feedback and guidance that is typically absent from standard handwriting techniques. Consequently, this exclusion of the kinesthetic and tactile feedback and guidance experience in the traditional handwriting approach might limit the cognitive benefits derived from handwriting, particularly for children who thrive on sensory engagement, such as those with dyslexia.

Another group of researchers from Malaysia highlights that dyslexic children often exhibit a unique learning preference, appropriately described as the "touching" process, in which they excel by physically manipulating and assembling parts of objects[29]. Recognizing this tactile learning style is crucial in designing effective instructional methods. Academic assessments tailored for dyslexic children are vital due to their challenges in academic abilities. Teachers play a significant role in improving dyslexic learning through appropriate assessments. One such approach is the multisensory technique, offering various tools for educators aiming to enhance the learning of dyslexic individuals. These techniques encompass approaches like VAKT. However, mobile learning technology does not incorporate the helpful assistance of kinesthetic and tactile learning. Incorporating kinesthetic and tactile learning styles into instruction becomes essential to cater to dyslexic children's optimal learning experiences.

1.2.3 Lack of Motor Skills Incorporation

A team of Malaysian researchers has suggested that children with dyslexia may exhibit a heightened level of attention, which could serve as a compensatory mechanism within the neural brain network to address specific deficiencies in attentional processing [30]. The integration of motor skills is a crucial component of their proposed technique. They suggested that the increased attention levels found in children with dyslexia might function as a compensating mechanism in the neural brain network. This compensation could be helpful in addressing specific deficits or shortcomings connected with attentional processing often spotted in individuals with dyslexia.

By focusing on motor skill development as a complementary aspect to attentional processing, they aim to leverage this compensating factor observed in children with dyslexia. This technique could potentially enhance their overall cognitive abilities, ultimately contributing to improved learning outcomes and academic performance. The integration of motor skills activities into educational interventions may offer an innovative approach to support and augment the cognitive strengths that children with dyslexia possess.

Another group of researchers emphasizes that cognitive skills help in reading and writing but in Malaysia, the majority of dyslexic children are beyond the cognitive functions [31]. Research in Malaysia concerning cognitive enhancement for children with dyslexia has primarily relied on multisensory and multimedia techniques, focusing predominantly on language components like alphabet mastery and identification. While some studies have explored morphological awareness to aid reading, spelling, and vocabulary, there's a notable absence of comprehensive approaches integrating interventions for both cognitive functions and linguistics-literacy deficits. Malaysian research has often overlooked the underlying cognitive aspects influencing dyslexic children's reading and writing performance, emphasizing literacy and linguistic skills exclusively. There's a crucial need for researchers to broaden their scope beyond literacy, considering the pivotal role of cognitive functions in dyslexia. Integrating a comprehensive model addressing both cognitive functions and linguistic-literacy deficits might offer more effective management strategies and better outcomes for Malaysian children dealing with dyslexia, potentially revolutionizing interventions in this domain.

This section emphasizes the findings of researchers in Malaysia, it is important to note that extensive work on incorporating motor skills in dyslexia interventions has been conducted globally, including in the United States, Europe, and Australia. Replicating or introducing these international methods with further research in Malaysia is crucial for validating their effectiveness within the local context and ensuring that Malaysian interventions benefit from proven, globally-recognized strategies. This approach can enhance the overall efficacy of dyslexia support programs in Malaysia.

1.3 Research Questions

1) What are the haptic interventions practiced on dyslexic children in Malaysia?

This research question is designed to comprehensively investigate the current state of haptic interventions tailored specifically for dyslexic children within Malaysia. Haptic interventions encompass a range of tactile and kinesthetic approaches that leverage touch, physical manipulation, or sensory engagement to aid in learning and understanding. Despite the growing acknowledgment of diverse intervention strategies for dyslexia, there exists a gap in understanding the specific utilization and effectiveness of haptic interventions within the Malaysian educational context. This inquiry seeks to delve into the spectrum of tactile interventions employed—such as tactile learning materials, manipulatives, sensory-based activities, or touch-sensitive technologies—to discern their efficacy in supporting dyslexic children's learning experiences. By examining these interventions and their impact on learning outcomes, this research aims to offer insights into effective methodologies and practices that harness tactile modalities, potentially paving the way for the advancement of tailored interventions catering to the needs of dyslexic children in Malaysia.

2) How to develop haptic intervention incorporating motor skills and cognitive skills elements for dyslexic children in Malaysia?

This research question focuses on haptic elements necessary to formulate a haptic intervention specifically designed for children with dyslexia in Malaysia, emphasizing the fusion of motor skills and cognitive elements. Haptic interventions encompass tactile and kinesthetic techniques that engage touch and physical interaction to enhance learning experiences. However, the development of interventions tailored to children with dyslexia in Malaysia, particularly those that incorporate both motor skills and cognitive components, remains underexplored. This inquiry seeks to identify and propose elements that merge activities targeting motor skills (such as hand-eye coordination exercises, tactile manipulations, or sensory-based tasks) with cognitive elements (including memory enhancement exercises, attention-building activities, or language processing tasks). Understanding how to effectively blend these components in a haptic intervention specifically crafted for children with dyslexia within the Malaysian educational context will provide valuable insights into creating comprehensive interventions that address the multifaceted challenges faced by these individuals. This exploration aims to contribute to the design and implementation of innovative, holistic haptic interventions that promote improved learning outcomes for children with dyslexia in Malaysia.

1.4 Research Objectives

1) To study the existing haptic interventions practiced on dyslexic children in Malaysia.

This research objective seeks to comprehensively examine the spectrum of haptic interventions utilized specifically for dyslexic children in the context of Malaysia. Haptic interventions involve kinesthetic and tactile methods that physical interaction, leverage touch, or sensory engagement to enhance learning experiences. The objective is to conduct a thorough exploration and assessment of the existing interventions employed within Malaysia's educational settings for dyslexic children. This investigation will encompass a review of various haptic intervention strategies, including tactile learning materials, sensory-based activities, touch-sensitive technologies, and other kinesthetic approaches utilized to support dyslexic children's learning needs. By scrutinizing and documenting these interventions, their methodologies, and their application within Malaysian educational environments, this objective aims to provide a comprehensive overview of the current practices. The findings from this exploration will offer insights into the diverse array of haptic interventions available, their effectiveness, and their alignment with the needs of dyslexic children in Malaysia, thereby contributing to the understanding and improvement of tailored interventions for this demographic.

2) To propose an accessibility framework incorporating haptics elements to facilitate the learning process of dyslexic children in Malaysia.

This research objective focuses on the creation of an accessibility framework specifically tailored to meet the learning needs of dyslexic children within the Malaysian educational context. The objective is to design a comprehensive framework that incorporates haptic elements—tactile and kinesthetic approaches that engage touch, physical interaction, or sensory stimuli—to facilitate and optimize the learning process for dyslexic individuals. The framework will be structured to address accessibility challenges encountered by dyslexic children in traditional educational settings. It aims to provide an inclusive learning environment by leveraging haptic interventions that promote engagement, comprehension, and retention among dyslexic learners. The proposed framework will encompass diverse elements, such as tactile learning materials, interactive activities emphasizing touch and manipulation, sensory-based technologies, and instructional strategies that cater specifically to the unique learning preferences of dyslexic children. By outlining this comprehensive accessibility framework, this research objective aims to contribute to the development of innovative and effective approaches that foster improved learning outcomes for dyslexic children in Malaysia, promoting inclusivity and accessibility within educational settings.

3) To evaluate the proposed accessibility framework heuristically with domain experts in Malaysia.

The evaluation of the proposed accessibility framework with domain experts in Malaysia begins with a two-fold approach: expert evaluation and prototype testing. This research objective involves a systematic assessment of the developed HapticLearn 1.0 model through heuristic evaluation, a method involving domain experts in the field of dyslexia and education within Malaysia. The objective aims to gather expert feedback and insights to evaluate the effectiveness, usability, and relevance of the proposed accessibility framework tailored for dyslexic children. Domain experts possessing expertise in dyslexia, education, assistive technologies, and haptic interventions will be engaged in this evaluation process. Their insights and evaluations will focus on assessing the framework's alignment with the specific needs and challenges faced by dyslexic learners in Malaysian educational contexts. By employing established heuristic evaluation criteria, such as effectiveness, efficiency, learnability, satisfaction, and accessibility, the experts will critically analyze and provide feedback on the framework's comprehensiveness, suitability, and practicality. This evaluative phase aims to refine and enhance the proposed accessibility framework by incorporating expert recommendations and addressing any identified shortcomings or areas for improvement.

In the prototype testing phase, the prototype was tested with both a control group and an experimental group of dyslexic children. This approach likely aimed to compare the effectiveness of the accessibility framework against a standard or existing method, with the experimental group using the new framework and the control group using the traditional method. By comparing the outcomes between the two groups, researchers can assess the impact and effectiveness of the new framework in supporting dyslexic children. The outcomes of this evaluation process will contribute to validating the proposed framework's efficacy and applicability, ensuring its alignment with the requirements of dyslexic learners in Malaysia, and ultimately striving towards enhancing educational inclusivity and effectiveness for this demographic.

1.5 Scope of Study

This research aims to undertake a thorough investigation into haptic interventions designed for dyslexic children age group 5 to 13 years within the educational landscape of Malaysia. The scope encompasses an extensive review and analysis of existing haptic intervention strategies, specifically focusing on tactile or kinesthetic methodologies integrating motor skills and cognitive elements to support dyslexic learners. This study will scrutinize the interplay between tactile learning materials, sensory-based activities, touch-sensitive technologies, and other kinesthetic approaches targeted at enhancing both motor skill development and cognitive proficiency among dyslexic children within Malaysian educational settings. Furthermore, the research will delve into elucidating the methodologies that combine activities enhancing motor skills—such as hand-eye coordination exercises, tactile manipulations, or sensory-based tasks—with cognitive enhancement strategies, including memory enhancement exercises, attention-building activities, and language processing tasks tailored for dyslexic learners.

Expanding on this scope, the research seeks to propose an innovative accessibility framework that integrates haptic elements, emphasizing the fusion of motor skills and cognitive elements. This framework aims to optimize and customize the learning experiences for dyslexic children within the Malaysian educational context, addressing the specific needs of dyslexic learners by merging tactile or kinesthetic activities targeting motor skills development with cognitive enhancement strategies. Through a comprehensive exploration of these integrated facets, this study aspires to contribute significantly to the advancement of tailored interventions, ultimately fostering inclusive and effective educational practices for dyslexic children in Malaysia.

1.6 Significant of Study

This research seeks to address a critical issue faced by dyslexic individuals in Malaysia, in accessing educational materials and learning platforms. Preliminary exploration and an extensive literature review highlight the current inadequacies in haptic interventions catering to the diverse needs of dyslexic learners within the Malaysian educational landscape. Dyslexic students in Malaysia encounter significant hurdles due to the absence of integrated haptic strategies that effectively merge motor skill development and cognitive enhancement approaches. This study's findings are anticipated to lay the groundwork for future research endeavors in the realm of tailored interventions for dyslexic learners. By proposing and developing an innovative accessibility framework that integrates haptic elements, this study aims to bridge the gap in meeting the unique learning requirements of dyslexic students within Malaysia's educational context. The outcomes of this research endeavor are expected to significantly contribute to the advancement of inclusive and effective educational practices for dyslexic individuals in Malaysia, aligning with the goals outlined in educational plans and striving towards improved learning experiences for dyslexic students.

1.7 Summary

The chapter sheds light on Specific Learning Disorder, specifically focusing on dyslexia and its profound influence on children's literacy skills and cognitive abilities. It articulates dyslexia as a cognitive condition that significantly impacts reading, writing, and language skills, resulting in challenges related to vocabulary, fluency, and word recognition. There is a strong emphasis on the interconnected nature of reading, writing, and cognitive proficiency, highlighting how these difficulties adversely affect the learning process.

Moreover, it highlights the significance of sensory systems like VAKT and advocates for multisensory techniques, particularly beneficial for dyslexic learners. The chapter draws attention to the scarce use of haptic technology in Malaysia and its untapped potential to improve learning experiences for dyslexic children.

The content culminates by outlining the primary goal of this endeavor: the development of "HapticLearn 1.0". This conceptual model aims to integrate haptic elements to support the development of sensory-motor and cognitive skills among dyslexic children. It intends to serve as a guiding framework for future technologists and educators in crafting accessible learning applications tailored for dyslexic children and their caregivers.

The Table 1.1 shows the summary of the problem statement, research question, research objectives, techniques used to achieve these objectives and the deliverables.

Table 1.1: Mapping of Problem Statements, Research Questions, Research Objectives, Techniques, and Outputs

Problem Statement	Research Questions	Research Objectives	Techniques	Output
Currently, the lack of intervention practices for dyslexic children in Malaysia is twofold; (1) lack of utilization of haptics	What are the haptic interventions practiced on dyslexic children in Malaysia?	To study the existing haptic interventions practiced on dyslexia children in Malaysia.	Literature review, Interviews and observations data collected from Persatuan Dyslexic Malaysia.	Validated list of elements contributing to accessible learning framework for children with dyslexia.
(2) lack of incorporating motor skills and cognitive skills elements in haptics.	How to develop haptic intervention incorporating motor skills and cognitive skills elements for dyslexic children in Malaysia?	To propose an accessibility framework incorporating haptics elements to facilitate the learning process of dyslexic children in Malaysia.	Designing haptic-based practicing activities. Elements mapping	An accessibility framework incorporating haptics element for dyslexic children.
		To evaluate the proposed accessibility framework heuristically with domain experts in Malaysia.	Heuristic evaluation by domain experts, and system effectiveness testing.	Expert feedback, and system effectiveness testing results.

However, within this landscape, the "Problem Statement" surfaces critical gaps in the current intervention practices for dyslexic children in Malaysia. It points out the inadequate utilization of haptic technology and the absence of motor and cognitive skill elements in haptic-based interventions. Haptic technology can enhance the learning experience by providing tactile and kinesthetic feedback, which are particularly beneficial for dyslexic individuals who may have difficulty with traditional visual or auditory learning methods. Existing research and successful implementations of haptic technology in related fields in other countries, indicating its effectiveness and relevancy to the learning interventions and Malaysian context. These deficiencies highlight the pressing need for innovative approaches, such as the incorporation of haptics and comprehensive cognitive and motor skill elements, to better support the learning needs of dyslexic children in Malaysia.

CHAPTER 2

LITERATURE REVIEW

In this chapter, a thorough literature review of the research topic is conducted. The chapter initiates by delving into the core subject of accessible learning and proceeds to explore various aspects including multisensory techniques like visual, auditory, tactile, and kinesthetic approaches, cognitive aspects, and motor skill development for dyslexic learners within the educational landscape of Malaysia. The review encompasses in-depth discussions on the utilization of haptic elements, existing intervention approaches, cognitive models, and motor skill integration in educational practices targeting dyslexic children. Additionally, this chapter critically analyzes the efficacy of current approaches, examines the usability of haptic interventions, and studies the design elements employed in educational settings for dyslexic learners. The findings concluded from this extensive review provide an insightful interpretation aligning with research question one (RQ1), which evaluates the appropriateness of existing haptic intervention models in fostering educational accessibility for dyslexic children in Malaysia. Moreover, a comprehensive survey of recent studies in the field contributes to highlighting the evolving landscape of tailored interventions, emphasizing the current advancements and revealing key research gaps essential for addressing the problem statement outlined in Chapter 1.

2.1 Dyslexia and Accessible Learning

Indeed, understanding dyslexia and adapting to diverse learning styles are crucial in formulating efficacious strategies for learning [32]. Recognizing the unique difficulties faced by individuals with dyslexia and adapting teaching methods to align with their preferred learning styles greatly improves their achievements in both academic and personal endeavors [33].

Providing suitable educational assistance is crucial in empowering individuals with dyslexia to surmount challenges and achieve their maximum capabilities. Ongoing study and encouragement are essential for enhancing our understanding of dyslexia and therefore, developing novel approaches to effectively assist individuals with dyslexia.

Accessible learning refers to the deliberate process of creating courses and implementing teaching methods that accommodate the distinct requirements of individuals from different backgrounds, skills, and learning preferences [34, 35]. It prioritizes inclusion by ensuring that educational content and methods are flexible and beneficial for a diverse range of learners, including individuals with dyslexia and other learning challenges.

Understanding learning styles is essential while considering dyslexia and its influence on education [36]. A learning style refers to an individual's preferred method of acquiring, processing, and retaining information [37]. The styles can differ and include visual, auditory, kinesthetic, and tactile preferences. Significantly, students can possess numerous learning modalities, and these preferences are not inflexible or permanent.

Establishing a connection with dyslexia is crucial to tackling the misunderstandings associated with this disorder, which frequently goes unreported. In order to effectively adjust instructional techniques, educators must have a thorough understanding of the nature of dyslexia. It is important to clarify that not all individuals with dyslexia exhibit the common misunderstanding of universally reversing letters and words, which is an inaccurate assumption [38]. Certain individuals may encounter just negligible difficulties in this particular area.

Furthermore, there is a prevailing misconception that individuals with dyslexia have a lower intellectual capacity or lack intelligence [39]. Dyslexia is a unique learning style that is not dependent on intellectual talents. For example, there could be kids without dyslexia who have lower Intelligence Quotients (IQs) and study at a slower pace compared to persons with dyslexia. Individuals with dyslexia may face challenges in reading and spelling, but they might demonstrate exceptional abilities in comprehending novel ideas and intricate concepts.

Interestingly, techniques that assist dyslexic kids often have positive effects on non-dyslexic pupils as well. Dyslexic students, by virtue of their heightened awareness of inadequate instructional methods or systems, are capable of identifying and indicating areas that require enhancement. Adapting teaching approaches to suit dyslexic learners not only provides them with better support but also improves the overall learning environment for all students.

Understanding the effects of dyslexia on learning is essential, particularly given the difficulties in recognizing dyslexic students who succeed academically but yet face difficulties as a result of their condition. Frequently, dyslexic children who possess high intellectual capabilities may not display significant challenges that would enable teachers to identify their learning disability, so limiting the opportunity to understand and improve the way they learn in an efficient manner[40].

Conversely, dyslexic pupils who are greatly impacted by their condition may encounter stigmatization, being branded as 'slow' or 'dumb,' which discourages them from seeking assistance or obtaining an official diagnosis for their learning problems [41]. Additionally, their exasperation and absence of self-assurance or drive in reaction to educational challenges could be mistakenly perceived as basic behavioral issues rather than suggestive of an inherent learning impairment.

Gaining an understanding of the learning process of dyslexic persons, or their sometimes failure to learn is crucial. In general, individuals with dyslexia succeed in educational settings that integrate physical experiences, demonstrations, experimentation, observation, and visual aids. These methods deal with their preferred learning patterns, improving their understanding and retention of information.

2.1.1 Bloom’s Taxonomy

Bloom's taxonomy will be used as a foundational guide in this study to systematically analyze and categorize the cognitive processes involved in learning and skill development among dyslexic children. By aligning the haptic-based framework with Bloom's taxonomy, this research aims to provide a structured approach for designing and evaluating interventions that target specific cognitive skills, such as remembering, and understanding, thereby enhancing the effectiveness of educational technologies for children with dyslexia. The utilization of Bloom's Taxonomy functions as a clear and structured guide for educators. This framework facilitates the creation of educational experiences that focus on a range of mental abilities, fostering cognitive growth [42]. Bloom's Taxonomy aids educators in organizing learning goals, evaluations, and tasks, ensuring a comprehensive teaching method that caters to various learning requirements, including those of individuals with dyslexia [43].

The cognitive domain focuses on the acquisition and application of knowledge and understanding, which includes tasks such as remembering, understanding, and information analysis. This domain, consisting of six stages - remembering, understanding, applying, analyzing, evaluating, and creating - is commonly used in educational settings to assess and improve cognitive abilities [44].

Researchers highlight the significance of Bloom's Taxonomy as a means to improve both evaluation and the processes of teaching and learning [45]. They promote the utilization of this approach to enhance learners' abilities beyond basic remembering, towards more advanced levels of analysis, evaluation, and creativity. Through the utilization of Bloom's Taxonomy, educators have the ability to direct students towards actively analyzing information, fostering a more profound understanding and the utilization of knowledge in inventive manners.

Furthermore, another research indicates the successful use of Bloom's Taxonomy in online learning platforms [46]. This connection ensures the achievement of learning objectives, especially in digital educational environments. Integrating Bloom's Taxonomy into online learning environments allows for the organization of activities and assessments that encourage different levels of thinking, leading to a more thorough and adaptable learning experience.

2.1.2 Cognitive Development

There is a lack of intervention research in Malaysia that focuses on improving cognitive functioning in children with dyslexia [47]. Previous studies suggest that the majority of researchers in the country have mostly used multisensory and multimedia techniques in dyslexia intervention [48]. The main emphasis has been on language components, specifically the recognition and mastery of the alphabet, as the key results. Nevertheless, there is a conspicuous absence of focus on developing modules specifically designed to enhance cognitive abilities such as attention, memory, and executive function.

Addressing this gap, future local research efforts should focus on addressing cognitive function deficiencies in children with dyslexia. To do this, reading and writing instruction programs designed for kids with dyslexia may need to incorporate elements of mental skills like working memory, attention, and psychomotor speed. Interventions should also be more focused, focusing on specific deficit domains and taking into account a variety of cognitive and language aspects in order to ensure better results.

A comprehensive curriculum that combines cognitive and linguistic abilities will greatly benefit local students with dyslexia in successfully navigating the requirements of the current examination-oriented educational system. The primary focus in designing this module should be on practicality and applicability, ensuring that it can be readily implemented by teachers in schools and is user-friendly for parents to facilitate their child's learning requirements at home.

2.2 Multisensory Technique

The term "multisensory" refers to the process of facilitating learning by engaging multiple senses simultaneously [49]. The utilization of multisensory techniques aids children with dyslexia in utilizing their senses during the learning process, particularly in the areas of spelling, reading, and writing. The multisensory technique involves the incorporation of many senses in the teaching process, hence enhancing the learning experience for the students. When learning occurs through several senses, it enhances students' learning abilities and improves their retention of the material [50]. The majority of instruction in schools is delivered through either visual or auditory means. The multisensory technique is often referred to as the VAKT approach. The four learning style modalities tend to be referred to as VAKT, which stands for Visual, Auditory, Kinesthetic, and Tactile. • Visual: related to the sense of sight; • Auditory: relating to the sense of hearing; • Kinesthetic: including physical touch and movement; • Tactile: referring to the child's interaction with items through touch. The most effective method of instruction involves engaging the student's various senses, particularly tactile and kinesthetic experiences. This will provide the student's brain with touch and kinesthetic memories to retain, in addition to the visual and auditory ones [51]. Populations undergo constant changes and adjustments in response to their surroundings, whereas species undergo divergence, resulting in the emergence of wholly novel lineages.

2.2.1 Multisensory Techniques and Brain Function

The multi-sensory learning technique maximizes the utilization of several senses, which in turn enhances the brain's connectivity and associations. This facilitates memory and learning by promoting the retrieval of knowledge in the future [52]. The sensory memory system allows individuals to retain sensory information long after the end of the initial stimulus. Working memory is a conscious cognitive system that has a limited capacity. Its function is to temporarily store, process, and manipulate information [53]. They entirely agree on the method of information processing. Cognitive activities, such as reasoning and decision-making, rely on information processing as a fundamental component. By actively involving our senses, we provide the brain with greater chances to interpret information according to our personal preferences. By using several senses, including those of students with dyslexia, it is possible to enhance their potential by combining conventional teaching methods with these sensory capabilities [5]. Dyslexic children benefit from being taught using multimodal techniques, such as including visual, auditory, tactile, and kinesthetic elements. This type of instruction enables them to learn at a faster pace, improve information retention, and apply concepts more easily to new learning situations [21]. Figure 2.1 demonstrates that multisensory techniques involve learning through the use of vision, hearing, movement, and touch.

Dyslexia is most effectively addressed through the use of multisensory techniques.

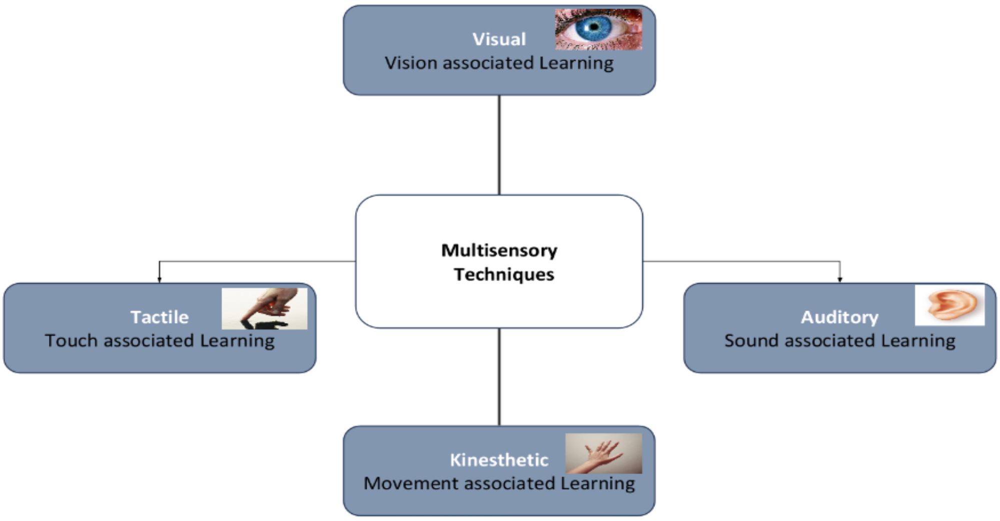


Figure 2.1: Multi-sensory Techniques and Associated Learning

2.2.1.1 Visual

The visual cortex, seen in Figure 2.2, is responsible for sensory-motor functions in the brain. The visual cortex, located in the Occipital lobe of the brain, regulates visual functions [54]. Vision functions as the main channel for guiding physical reactions and transmitting information. It includes not only the ability to see clearly but also other important abilities necessary for performance [55]. Any errors or delays in the processing of visual signals might have a negative effect on overall performance. Individuals with dyslexia frequently face difficulties in visual memory and perception as a result of underlying cerebral function impairments [9]. Visual memory is an essential element in the processing and retention of activities that include actions. Optimal visual acuity is especially vital for the challenging activity of reading.

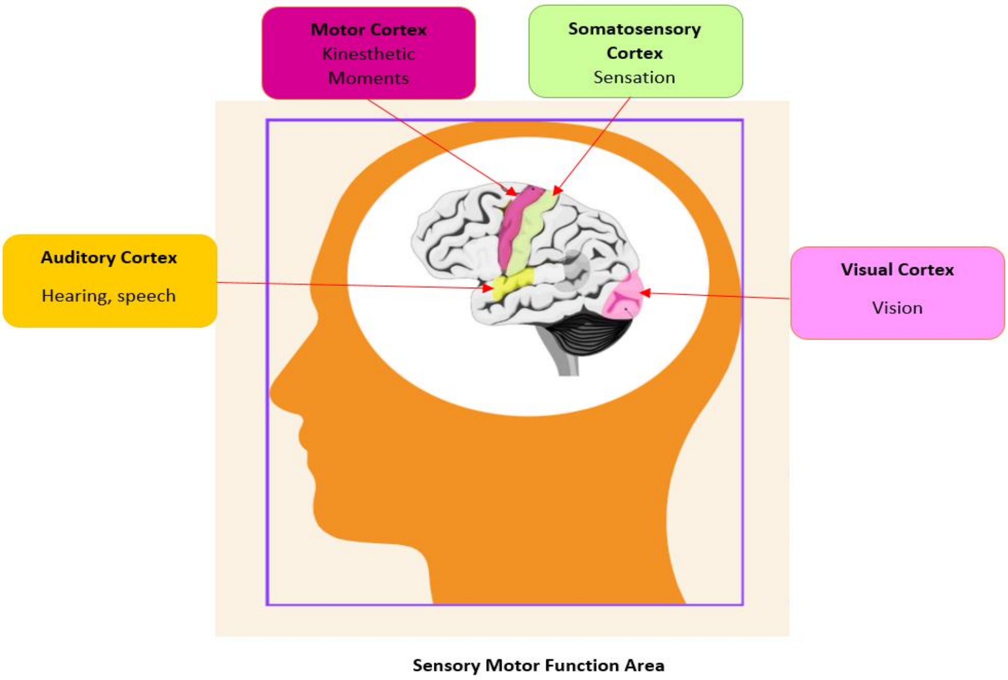


Figure 2.2: Sensory Motor Function Areas

2.2.1.2 Auditory

The auditory cortex, located in the temporal lobe of the brain, serves as the sensory-motor function area for sound, as depicted in Figure 2.2 [56]. Sound offers us a diverse range of information regarding the external environment. Neural processing enables the conversion of sound waveforms entering the ear into cortical representations [56]. These representations are believed to make the important features of sound apparent for action. The auditory stimulus prompts the body to respond and transmits data.

2.2.1.3 Kinesthetic

The motor cortex in the brain, as seen in Figure 2.2, is responsible for the sensory-motor function of movement. Kinesthetic refers to the bodily movements employed by a learner to engage with their surroundings. The human kinesthetic system possesses the capacity to process, integrate, and retain information, relying on the direct awareness of motion impulses [23]. The motor cortex in the brain, as seen in Figure 2.2, is responsible for the sensory-motor function of movement. Kinesthetic refers to the bodily movements employed by a learner to engage with their surroundings. The human kinesthetic system possesses the capacity to process, integrate, and retain information, relying on the direct awareness of motion impulses [22]. However, it is crucial to bear in mind that our human kinesthetic system not only performs sensory functions, such as processing motor impulses but additionally interprets and retains motor nerve signals. Learning is most efficient when individuals engage in kinesthetic activities that involve the activation of their large or gross motor muscles [51].

2.2.1.4 Tactile

The somatosensory cortex of the brain, as depicted in Figure 2.2, is responsible for processing touch-related sensory and motor functions. The tactile sensation is the most complicated and fundamental sensory system. It possesses the capacity to convert information from the external physical world into internal sensations [22]. In humans, touch activates a neural network responsible for processing sensory input, including a key hub located in the Superior Temporal Sulcus (STS). The vulnerable status to individual diversity in processing tactile sensations is widely acknowledged in the STS area.

2.3 Related Work on Learning Interventions

2.3.1 Non-technological

There are plenty of non-technological methodologies accessible for facilitating the educational development of dyslexic children. These conventional methods demonstrate a beneficial impact on the educational progress of children with dyslexia. Primarily, these practices center on the skills of reading, writing, handwriting, and spelling. The practices utilized different mixes of the VAKT approaches, as indicated in Table 2.1. These strategies involve processing sensory information and generating reactions that promote cognitive development. The execution of the VAKT approach involves several tasks and activities such as word tracing, skywriting, writing on the wrist, phoneme identification, rhyming repetition, and finger drawing of grapheme shapes.

Table 2.2: Summary of Non-technological Interventions

Sr.No	Ref	Modalities used				Effects of Approaches	Study Approach
		Visual	Auditory	Kinesthetic	Tactile		
1	[57]	✓	✓	✓	✓	Oral reading and reading comprehension	Quasi-experimental
2	[58]	✓	✗	✓	✗	Reading, spelling, and handwriting	Single-case intervention study
3	[59]	✓	✗	✗	✗	Reading	Case-control study
4	[60]	✓	✓	✓	✓	Reading, writing, and spelling	Quasi-experimental
5	[61]	✓	✓	✗	✗	Reading	Qualitative case study
6	[62]	✓	✓	✗	✗	Reading and spelling	Correlational study
7	[63]	✓	✓	✓	✗	Reading, writing, and spelling	Experimental study
8	[64]	✓	✓	✗	✗	Reading and spelling	Qualitative and Quantitative study
9	[65]	✓	✓	✗	✗	Spelling	Qualitative study
10	[66]	✓	✓	✓	✗	Reading and writing	Experimental study
11	[67]	✓	✓	✗	✗	Reading	Longitudinally study
12	[68]	✓	✓	✗	✗	Reading	Longitudinal study
13	[69]	✓	✓	✗	✗	Reading	Experimental study

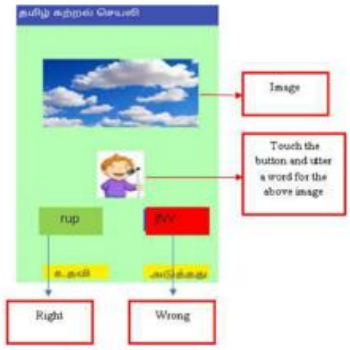
A group of researchers from Jordan [57], employed the VAKT approach to investigate its impact on the oral reading and reading comprehension abilities of children with dyslexia. The study used a Quasi-experimental methodology, incorporating pre and post-test measuring phases. The study involved the division of 39 dyslexic children into two groups: a control group consisting of 19 children, and an experimental group consisting of 20 children. The experimental group engages in targeted educational activities, including word tracing, skywriting, wrist writing, including the word in passages, visually manipulating words, and utilizing teaching resources such as word cards, highlighted and colored pens, mirrors, sand, and whiteboard. The control group participated in the standard curriculum classes at the dyslexia center. The findings of this study indicate that the experimental group exhibited greater enhancement in both oral and comprehension reading compared to the control group. The study's data was limited to categorical data, hence it is recommended to utilize continuous scale assessment. Additional research is required to investigate the suitability of using the VAKT approach in educational institutions and at-home environments.

A study conducted in Belgium [28], found that finger-writing intervention had a greater positive impact on reading, spelling, and handwriting ability compared to visual discrimination intervention. This study used the single-case intervention technique, which includes pre and post-test measuring stages. For their research, a group of five children diagnosed with Developmental Language Disorder were chosen. These children were then divided into two separate intervention groups, and each child received personalized finger-writing intervention for a duration of two months. The finger-writing intervention includes many tasks, such as tactilely detecting the graphemes and letters and incorporating the corresponding phoneme inside the syllable of the word. The identical intervention activities were executed, with the exception that the two finger-writing tasks were substituted with two visual discrimination tasks. The children's performance was evaluated both prior to and following the treatment, with a focus on reading, spelling, handwriting, and phonological awareness. The study features a small number of participants and a limited number of items in the grapheme reading test and handwriting training, which negatively impacts the accuracy of the results.

In this study, a team of researchers from Malaysia [59], In their study [59], investigated the efficacy of basic visual aids in improving the reading abilities of children with dyslexia, as depicted in Figure 2.3(a). A case-control research was done to evaluate reading skills at four different time points: baseline, 2nd week, 6th week, and 12th week. A total of 80 dyslexic children, ranging in age from 8 to 11 years, were carefully chosen for the study. These participants were then placed into four distinct groups: a control group and three experimental groups, each allocated with a different tool the typoscope, Visual Tracking Magnifiers (VTM), and magnifier. The analysis is conducted by evaluating the duration required to finish reading the text and the rate of errors made throughout the reading process. The magnifiers and VTM group exhibit a substantial boost in reading performance, with a reading speed that is 2.5 times faster compared to the typoscope and control group.

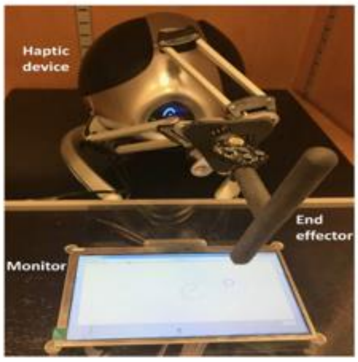
(a) Learning with Magnifiers

(b) Learning with Toys



(c) Learning with Game

(d) Learning with App



(e) Learning with Haptic Device

(f) Learning with Haptic Device

Figure 2.3: Components used in Interventions

In this study [70], a team of researchers from Malaysia developed two programs that utilize many senses and are based on phonics. These programs aim to improve the reading, writing, and spelling abilities of children who struggle with reading. There are two phonics programs available: SMARTER*phonics for English and foniks*PINTAR for Malay. This study used the quasi-experimental approach, incorporating both pre and post-test measures. This study includes a total of 28 people who experience difficulty in reading. A total of 16 participants were assessed in the English language, while 12 people were assessed in the Malay language. The youngsters employ multimodal techniques that involve several activities, such as identifying letters using bottle caps (as depicted in Figure 2.3(b), mentally envisioning letters through sky-writing, and stimulating finger nerves through the use of a tactile mat while writing. The analysis was conducted using task duration as the primary measure. These techniques enhance the pedagogical approach of educators who instruct language to children with reading difficulties.

Another Spanish group of researchers in his study [63], examines the correlation between spelling and handwriting challenges in children with dyslexia through the utilization of visual, auditory, and kinesthetic tasks. The study employs an experimental methodology, wherein dyslexic children were compared to a control group of the same age and reading level. This study included a group of 20 dyslexic children who underwent assessments including a spelling to-dictation task, an alphabet writing task, and two graphic tasks. The statistical study encompassed many parameters, such as writing delay, overall writing duration, writing speed, and speed peaks. The results revealed that children with dyslexia had slower and less accurate written responses compared to typically developing students. However, their spelling abilities were in line with their reading skills.

In this study [64], a team of researchers from the Netherlands investigated the reading and spelling abilities of children with dyslexia following a phonics-based spelling intervention. The researchers specifically tested the children's proficiency in reading both real words and pseudo words. Additionally, they examined the degree of consistency in the intervention's response across different cognitive traits. The study employs both qualitative and quantitative methodologies. This study included a group of 54 Dutch children. Prior to the study, the parents and teachers were asked to fill out questionnaires detailing the child's developmental and current challenges. Additionally, the parents were interviewed to eliminate any other possible factors that could contribute to the child's difficulty in reading and spelling. These students received a systematic intervention that included activities focused on reading and spelling, as well as phonics instruction. Throughout the pre-test to post-test period, there were beneficial effects on the speed of reading words and pseudo-words, as well as on word spelling. This study concludes that the combined reading and spelling intervention positively enhances the efficiency of word and pseudo-word reading, as well as word spelling, regardless of cognitive traits. Although the study yielded positive results, it also revealed that reading and spelling challenges in children with dyslexia continued to exist even after an intervention, with reading issues proving to be notably more persistent.

In this study [65], a team of researchers from the Netherlands examined the responses of dyslexic children by analyzing the phonological, morphological, and orthographic spelling errors made by these children before and after they underwent a phonics-based spelling intervention. Additionally, inquiries were made to determine if semantics could have a compensating impact on the results of the intervention. The study included a total of 52 dyslexic children and 105 Typically Developing (TD) children, all of whom were native Dutch speakers. The results indicated that both children with dyslexia and typically developing children produced a greater number of errors related to morphology compared to errors related to orthography or phonology, prior to the intervention. Children with dyslexia exhibited a higher number of errors in all areas, with phonological errors demonstrating the most significant disparities when compared to children with typical development. Children with dyslexia who possessed more well-formed semantic representations demonstrated reduced levels of phonological, morphological, and orthographic errors compared to those with less developed semantic representations. This study suggests that dyslexic or at-risk children who are in the process of developing their spelling abilities may have positive effects from semantic stimulation.

A researchers group from Brazil in his study [71], employed behavioral and objective measurements to evaluate the impact of a phonological rehabilitation program on the reading and writing abilities of dyslexic children. A total of 20 children diagnosed with dyslexia, aged between 8 and 14, were included in this research. The children were categorized into two groups: group 1, consisting of those who took part in the program, and group 2, comprising 10 individuals who didn't take part in the rehabilitation. The evaluation included pre and post-testing to measure working memory, phonological awareness, rapid naming, word and non-word reading and writing skills, thematic writing ability, and auditory evoked potential. A total of 24 sessions were conducted for the phonological reading and writing rehabilitation program. These sessions took place twice a week and lasted for 30 minutes each. A notable disparity was noted between the pre and post-test results. The written language skills of the dyslexic children showed rapid improvement due to the phonological remediation program, which is a highly successful therapeutic technique.

2.3.2 Technological

In the current era of digital technology, there are numerous technological methods aimed at facilitating the education of children with dyslexia. Researchers implemented technology into the educational methods for dyslexic children, enhancing the teaching approach and simplifying the learning process for students. During the Coronavirus Disease of 2019 (COVID-19) pandemic, when schools were shut down, dyslexic educators extensively utilized these programs in online classes. The technological methods are mostly categorized into two groups: Apps/Games and Haptics.

2.3.2.1 Apps and Games

The increasing use of laptops and mobile devices presents a potential tool for creating systemic methods to support children with special needs. Students can learn easily and engagingly with the help of apps and games. Table 2.2 displays that the majority of apps and games offered both visual and audio ways. Children with dyslexia benefit from apps and games in terms of phonological awareness and grapheme-phonemes. Children with dyslexia get more interested in this technique as well. From an educational perspective, applications and games reduce the amount of time students need to practice skills and provide them the chance to work on them alone [72]. High-quality research from all around the world demonstrates how important games and apps are to children with dyslexia learning.

Table 2.3: Summary of Apps and Games Interventions

Sr.No	Ref	Modalities used				Effects of Approaches	Study Approach
		Visual	Auditory	Kinesthetic	Tactile		
1	[73]	✓	✓	×	×	Reading	Longitudinal study
2	[74]	✓	✓	×	×	Reading	Case-study
3	[75]	✓	✓	×	×	Spelling and Speech	Qualitative and Quantitative study
4	[76]	✓	✓	×	×	Reading	Experimental study
5	[77]	✓	✓	×	×	Reading	Experimental study
6	[78]	✓	✓	×	×	Reading	Pilot study
7	[79]	✓	✓	×	×	Reading and writing	Case study
8	[80]	✓	✓	×	×	Reading, writing, and pronunciation	A Pilot study with a case study approach
9	[81]	✓	✓	×	×	Reading	Clinical trials
10	[82]	✓	✓	×	×	Reading	Exploratory study
11	[83]	✓	×	×	×	Reading	Experimental study
12	[53]	✓	✓	×	×	Reading, & attention control	Experimental study
13	[84]	✓	✓	×	×	Reading, phonological awareness	Case study
14	[85]	✓	✓	×	×	Reading comprehension	Clinical study
15	[86]	✓	✓	×	×	Reading and visual attention	Clinical study

In this study [87], Swiss researchers developed a computer game utilizing grapheme-phoneme principles to aid dyslexic children with their reading abilities. This longitudinal study had a total of 34 dyslexic children who were carefully chosen and separated into two groups: the control group (N=16) and the training group (N=18). This game incorporated several tasks such as rhyming exercises, constructing words, and forming sentences. The GraphoLearn game enhances the reading skills and instructional methods of dyslexic youngsters by utilizing phonological decoding and phoneme awareness.

Another team of researchers from the Philippines [76], created a game that aims to determine the particular aspects of a game that cater to the learning requirements of dyslexic children. These elements are intended to be incorporated into the Larolexia application, as shown in Figure 2.3(c). The game utilizes aural and visual techniques. The study seeks to ascertain the enhancement in the reading proficiency of children with dyslexia. This study used an experimental methodology that includes both a pre and post-training assessment. To enhance reading performance, several game components such as narrative, objectives, incentives, scoring, accomplishments, feedback, and progression through multiple stages are employed. The T-test is utilized for the examination of before and post-test data. This game is regarded as an intervention aimed at improving the reading abilities of children with dyslexia.

Another team of Norwegian researchers [77], developed a dichotic listening application to demonstrate the impact of auditory training on dyslexic children. For this experimental study, a total of 47 children, all 8 years old, were chosen. A total of 31 children without any documented learning difficulties were chosen and split into two groups: the control group (N=16) which did not get any training, and the experimental group (N=15) which received training. The training was provided to a group of 16 individuals who were specifically chosen due to their challenges in reading and writing. This software incorporates many auditory exercises, including 36 combinations of stimuli, pairs of homonyms, syllables played through earbuds, and identifying the right syllables. To summarize, this study found a correlation between strong language processing and verbal working memory capabilities and the ability to maintain concentration and shift attention effectively.

In this study [78], Indian researchers developed a game-based remedy designed to reduce the dependence on experts by providing a standardized platform that can assist both dyslexic experts and children. This pilot study incorporates various training and testing activities, such as tasks involving word-sound relationships, tasks involving letter-word-sound relationships, tests for simple word identification, constructing a sight word from disorganized letters, and requiring accurate pronunciation through verbalization. The evaluation findings of the proposed game-based intervention were deemed satisfactory, indicating its potential as an effective learning tool for dyslexic children.

In this study [88], Indian researchers built and developed a mobile application, depicted in Figure 2.3(d), with the aim of enhancing and facilitating the reading and writing abilities of children with learning disabilities. This study adopts a case study methodology, wherein two distinct learning groups, aged 9-

12 and 13-15, are chosen. This application presents a voice-enabled interface that is designed for children with reading disabilities. It allows the child to have text read aloud to them as many times as they need. Another feature is the implementation of voice recognition technology specifically designed for children with writing disabilities. This function allows the child to input speech, which is then converted into written text. The evaluation of children's proficiency in learning Tamil words is conducted by pre and post-assessments, which involve assessing their ability to read words, recall words, demonstrate reading fluency, and exhibit quick naming skills. The smartphone application aims to assist children with learning disabilities by enhancing their reading and writing skills while also providing motivation.

In this study [89], researchers create a game using the Cosmic Sounds toolkit to enhance the learning experience of children with dyslexia. This research employs a case study approach to enhance the phonological awareness abilities of dyslexic children aged 9 to 12 years by providing support through instructional techniques. Various strategies are employed to enhance the phonological awareness abilities of dyslexic children, including the utilization of blocks to combine words, exercises involving words with absent consonant digraphs, identification of sounds and symbols, letter blends, word decomposition, and recognition of open and closed vowels. The cosmic sounds game enhances teachers' ability to increase dyslexic children's phonological awareness abilities and engagement in learning.

A group of Italian researchers [81], restructured the rehabilitation protocols for Learning Disorders (LDs) in response to the COVID-19 pandemic.

Tele-rehabilitation offered a means to continue training therapies while enabling social isolation during the lockdown time. During a period, an investigation was conducted to evaluate the effectiveness of tele-rehabilitation and in-person dyslexia rehabilitation. The study focused on a rhythm-based reading intervention and was carried out on a modest scale. Thirty children, aged 8 to 13, diagnosed with developmental dyslexia, were divided into two groups: one receiving in-person rehabilitation and the other receiving tele-rehabilitation. Both groups underwent a rhythm-based reading intervention called Rhythmic Reading Training (RRT) for ten sessions, each lasting 45 minutes. The sessions were held every two weeks and were supervised by a qualified professional. The results indicated that both tele-rehabilitation and in-person rehabilitation were effective in improving reading skills and rapid automated naming in children with dyslexia. Based on this information, it has been demonstrated that RRT is effective regardless of whether it is administered remotely or in person. These findings provide evidence for the effectiveness of telemedicine in treating LDs.

2.3.2.2 Haptics

The sector of education has seen a tremendous transformation due to digitalization and rapid technological breakthroughs, leading to a revolution in teaching and learning methods. One notable and encouraging technology, known as "Haptic," emerged among these significant changes. Haptic refers to the perception and control of an object by means of touch. Several haptic gadgets have already been introduced to facilitate children's learning. The primary purpose of the haptic device is to transmit the operator's external force to the virtual world, enabling the operator to perceive and experience the force within the virtual environment. This ensures that the operator feels a sense of realism and immersion when interacting with the virtual environment. Table 2.3 displays the utilization of different combinations of modalities across a range of jobs and devices.

Table 2.4: Summary of Haptic-based Interventions

Sr.No	Ref	Modalities used				Effects of Approaches	Study Approach
		Visual	Auditory	Kinesthetic	Tactile		
1	[90]	✓	✗	✓	✓	Handwriting skills	Longitudinal experimental study
2	[24]	✓	✗	✓	✓	Handwriting skills	longitudinal experimental study
3	[91]	✓	✗	✓	✓	Prospective control of movements used in drawing performance.	Experimental study
4	[25]	✓	✗	✓	✓	Handwriting skills	Experimental study
5	[92]	✓	✓	✓	✓	Read musical notation	Experimental study

A group of researchers from the US [91], has created an automated technique that utilizes haptic-based tasks to enhance the manual compliance control and prospective control of the stylus shown in Figure 2.3(e). For this empirical investigation, a sample of 16 children aged 7-8 years was chosen, consisting of 8 children diagnosed with Developmental Coordination Disorder (DCD) and 8 TD children. Pre and post-training performance comparisons were conducted, and individuals underwent a 5-week training program. Various levels of training activities were offered, such as guiding a bead down a Three Dimensional (3D) wire path that is magnetically attractive to the stylus. The difficulty of the path increases as tasks are completed. The implemented automated technique enhanced children's proficiency in drawing and handwriting.

The study [90], conducted by researchers from Dubai examined the impact of several haptic guidance techniques on the handwriting abilities of typically developing children. The study employed a 9-week longitudinal experimental design, with a total of 42 children aged 4-7 years participating. The participants were categorized into five groups: full guidance (N=9), partial guidance (N=9), disturbance guidance (N=8), no haptic guidance (N=8), and the control group (N=8). The researchers devised haptic guidance systems for the four groups, except the control group, whereby distinct computed haptic force was implemented. Each child underwent pre and post-training assessments that consisted of 10 characters (e, a, r, i, o, t, n, s, b, and g). These characters were categorized into levels of complexity: low, medium, and high. Each student was assigned 5 sets of these characters according to their guidance category, with the exception of the control group. The results were assessed by three teachers, indicating that for activities with high complexity, the disruption haptic assistance proved to be the most effective. The complete and partial haptic guiding yielded optimal outcomes for activities of medium difficulty, while full guidance was most successful for low-complexity tasks. Furthermore, the efficacy of the haptic assistance is dependent upon the level of difficulty of the handwriting exercise.

Another team of researchers from Dubai [24], developed a training platform that utilizes haptic feedback, as depicted in Figure 2.3(f), to assist adults and children in improving their handwriting skills. This study adopts a longitudinal experimental study design, involving a group of 12 children who exhibit intellectual challenges, fine motor challenges, and difficulties with gripping objects. The children were divided into two distinct groups. The participants who completed the haptic-based guided training, along with the pre and post-training test, were the target group. The control group, on the other hand, only participated in the pre and post-training pencil-and-paper test. The students engage in the experiment on a weekly basis for a duration of nine weeks. During this time, they will complete various activities such as replicating numbers, letters, shapes, and emojis. This study concludes that the efficacy of haptic guiding is significantly influenced by the training activities that are supplied. Haptic guiding significantly enhances the motor function of handwriting in children with cognitive and fine motor deficiencies when the activity is visually familiar but physically demanding.

In this study [25], a team of researchers from Canada and Columbia employed a Haply force feedback device and a Writely program to ascertain the impact of force feedback on the handwriting of the non-dominant hand. This experimental investigation consisted of two daily sessions over a period of seven days, with each session comprising 28 tasks involving writing the alphabet. This study employs three feedback conditions, namely user guidance, anti-guidance, and no-force feedback, to conduct writing tasks. The writing exercise comprises many activities involving the creation of letters using a sequence of line segments, with the forces providing guidance throughout the writing process. Data is gathered prior to, during the course of, and subsequent to the experiment for evaluation purposes. Haply and Writely have a beneficial impact on the visual aesthetics of non-dominant handwriting, specifically enhancing its smoothness and consistency. This is achieved through the controlled application of jerk and acceleration during the writing process. It is recommended to conduct additional research in order to maximize the utilization of the Haply device and establish a comprehensive experimental methodology.

2.4 Summary

The review findings indicate that there are now two types of interventions being used to support the learning of students with dyslexia: technological and non-technological. However, despite the advancements in technology during this digital age, there has been a growing interest and adoption of non-technological techniques by educators, students, and researchers this shift may be as a result of the foundation of intervention approaches [93, 94]. One noteworthy finding is that, as Tables 2.1, 2.2, and 2.3

demonstrate, every study that was included in this evaluation used the VAKT approach for intervention in different combinations.

Research has shown that various people have diverse preferences when it comes to learning. Studies show that those who learn well visually prefer to digest information using charts, graphs, and other visual aids [95]. When they can see and observe information, they learn best. Effective learning occurs for auditory learners when they communicate verbally and listen [96]. Information is more easily understood by them when it is discussed, delivered orally, and through lectures. Kinesthetic learners absorb information through doing and participating in hands-on activities [97]. When kids can engage in physical tasks related to the subject matter, like in simulations or experiments, they do best. Similar to kinesthetic learners, tactile learners especially pick up information through touch and bodily experiences [98]. Activities that require them to manipulate things or textures are beneficial to them. VAKT approaches have been shown to increase motor and sensory processing, release neurotransmitters, activate neuronal pathways, and strengthen synaptic connections, among other primary aspects of these interventions [57]. It is possible to boost brain activation and improve students' learning experiences by implementing VAKT approaches into teaching practices [99]. These techniques enhance the brain's innate ability to learn and adapt by activating a variety of sensory channels and encouraging neuronal plasticity.

When it comes to designing and implementing interventions for dyslexic students, it is advisable to stimulate all the VAKT processing areas in the brain. This is because dyslexic students struggle with processing information. The multimodal technique is more effective in stimulating many regions of the brain. Several researchers employed the various VAKT modalities, which are incorporated into distinct modules. However, this teaching technique is notably slow and poses significant challenges for instructors. Therefore, it is advisable to incorporate all modes of VAKT learning in a single module as an intervention. Research indicates that providing students with timely feedback and advice significantly enhances their learning outcomes [100, 101]. The intricate correlation between the design and the timeliness of feedback, advice, and support provided to students during the learning activity or assignment is the root cause of the difficulties encountered by learners in any subject matter [101]. Another recommendation is to incorporate haptic technology for the implementation of the recommended intervention. Haptics, when combined with apps/games, can offer real-time visual, auditory, tactile, and kinesthetic feedback and guidance, which is currently lacking in both apps/games and non-technological interventions on their own.

CHAPTER 3

METHODOLOGY

This chapter outlines the methodology employed to accomplish the research goals established in Chapter 1. The chapter begins with a flow chart illustrating the number of phases and the task definition contained within each stage. The problem is identified and the study's purpose is established. This is then followed by a concise explanation of the aims of the proposed solution in addressing the research topic. The strategies used to achieve the first objective of the study have also been justified. Next, the techniques employed in developing the proposed conceptual model to accomplish the second objective of the study are outlined. The demonstration method and evaluation setup of the conceptual model are explained to illustrate the techniques used to accomplish the final objective of the study.

3.1 Research methodology

In this research, the design science methodology has been employed, primarily chosen for its problem-solving orientation [102, 103]. This methodology is characterized by its ability to devise effective solutions, particularly when a project heavily relies on human cognitive capabilities [103, 104]. Design science encompasses two distinct classes: "design as research" and "researching design" [103]."Design as research" primarily aims to contribute knowledge by emphasizing innovation within a specific domain, whereas "researching design" concentrates on developing methods that are applicable across different domains [103]. Notably, "design as research" has been widely utilized in the fields of information technology and computing, while "researching design" has gained traction, particularly in architectural and engineering practices [103].

This methodology involves six key activities: (i) problem identification and motivation; (ii) objective definition; (iii) design and development; (iv) demonstration; (v) evaluation; and (vi) communication [102, 103]. These segmented activities align well with the objectives of this research, emphasizing innovation and the necessity of a demonstration to support the generated knowledge. In this study, a prototype has been created to serve as a demonstration of the contributed knowledge, specifically reflecting the elements of a conceptual model.

It's important to note that design science can be both a research approach and a research methodology, depending on its degree of adoption in a given research context [103, 105]. Many projects in the realm of information systems have favored design science as a methodology due to its well-defined structure of the six activities, which provides a systematic workflow, and its insistence on the requirement of a demonstration, typically in the form of a prototype or another tangible representation, to support the developed theory [106, 107].

In this particular study, "design as research," belonging to class one of design science, has been adopted as the research methodology. The processes within this approach have been illustrated in Figure 3.1 (methodology flowchart), tailored to fit within the framework of the six activities characteristic of design science methodology [103].

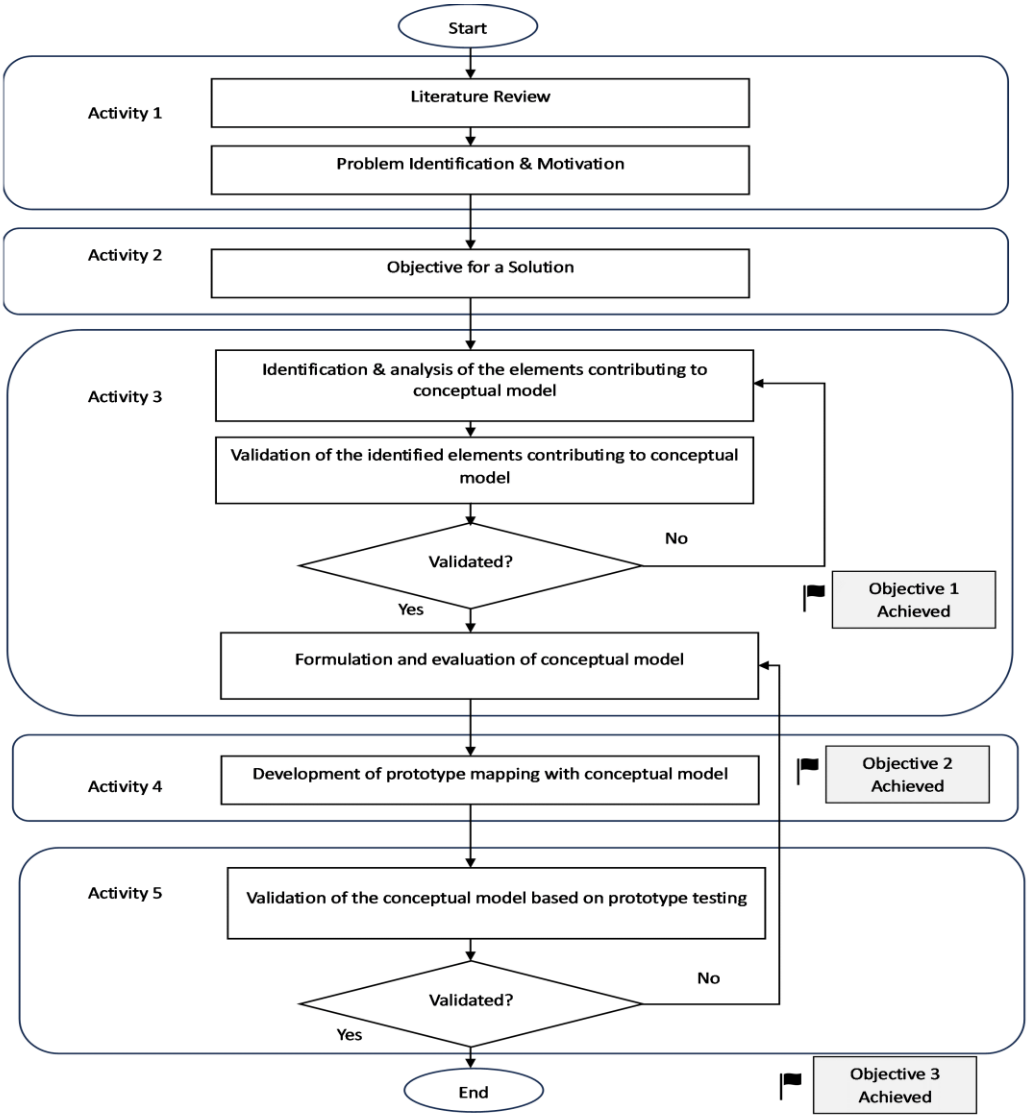


Figure 3.1: Methodology of the Research

3.1.1 Activity 1: Problem Identification and Motivation

The initial step within the design science methodology involves the clear delineation of the problem statement and the determination of the significance of potential solutions [102, 108, 109]. At this stage, it's essential to have a general expectation regarding the solution, as it serves to motivate the researcher to achieve the research objectives and piques the interest of prospective users in accepting the proposed solutions [104]. The primary objective of this process is to enhance the understanding of the relationship between the solution and the research problem for both the researcher and the users [104].

The problem statement outlined in section 1.2 reads as follows: Currently, the lack of intervention practices for dyslexic children in Malaysia is twofold; (1) utilization of haptics and (2) incorporation of motor skills and cognitive skills elements in haptics. This statement highlights the existing challenges in addressing the needs of dyslexic children in Malaysia. Specifically, there is a gap in intervention practices, which involves the utilization of haptic technologies and the integration of motor skills and cognitive skills elements within haptic interventions.

Consequently, the proposed solution to address this issue involves the development of an intervention model that incorporates haptic technologies to enhance the learning experience for dyslexic children in Malaysia. This solution is designed to capture, analyze, and comprehend the specific learning preferences and challenges of dyslexic children, translating these findings into a conceptual model. The components within this conceptual model underwent validation and verification through prototype testing and expert evaluation to ensure that it serves as a guiding framework for the development of effective intervention practices for dyslexic children, which fully leverage haptic technologies and encompass motor and cognitive skill elements.

3.1.2 Activity 2: Define the Objective for a Solution

During this activity, it is essential to provide a comprehensive explanation of the research question and the underlying rationale for the objectives of the proposed solution [102, 104, 108].

The objective of the proposed solution is to formulate a conceptual model that serves as a guide for practitioners involved in designing computer applications for dyslexic children in Malaysia. The primary rationale behind this objective is to ensure that haptic interventions effectively address the specific learning needs of dyslexic children, ultimately enhancing their learning experiences. The tangible outcome of this solution is the development of a prototype, as outlined in activity 4 of the methodology. This prototype will undergo testing with the target group of users to establish an improved and accessible learning platform for dyslexic children.

The efficiency and effectiveness of current solutions are paramount in this section [102, 104], and a preliminary investigation has been conducted to address these aspects. This section also addresses the first research question, 'What are the haptic interventions practiced on dyslexic children in Malaysia?' The primary aim of the observation, interviews, and Systematic Literature Review (SLR) was to conduct an in-depth examination of dyslexic children's learning experiences with technology specifically haptic interventions. This comprehensive analysis was carried out to identify the challenges faced by dyslexic children in Malaysia when it comes to haptic interventions, thus highlighting any inefficiencies in the existing solutions. The details of the observation, interviews, and SLR setup have been provided in section 3.2.1, and the results of these findings have been incorporated in section 4.1. The findings of this phase will help achieve the first research objective of the study, 'To determine the existing haptic interventions practiced on dyslexic children in Malaysia.'

3.1.3 Activity 3: Design and Development

The third stage involves the design and creation of the research artifact [102, 103]. The term 'artifact' encompasses constructs, models, methods, instantiations, or features of technical, social, and/or information resources [104]. In this phase, the focus is primarily on developing the conceptual model, while the actual construction and demonstration of the prototype are addressed in Activity 4. The artifact plays a pivotal role in enhancing the learning experience of dyslexic children in Malaysia, particularly concerning the second research question, 'How to develop haptic intervention incorporating motor skills and cognitive skills elements for dyslexic children in Malaysia?' This question delves into methods for developing haptic interventions that incorporate motor skills and cognitive skills elements to improve the learning experiences of dyslexic children. Consequently, the artifact represents the realization of the second research objective of the thesis, which is 'To develop an accessibility framework incorporating haptic elements to facilitate the learning process of dyslexic children in Malaysia.'

This phase involves four significant tasks: (i) identifying and analyzing the elements contributing to learning ease (section 4.1), (ii) validating the identified elements contributing to learning ease (section 4.1), (iii) formulating the model (section 4.2), and (iv) evaluating the components within the

HapticLearn 1.0 model (section 4.3). The evaluation of the components in the learning ease model is a crucial component of the third research objective of the study, which aims to 'evaluate the proposed model heuristically with domain experts in Malaysia.' These tasks collectively represent the development of the model intended to facilitate the learning process of dyslexic children in Malaysia.

3.1.4 Activity 4: Demonstration

As described in Activity 3, the process of developing and validating the prototype is detailed in Activity 4. During this phase, it is crucial to demonstrate the prototype's ability to effectively address specific challenges identified in the study [102-104]. The structural design of the prototype and its seamless integration with the conceptual model as a functional component are comprehensively documented in section 5.1.

To illustrate the prototype's impact in addressing one of the research inquiries, consider the following scenario. At the outset, individuals with dyslexia encountered obstacles in their learning journey, a challenge that came to light during the literature review. However, the implementation of the prototype has empowered users with dyslexia to enhance their learning autonomously, even in the absence of an instructor. This transformation embodies the essence of our research endeavor, which aims to foster more effective and accessible learning experiences for individuals with dyslexia.

3.1.5 Activity 5: Evaluation

The fifth phase assesses the effectiveness of the framework in addressing the research problem [103, 104]. The outcomes of the prototype testing are obtained during the pre-data and post-data stages, demonstrating the extent to which the identified issues have been resolved [102-104]. Various measurable techniques can be employed to gauge the degree of success of the framework in achieving the solution's objectives [104]. The evaluation phase consists of three main components: (a) Pre-data, (b) Post-data, and (c) Expert evaluation.

Initially, pre-data tasks were conducted in the research to highlight the challenges faced by individuals with dyslexia. Subsequently, prototype testing was carried out at the conclusion of the research to showcase the improved educational interventions following the implementation of the prototype (Chapter 5). The evaluation of the prototype contributes to the fulfillment of the third research objective, which is 'To evaluate the proposed model heuristically with domain experts in Malaysia.' Notably, the results of the prototype testing demonstrate a marked improvement, indicating that a prototype constructed based on the elements of the conceptual model provides an ease platform for learners with dyslexia. The prototype is then evaluated by IT experts to assess the relevance of the included elements and the ease of development.

3.1.6 Activity 6: Communication

The final activity in the design science methodology revolves around communicating the problem, objectives, empirical findings, and research outcomes through scholarly publications [103, 104]. To date, one of the research objectives has been successfully published in a reputable journal, while two more objectives are currently in the process of being prepared for publication. Comprehensive information regarding these articles and their status can be found in Appendix D the 'Publication and Achievements' section.

3.2 Research Techniques

At every stage of the research process, a variety of methodologies were used. Before these approaches were put to use, a thorough assessment of their suitability was conducted. The next subsections provide in-depth descriptions of various methods.

3.2.1 Data Collection

To achieve the first research's objective, a variety of requirement gathering methodologies were employed to obtain the users' requirements. The data collecting section includes various techniques such as interviews, observations, SLR, and others [110]. Therefore, this study involved conducting interviews with dyslexic experts, observations of dyslexic center, and SLR focusing on dyslexic learning, in order to collect raw data.

3.2.1.1 Interviews Technique

Three distinct techniques were selected for implementation in this phase to guarantee a comprehensive data collection has been conducted. The preliminary investigation started by selecting the research site, determining the characteristics of the target users, and executing the data collection technique.

3.2.1.1.1 Selection of the Research Site and Interview Technique

The PDM center supports children who are dyslexic and gives special attention to their requirements. In order to carry out a thorough investigation on the target population, we have chosen an appropriate research site that complies with the needs of the dyslexic community.

Our study focuses on giving children with dyslexia individualized support and empowering them. Thus, the best site for our research was one that specialized in dyslexia instruction and assistance. This particular center offers customized programs and services to meet the specific learning needs of dyslexic children in relation to technology, courses, and educational resources.

Semi-structured interview techniques [111], were used in this study's materials to collect information from five dyslexic experts who were teaching in dyslexia centers in Malaysia. A semi-structured interview protocol with open-ended questions was adopted and used for the interviews. The interview questions were adopted and created to examine the difficulties of incorporating technology into the classroom and the desired enhancements for teaching dyslexia. Within the confines of the research topic, the participants were given the freedom to determine the focus and track of their interviews.

The interview questions were reviewed by five experts to validate the interview questions clarity and efficacy. Three are the domain experts and 2 are the research colleagues. No modifications to the interview protocol were made in light of the positive results of the expert review, and the information gathered from it was used in the study. Appendix A contains the list of interview questions.

Overall, the study's material, such as the semi-structured interview protocol, offered a thorough method for gathering information from the experts on dyslexia [112]. This allowed for a thorough examination of the difficulties and desired advancements in the teaching of dyslexia with a particular focus on the use of technology.

3.2.1.1.2 Determining the Characteristics of the Target Experts

The study employed the judgmental sampling technique, also known as purposive sampling, which is a non-probability sampling method [113]. Rather than using random selection, researchers use judgmental sampling to pick research samples based on their knowledge and experience. This technique was chosen as it is practical for acquiring specific data from a targeted group [114]. Moreover, judgmental sampling is recommended when working with established professionals or authorities [115]. Given the study's focus on dyslexic children and the selection of PDM as the research site, the judgmental sampling technique aligned well with the research objectives. The primary aim was to select dyslexic experts familiar with computer applications for educational purposes. Proficient dyslexic experts who help dyslexic children in seeking enhancement in their learning were included. These experts displayed a strong enthusiasm for learning with technology and were highly motivated to explore new learning approaches to facilitate children with dyslexia's educational journey.

This study involved five participants with extensive experience teaching in dyslexia centers and expertise in dyslexia. A total of 5 participants were determined to be the appropriate number for inclusion in this research. Research literature, particularly the works of Nielsen and K. Landauer (1993), suggests that a small set of experts is adequate for usability studies. This quantity of experts has been found to effectively identify a substantial portion of usability issues within a specific context [116, 117]. It has been emphasized that conducting multiple inquiry sessions with the same small set of users can yield more insightful results compared to involving a larger group [116, 117]. The rigorous criteria used for selecting the five experts, emphasizing their extensive experience and qualifications in the field. Highlight that their specialized knowledge provides high-quality insights, compensating for the smaller number. The nature of the study is qualitative, which typically involves in-depth analysis of a smaller sample size. Emphasize that qualitative research aims for depth of understanding rather than breadth, and small, carefully selected samples are common in such studies. This approach was consistently applied even during the validation process and interview sessions with experts to maintain coherence with the concept of an optimal number of users.

The participants were chosen based on their expertise, knowledge, and actual experience in Malaysia's dyslexia education field. Two participants had more than 10 years of experience, and every participant had at least five years as shown in Table 3.1. Setting a minimum of five years of experience as a requirement for interview candidates helps in making sure that the insights gathered are informed, stable, and deeply reflective of the subject matter. It improves the quality and credibility of the research findings. Participants with different levels of experience were included, offering a variety of viewpoints and insights into the difficulties and desired advancements in dyslexia teaching.

Table 3.1: Characteristics of Study Participants

Participants	Gender	Experience
Participant 1	Female	More than 10 years
Participant 2	Male	More than 10 years
Participant 3	Male	7 years
Participant 4	Male	7 years
Participant 5	Female	5 years

Participant 1 had been working with dyslexic students for over ten years. They were a highly skilled dyslexic expert who was actively involved in teaching dyslexic students, carrying out research, and offering other educators professional development. Their wealth of experience gave them an insightful understanding of the difficulties in integrating technology and the improvements for teaching dyslexia.

Participant 2 also had more than ten years of experience teaching dyslexia. They were a skilled dyslexia specialist who had experience working with a variety of dyslexic students. They provided profound insights into the practical application of technology and the potential improvements that could be made thanks to their knowledge and extensive involvement in the field.

The experience of participants 3, 4, and 5 in dyslexia education was at least five years. They contributed new perspectives and experiences to the study despite being relatively newer in the field than participants 1 and 2. Their involvement in dyslexia centers and their years of training dyslexic students gave them a unique perspective on the difficulties and desired advancements in integrating technology.

The study's participants were picked for their knowledge, real-world experience, and commitment to dyslexia education overall. Their combined expertise and perceptions allowed for a deep and thorough understanding of the difficulties in implementing technology in the classroom and the desired advancements for dyslexia teaching in Malaysia.

3.2.1.1.3 Executing the Data Collection Technique

To ensure the collection of important data from the five dyslexic experts who were lecturing in dyslexia centers in Malaysia, the procedure for this study included a number of crucial steps. The study used a qualitative research design and concentrated on semi-structured interviews to learn more about the difficulties and desired advancements in dyslexia teaching, particularly with regard to the use of technology. The process that was used was as follows:

1) **Selection of Participants**: For the study, five dyslexic experts were chosen, two of whom had more than ten years of experience teaching dyslexic students, and three of whom had experience of not less than five years. Through professional networks and referrals from dyslexia centers in Malaysia, the participants were found.
2) **Informed Consent:** Participants received comprehensive information about the goal, design, and methods of the study prior to the study's start. Each participant gave their informed consent, ensuring that their participation was voluntary and that their rights were protected.
3) **Semi-Structured Interviews:** The open-ended, semi-structured interview protocol was created based on the themes

and research goals found in the literature. The interview questions centered on how difficult it is to incorporate technology into the classroom and how to improve dyslexia teaching. Prior to data collection, the protocol was pilot-tested with a dyslexia specialist to ensure its effectiveness.

4) **Data collection:** Each participant underwent an individual interview, allowing for an in-depth exploration of their experiences, viewpoints, and practices. With the participants' permission, the interviews were audio recorded and verbatim transcribed for analysis, and the interviews ranged between 15 to 40 minutes. The interviews took place in a relaxed, private setting that encouraged open, sincere communication.

5) **Data Analysis:** Thematic analysis was used to examine the field notes and interview transcripts[118]. The information was coded and divided into themes and sub-themes, enabling an organized and thorough examination of the difficulties and desired advancements associated with technology integration in dyslexia teaching.

6) **Ethical Considerations:** To ensure participant confidentiality, anonymity, and data protection, ethical standards were followed throughout the study. The study followed ethical guidelines and regulations established by the Universiti Tunku Abdul Rahman research ethics committees and institutions.

This method was used in the study to gather the diverse experiences and viewpoints of the dyslexia specialists, highlighting the difficulties encountered and the desired advancements in dyslexia teaching, with a specific focus on the incorporation of technology.

3.2.1.2 Observation Technique

Observations were conducted during the classes at PDM Ampang, involving all students present at the center. Their diverse activities and interactions were closely observed and documented for the purpose of research. These observations provided a more profound understanding of the difficulties dyslexic children encounter while utilizing specific computer apps and engaging in learning activities. In addition, these sessions were also recorded on video for later examination, enabling a more thorough investigation.

The decision to utilize observations in this study was based on its efficacy in capturing users' behaviors throughout their interactions with computer programs and other classroom activities. This approach played a crucial role in identifying and resolving any concerns that may have been magnified during the interview sessions, hence revealing new problems as well [115].

Observations are particularly effective in capturing current situations, without being influenced by previous or future experiences [115]. In addition, this approach did not require the users' active participation, allowing researchers to have the freedom and opportunity to thoroughly evaluate the users' actions.

The recorded videos were subjected to thorough examination, undergoing three rounds of evaluation to identify the wide range of emotions shown by the users. The emotions were carefully classified to enhance the detection of elements that contribute to accessibility concerns.

3.2.1.3 Systematic Literature Review Technique

The review utilized an SLR to gather pertinent data related to the study's focus. The review followed well-established procedures, adopting the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [119, 120], known for their clear and structured approach in conducting systematic reviews and meta-analyses as shown in Figure 3.2. The PRISMA method encompasses three key phases: conducting a literature review, selecting eligible publications, and extracting and summarizing data.

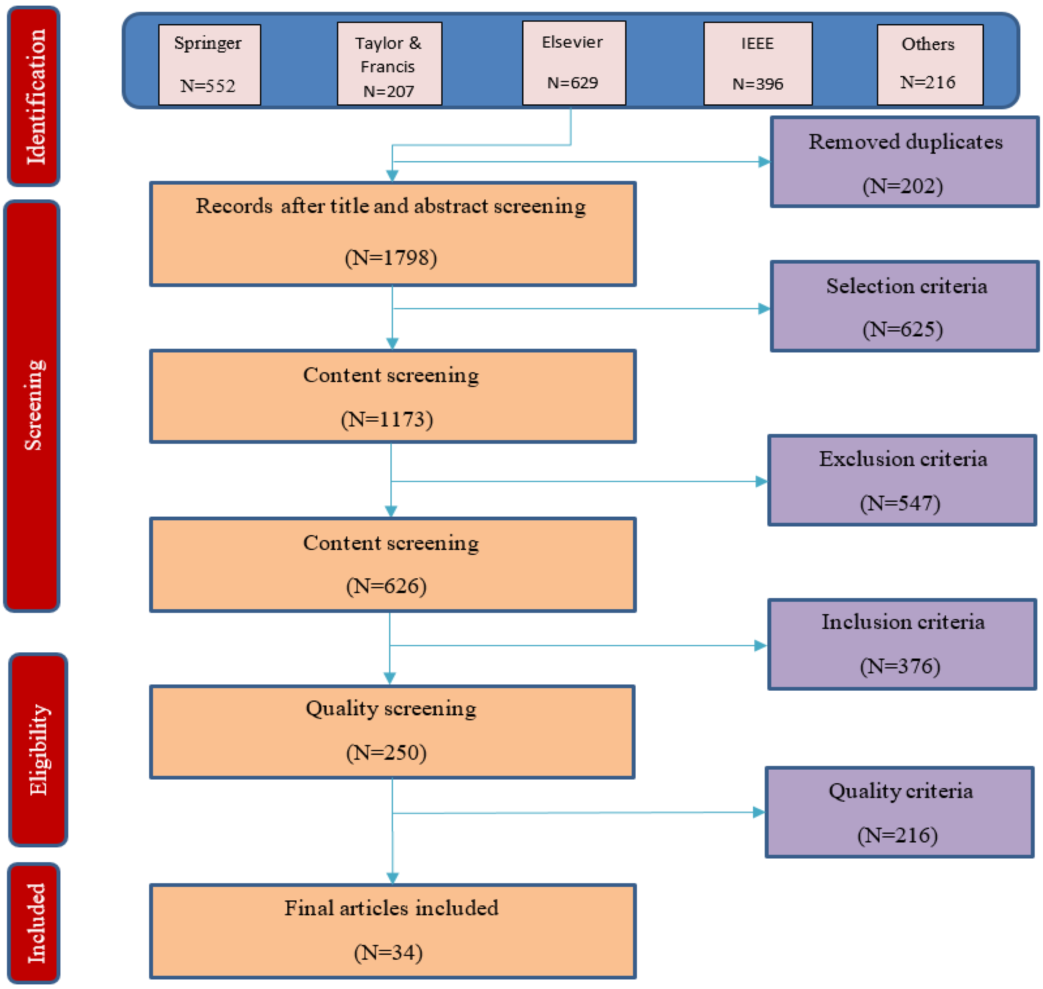


Figure 3.2: Flow Diagram of PRISMA

To ensure a representation of the latest trends, publications within the last five years were chosen as the suitable timeframe for review. This timeframe aimed to encompass the most recent and relevant information regarding interventions designed for pupils with dyslexia.

This review specifically details the methodology and findings focusing on interventions based on sensory approaches for pupils with dyslexia. Aligned with the PRISMA guidelines, Research Questions (RQs) were formulated as the primary focus of this work:

RQ1: What interventions are currently employed to facilitate the learning of pupils with dyslexia, and what are the key characteristics of these interventions?

RQ2: What primary approaches form the basis for interventions aimed at pupils with dyslexia, and what factors contribute to the prevalence of specific approaches?

RQ3: What gaps exist in the current understanding of dyslexia learning interventions, and how can addressing these gaps improve the learning process for pupils with dyslexia?

The primary aim of this SLR is to provide an updated overview of interventions designed for the learning of pupils with dyslexia, aiming for a comprehensive and critical analysis. This review aims to present an in-depth description of research conducted in the past five years within this field, identifying research gaps crucial for improving interventions and enhancing the learning process for pupils with dyslexia. These objectives are effectively achieved through the SLR.

3.2.2 Identification of Accessibility Elements from Data Collection

A complete assessment of a variety of data sources, such as interview scripts, observations, and an SLR, was conducted as part of the research. The purpose of the analysis was to identify elements that contribute to the accessibility of the HapticLearn 1.0 model for users who are dyslexic. Through the process of extracting statements, keywords, and patterns, the fundamental issues were brought to light. In addition, the feelings that were displayed by the experts and the activities that they took were documented. Special attention was paid to occasions in which displeasure was voiced during interviews, as well as the problems that were seen during observation. In addition, the difficulties and supportive elements that were discovered throughout the SLR were reported as additional factors. It was determined that the solution to these collective difficulties and supportive elements are key factors that contribute to the accessibility of the HapticLearn 1.0 model for users who are dyslexic. Thus, in this project, a conceptual model "HapticLearn 1.0" was developed to incorporate important elements that are able to guide mainly future IT developers and multimedia designers in designing an accessible learning application for children with dyslexia.

3.2.3 Verification of Accessibility Model (HapticLearn 1.0)

The assessment of the accessibility component necessitates evaluation by two distinct groups of testers: individuals affected by dyslexia (referred to as dyslexic users) and domain experts [121-123]. In this study, validation of the prototype according to HapticLearn 1.0 (as detailed in Section 3.2.6 & Section 5.3) was performed by affected users, while experts in various domains such as computer application design, user interface design, game development, Virtual Reality (VR) development, IT development, and research, scrutinized the visual components of HapticLearn 1.0 (Section 4.3.2). The expert-based evaluation aimed to verify the inclusion of the appropriate components in HapticLearn 1.0, ensuring compliance with laws, standards, guidelines, and general checklist requirements [122].

Each element within the conceptual model underwent meticulous scrutiny to ascertain its relevance in accomplishing the study's objectives. The selection of an expert evaluation as the preferred approach to appraise HapticLearn 1.0 components was primarily due to its inherent capacity for critical analysis and feedback gathering, enabling further enhancements [121, 124-126]. The experts' feedback served as a preliminary confirmation that all Human-Computer Interaction (HCI) components were appropriately integrated into HapticLearn 1.0.

The expert criteria have been condensed into Table 3.2, delineating the field of expertise as designing and developing computer applications, user interface design, game development, VR development, and IT development. This is because the research concentrates on presenting a model for an accessible learning platform to the dyslexic community. Hence, expertise in the domain of 'designing and developing applications' is pivotal for eligibility in reviewing the relevant subject matter. A prerequisite of at least 3 years of professional experience has been established as sufficient to comprehend and review the complexities of the environment [127]. Appendix B contains the expert review form.

Table 3.2: Criteria for the Domain Expert

Description	Criteria
Field	In the area of designing and developing computer application
Educational background	Minimum Degree
Years of experience in the field	>= 3 years

The criterion for 3 years of work experience, coupled with an educational degree, serves to ensure that the qualified expert is equipped to navigate and comprehend the problem domain and the core concept of this research without encountering any obstacles. According to Nielsen [124, 128], three to five regular experts proficient in the relevant field are adequate for conducting the evaluation process. These experts are individuals with expertise in the field under consideration. The feedback from five such experts was gathered and analyzed through an online survey, and the outcomes are detailed in section 4.3 Table 4.3 offers a summarized overview of the selected experts' backgrounds, adhering to the criteria outlined in Table 3.2.

3.2.4 Validation of HapticLearn 1.0 Model

The validation process of HapticLearn 1.0 involved testing a prototype constructed by integrating the features of HapticLearn 1.0. The assessment was carried out through prototype testing involving dyslexic children to gauge the enhanced accessibility of computer applications in the learning of dyslexic children.

The purpose of prototype testing was twofold. Firstly, it aimed to evaluate the learning accessibility level of the enhanced design of computer applications for dyslexic users.

3.2.4.1 Background of the Users for Prototype Testing

The participant criteria for this study have been delineated into four specific items to ensure a well-defined and focused selection process as shown in Table 3.3.

Firstly, it is imperative that the participants exhibit dyslexia, serving as the fundamental characteristic for inclusion in this research. Dyslexia, a specific learning disorder, is the primary aspect being investigated.

Table 3.3: Criteria for Prototype Testing Participants

Description	Criteria
Fundamental characteristics of the participant	Dyslexia
Concurrent specific learning disorder	Without any other concurrent disorder
Age group	4 to 13 Years
Relevance to the educational setting and learning processes	Currently enrolled in School

Secondly, to maintain the purity of the study sample, participants without any other concurrent disorders or disabilities will be selected. This criterion helps in isolating the impact of dyslexia specifically on the study's parameters.

Thirdly, the age range of the participants has been designated between 4 to 13 years. This age span is critical as it corresponds to the developmental stages during which dyslexia is typically diagnosed and addresses the specific age group that is within the schooling years.

Lastly, to ensure direct relevance to the educational setting and learning processes, participants must currently attend school. This criterion aims to capture the experiences and challenges faced by school-going children with dyslexia, offering insights into the dynamics within an academic environment.

By combining these criteria, the study seeks to create a well-defined and focused group that embodies the characteristics essential for examining dyslexia within the context of learning processes.

3.2.4.2 Ethical Approval

Ethical approval was granted by the Universiti Tunku Abdul Rahman Scientific and Ethical Review Committee.

3.2.4.3 Permission from PDM to Conduct Research

Permission was granted from PDM to conduct research.

3.2.4.4 Initial Students Enrollment

Initially, there were a total of 69 students enrolled in the PDM Ampang Center.

3.2.4.5 Parents' Consent

Among the 69 students, 37 parents have granted their approval for their children's participation in this study.

3.2.5 Prototype Testing Setup and Procedure

The prototype testing setup and procedure encompass three different phases: pre-testing, training, and post-testing. The pre-testing and post-testing phases are structured to evaluate the impact of the training sessions with prototype on the cognitive skills of dyslexic children, particularly emphasizing the ability of remembering and understanding.

3.2.5.1 Pre and Post-test Designing

The initial pre-testing phase involves assessing the baseline cognitive skills of dyslexic children before any training intervention. Pre-testing aims to establish a benchmark or starting point for the cognitive abilities related to remembering and understanding. This assessment allows for a clear understanding of the participants' cognitive capabilities before engaging in the training sessions.

Following the completion of the training sessions, the post-testing phase involves a reassessment of the participants' cognitive skills related to remembering and understanding. This assessment is conducted to evaluate and measure the progress, improvements, or changes in the cognitive abilities of dyslexic children after undergoing the training intervention. It serves as a means to gauge the effectiveness of the training program in enhancing the targeted cognitive skills.

3.2.5.2 Designing Writing-Based Tasks for Pre and Post-Testing:

Informed by a comprehensive exploration of the existing literature, a series of purposeful, writing-based activities was meticulously crafted to facilitate the collection of both pre and post-testing data. This method allowed for a nuanced examination of the participants' cognitive development.

3.2.5.3 Assessing Remembering and Understanding:

A total of 7 distinct tasks were designed to rigorously assess the participants' cognitive abilities, specifically focusing on their capacity for remembering and understanding. These tasks were thoughtfully developed to target these essential cognitive domains and to yield valuable insights into the participants' learning processes.

- Remembering tasks involve copying capital alphabets, writing alphabets within four lines, and counting shapes in a large box.

- Understanding tasks encompass writing lowercase capital alphabets, matching lowercase and uppercase alphabets, matching digits with shapes, matching geometric shape names with shapes, writing uppercase alphabets within four lines, and counting shapes in a large box.

3.2.5.4 Integrated Assessment Tasks

In addition to these seven activities, 2 unique tasks were engineered to evaluate both remembering and understanding concurrently, representing a holistic approach to cognitive assessment. As a result, these 2 tasks were counted both as part of the set designed to assess remembering and the set tailored for assessing understanding, thus bridging the two cognitive facets.

3.2.5.5 Comprehensive Cognitive Evaluation

In essence, the approach taken encompassed a total of 3 tasks tailored to assess the remembering capabilities of the participants and 6 distinct tasks purposefully crafted to delve into their understanding. This comprehensive approach provided a holistic view of the participants' cognitive development and learning outcomes.

3.2.5.6 Writing as the Central Assessment Tool

Crucially, all these activities were centered around the act of writing, recognizing it as a strong means of assessing and capturing the nuances of participants' cognitive growth. This method not only allowed for thorough data collection but also facilitated the extraction of profound insights into the participants' cognitive processes and learning journey.

3.2.6 Expert Validation of Designed Tasks

The integrity of the designed tasks was upheld through a rigorous validation process, guided by the insights of domain experts. A panel of 5 experts played an integral role in this validation, lending their extensive expertise to ensure the activities' quality and relevance. Table 3.4 shows the criteria for domain experts.

Table 3.4: Criteria for Domain Expert (Tasks Validation)

Description	**Criteria**
Field	In the field of teaching and learning
Educational background	Minimum Degree
Years of experience	>5years

3.2.6.1 Diverse Expertise

The panel was composed of experts from various domains, ensuring a multifaceted evaluation. Among these experts, 3 hailed from the field of dyslexic teaching and evaluation, possessing invaluable experience in understanding the unique needs of dyslexic learners. An additional expert, specializing in international teaching and learning methodologies, brought a global perspective. Finally, a Malaysian expert rounded out the panel, providing a local context and insight.

3.2.6.2 Validation Form and Feedback

Each activity, along with a comprehensive validation form, was shared with these experts. This form included criteria for assessing relevance and non-relevance, as well as a dedicated section for their comments and recommendations.

3.2.6.3 Collaborative Refinement

The collaborative process resulted in a thorough and constructive feedback loop. All the experts expressed satisfaction with the quality of the tasks, highlighting their precision and alignment with educational standards. Any comments or suggestions made by the experts were diligently reviewed and addressed, leading to amendments and improvements in the tasks.

3.2.6.4 Expert Approval

The collective endorsement of these domain experts served as a testament to the rigor and excellence of the tasks. Their approval not only affirmed the tasks' alignment with educational best practices but also highlighted their value as effective tools for the intended purpose.

3.2.7 Pre and Post-Tests Evaluation

On 16th Jun 2023, the pre-testing tasks were conducted at PDM Ampang. The researcher and supervisors first reviewed and evaluated the responses. Subsequently, two volunteer researchers who have teaching experience meticulously assessed the results to ensure accuracy and credibility. The expert feedback was also taken into account, enabling us to double-check and validate the outcomes. Figure 3.3 shows the pre-test evaluation procedure and the same procedure is also applied for post-test evaluation.

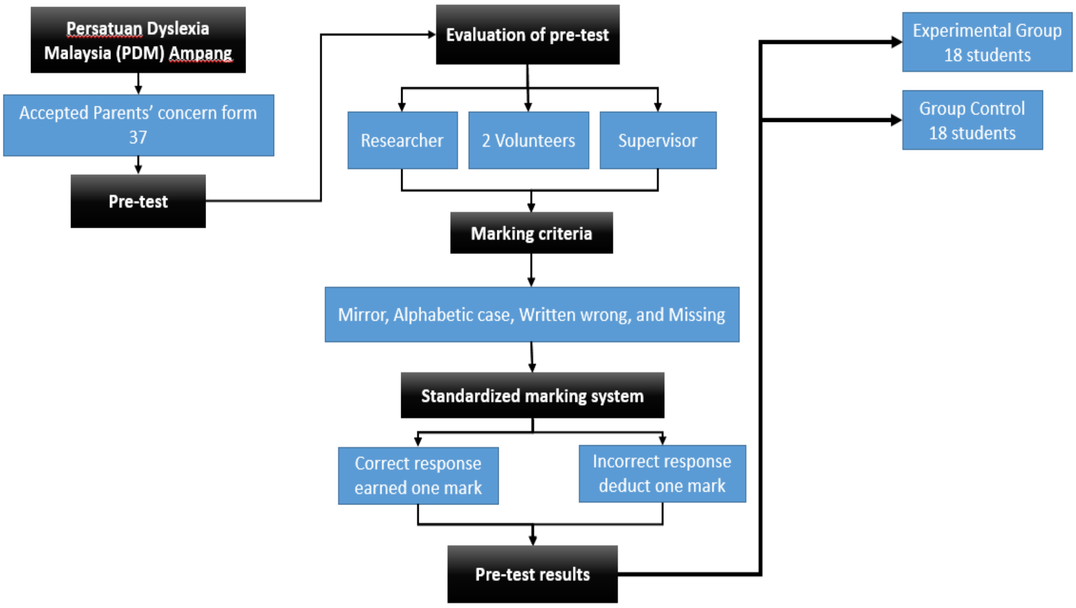


Figure 3.3: Pre and Post-test Evaluation Procedure

3.2.7.1 Error Analysis and Marking Criteria

Throughout the evaluation process, each task has specific marking criteria to check as shown in Figure 3.3, we identified mistakes made by participants, including mirror writing, errors in alphabet case, and incorrect writing, missing alphabets. To ensure fair assessment a standardized marking system was applied as shown in Figure 3.3, we assigned marks to each task, deducting one mark for each mistake made. By addressing these errors, we aimed to attain accurate and reliable results.

3.2.7.2 Calculation of Results

The total marks attained for remembering tasks and understanding tasks were individually summed up. Subsequently, we calculated the percentage scores for remembering and understanding abilities. Additionally, we computed the combined percentage score, reflecting the overall performance of each participant.

3.2.7.3 Group Division

To facilitate a balanced approach, participants with similar overall percentage scores in the pre-test were assigned to either the experimental group or the control group. Our objective was to balance the two groups, distributing participants with similar test scores as evenly as possible. For instance, if two participants scored within the range of 70-75, they were thoughtfully divided into both the control and experimental groups, with one participant in each. Out of the total 37 participants who took part in the pre-testing phase, one participant was excluded from the grouping process due to illness, leading to their absence from the research. Thus, we proceeded to divide the remaining 36 participants into two groups - an experimental group and a control group, each consisting of 18 participants as shown in Figure 3.3. This division was essential to conduct further analysis and draw conclusive findings regarding the effects of motor skills training on cognitive skills. To guarantee a balanced distribution and allow for a fair comparative evaluation of the intervention's effects, participants were assigned to these groups according to how well they performed on the pre-test. This sample size of 36 participants is justified by qualitative research standards, which emphasize depth and richness of data over larger numbers [129]. According to previous studies, qualitative studies can achieve significant findings with smaller samples due to the detailed, context-rich data they produce [130]. Additionally, research suggests that a smaller sample size is often adequate for qualitative studies, particularly when the goal is to achieve data saturation and rich insights [129]. Therefore, our use of 36 participants ensures a comprehensive evaluation of the prototype's effectiveness while adhering to qualitative research norms.

3.2.7.4 Control Group

The 18 children with dyslexia in the control group followed conventional classroom procedures found in ordinary educational environments as shown in Figure 3.4. The teachers in this group used traditional teaching techniques and conventional teaching materials to teach the standard curriculum. Without adding specific interventions or extra training sessions, the teaching approach primarily depended on established methods of teaching. These activities did not include the haptic-based intervention implemented in the Experimental Group. The Control Group served as a reference to assess the effectiveness of the haptic intervention.

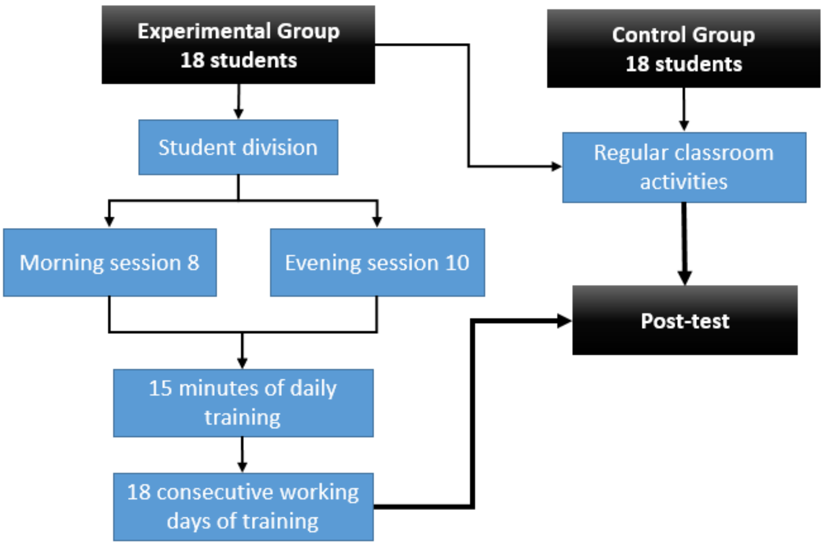


Figure 3.4: Training Procedure

Additionally, the same content for the activities was shared with the teachers so that they could teach this content in their own unique method. The entire concept is presented to the instructors, together with all of the content, before the beginning of the training phase. This decision was made to prevent the experimental group from experiencing any content-based discrepancies, emphasizing the necessity to overlook any inherent biases that might be present in the provided content.

3.2.7.5 Experimental Group

The experimental group, which also included 18 children with dyslexia, adhered to a traditional classroom learning structure, in contrast to the control group. Nevertheless, in addition to the standard curriculum, participants in this group took part in tailored training sessions. The experimental group underwent 18 consecutive working days of training. Each participant actively engaged in 15 minutes of daily training as shown in Figure 3.4. These training sessions focused on improving cognitive skills, particularly remembering and understanding. In order to improve dyslexic learners' remembering as well as understanding abilities, the customized intervention includes interactive activities.

This distribution made it easier to undertake a thorough comparison of the specialized training's efficacy versus traditional teaching methods.

3.2.8 Development of Prototype and Training Phase

The development of the HapticLearn 1.0 prototype was a strategic phase, utilizing a set of development tools including Unity for constructing interactive learning activities, Blender for creating engaging multisensory content, and the "Touch x" haptic device to provide a tactile dimension to the digital learning experience. This phase saw the careful assembly of various activities, each designed to address the diverse learning requirements of dyslexic individuals. These activities, once developed, were integrated into the prototype for use in the subsequent training phase. The training phase itself was the pivotal component of the intervention, where dyslexic children engaged with the prototype in structured sessions aimed at enhancing their cognitive skills, with a particular focus on remembering and understanding. These sessions consisted of the activities developed during the prototype phase, providing a targeted and immersive experience to help improve the cognitive abilities of children with dyslexia, and were tailored to meet their unique learning challenges.

3.2.8.1 Training Activities

A dynamic and interactive haptic-based educational application was meticulously crafted, encompassing a set of learning activities and multi-sensory experiences to enhance the learning process. This learning application environment seamlessly integrates visual and auditory elements while immersing users in kinesthetic and tactile sensations through the use of a haptic device. Within the application, a diverse set of activities develops, each designed to cater to specific learning objectives as shown in Figure 3.5.

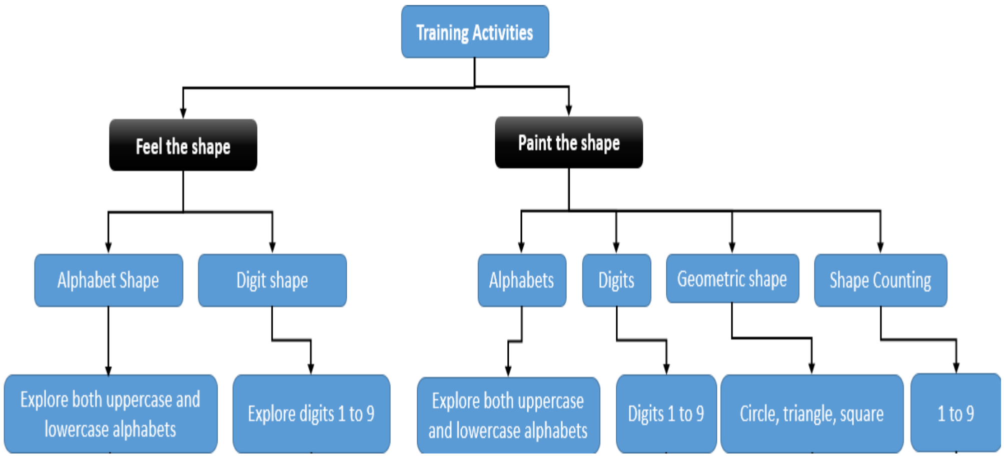


Figure 3.5: Training Activities Distribution

3.2.8.2 Task 1: Alphabet Shape Exploration

In this activity, the focus is on both uppercase and lowercase alphabets. Users are encouraged to feel the shapes of these alphabets. Upon selecting any alphabet, the game prompts with the corresponding auditory cue, reinforcing the shape's memory. This task ingeniously incorporates the concept of alphabet formation within the confines of four lines. The stylus, linked to the selected alphabet, offers haptic feedback to guide the user's exploration. If a participant deviates outside the alphabet's boundaries, immediate corrective force feedback comes into play, enhancing the understanding of writing within defined lines.

3.2.8.3 Task 2: Alphabet Painting

Building upon the previous activity, this exercise presents a unique twist. The structure of the alphabet is altered, leaving the center open, similar to writing inside a frame. Users are prompted to paint the alphabet while adhering to the confines of this structure. As with the earlier task, any deviation beyond the prescribed boundaries prompts the haptic device to provide guidance through force feedback. The primary goals here are to encourage memory retention and reinforce the concept of writing within a four-line structure.

3.2.8.4 Task 3: Digit Exploration

This activity goes into the domain of numbers and focuses on the numbers 1 through 9. The concept repeats the earlier alphabet exploration (Task 1), with the primary goal being to remember the shape and formation of these digits. The stylus's force feedback is instrumental in facilitating this exploration.

3.2.8.5 Task 4: Digit Painting

Parallel to the alphabet painting activity, this activity pertains to painting the digits 1 through 9. It builds upon the concepts introduced in Task 2, challenging participants to apply their knowledge of number formation while staying within prescribed boundaries.

3.2.8.6 Task 5: Shape Counting and Painting

Geometric shapes make their entrance into this counting-oriented activity. Children are tasked with counting the shapes using the stylus. Incorrect answers prompt corrective force feedback, withholding painting privileges until the correct answer is achieved. This activity effectively merges learning and play, reinforcing shape recognition while encouraging accurate counting skills.

3.2.8.7 Task 6: Shape Coloring

The final activity focuses on well-known geometric shapes such as circles, triangles, and squares. The application begins with visual shape and auditory prompts of the shape's name. As users commence painting, the shape's name is slowly reflected within the shape's form. This exercise simultaneously strengthens shape name recall and encourages a deeper understanding of the shapes themselves.

All these engaging activities were meticulously developed within the Unity game development environment. The alphabets, digits, and shapes were masterfully designed using Blender. Completing the synergy of this innovative learning experience, a haptic device was seamlessly integrated with the game through Unity, providing users with a multisensory and highly interactive platform for learning and skill development.

3.3 Measurement of Cognitive Development

Cognitive development refers to the process by which individuals acquire knowledge, problem-solving abilities, and comprehension over time, begins with foundational stages such as remembering and understanding, which are essential components in evaluating the advancement of cognitive skills among individuals [131]. The evaluation of cognitive development draws inspiration from Bloom's Taxonomy and is categorized into distinct levels such as remembering, understanding, applying, analyzing, evaluating, and creating. In this study, cognitive development is central to remembering and understanding how dyslexic children acquire and process information.

By selecting remembering and understanding tasks aligned with Bloom's Taxonomy, we aim to comprehensively evaluate the cognitive development of dyslexic children. Bloom's Taxonomy offers a hierarchical structure, with remembering and understanding forming the foundational levels.

This strategic approach not only covers fundamental cognitive skills but also facilitates a deeper understanding of their learning processes and potential areas for improvement.

Since our study incorporates a tailored intervention to enhance cognitive skills, assessing remembering and understanding aligns with the targeted intervention's objectives. The same set of pre-test tasks is administered to both groups as a post-test assessment. The post-test evaluation procedure as shown in Figure 3.6, which are similar to the pre-test evaluation procedure. The same set of marking criteria and standardized marking system has been applied as shown in Figure 3.6.

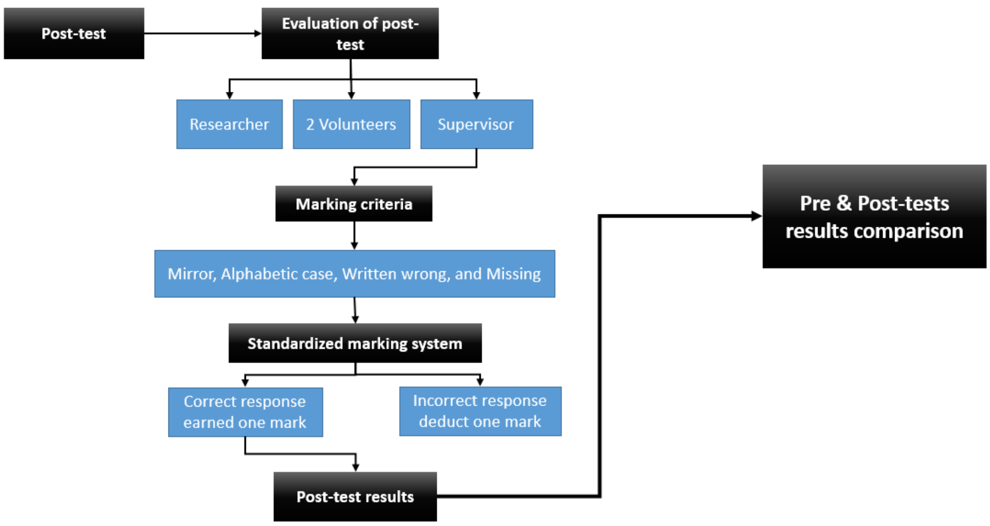


Figure 3.6: Post-test Evaluation Procedure

The evaluation method employed for the pre-test is repeated to ensure consistency in the assessment process as shown in Figure 3.6. The obtained results are then subject to comparative analysis between the control and experimental groups, utilizing statistical methods to identify any significant differences in performance. The data interpretation phase focuses on understanding the impact of the HaptiLearn 1.0 intervention on the targeted cognitive domains, attributing observed changes to the effectiveness of the educational tool.

3.3.1 Measurement of Remembering

The remembering section focuses on tasks that involve basic memory-related activities such as copying capital alphabets, writing alphabets within specific lines, and counting shapes. These tasks are intended to assess the participants' ability to retain and recall information, forming the foundational aspect of cognitive development. These tasks have been incorporated to evaluate the fundamental memory capabilities of dyslexic children and how they retain and reproduce information learned during the intervention sessions.

3.3.2 Measurement of Understanding

Understanding tasks encompass a broader spectrum of activities aimed at evaluating the participants' comprehension and grasp of concepts. These tasks involve writing lowercase letters, matching lowercase and uppercase alphabets, associating digits with shapes, linking geometric shape names with corresponding shapes, and more. By focusing on understanding, the study seeks to measure the depth of comprehension and knowledge retention achieved by dyslexic children. These tasks assess how well the participants understand and apply learned concepts beyond mere memorization.

In summary, the choice to include cognitive development, remembering, and understanding in the study is based on Bloom's Taxonomy, allowing for a comprehensive evaluation of dyslexic children's learning progress. Remembering tasks focus on memory retention, while understanding tasks delve deeper into comprehension and application abilities, providing a well-rounded assessment of cognitive growth and learning outcomes.

3.4 Summary

The methodology was structured into six primary activities: (i) Identification and motivation of the problem; (ii) Definition of objectives for a solution; (iii) Design and development; (iv) Demonstration; (v) Evaluation; and (vi) Communication. Activity one covers the problem statement, project objectives, the motivation of the study, and a comprehensive literature review. The goal of this activity is to encourage users to adopt the devised solution.
The objective and reason of the proposed model were pointed out in activity two. The third activity involves the process of selecting the research site, target users, and the methodologies for data collection. These choices are made based on the specific requirements of the study, which necessitate conducting a close session. The techniques employed to validate the identified components and formulate the conceptual model included the use of control and experimental groups, site observation, expert interviews, and SLR.

During activity four, the design features present in the proposed conceptual model are mapped to a prototype. This prototype is then evaluated based on cognitive development, remembering, and understanding. The fifth activity assesses the achievements to which the prototype fulfills the purpose of the study. The research findings about the initial phase, which includes gathering requirements, conducting observation, interviews, and SLR on the present state of the art, evaluating prototypes, and formulating the conceptual model, are disseminated to others through scholarly publications, as required in activity six.

CHAPTER 4

DEVELOPMENT AND VERIFICATION OF MODEL

(HapticLearn 1.0)

This chapter discusses the findings that provide evidence for the achievement of the RO1 and RO2 of the research. The primary objective of this research is to enhance the motor abilities associated with cognitive development in children with dyslexia. Additionally, the research aims to contribute a conceptual model that utilizes haptics to enhance the learning accessibility of children with dyslexia. Several methods of data collecting, validation, and decision-making, including interviews, observations, and SLR, were employed to develop the HapticLearn 1.0 model. The chapter concludes by presenting the verification result and analysis of HapticLearn 1.0, which serves as a partial fulfillment of the RO3.

4.1 Identification of the Elements for Learning Ease

The elements that influence the learning accessibility of dyslexic users have been determined using interviews, observations, and a comprehensive literature study. The significance of haptics is evident in the results of the observation, interviews, and SLR. The primary purpose of identifying the contribution of haptics is to provide a valid justification for including this aspect as a necessary design component in the conceptual modeling of the findings.

This research utilizes design principles in the field of HCI to address the identified elements. Consequently, the design elements are considered essential components in HapticLearn 1.0, with their significance being assessed according to their enhancing learning ease characteristics for children with dyslexia.

4.1.1 Result of Interviews

Finally, the purpose of these interviews was to investigate the use of technology in dyslexia education and its benefits, as well as the challenges associated with incorporating technology into classrooms. Through interviews with five dyslexic experts who teach in dyslexia centers, valuable insights into their experiences, perspectives, and desired improvements in dyslexia teaching in Malaysia were obtained. Thematic analysis was used to identify common themes and patterns in the interviews, providing a thorough understanding of the subject. A total of five themes were identified as shown in Table 4.1; 1) Experiences and Perspectives on Teaching Dyslexic Students in Malaysia 2) Addressing Limited Awareness and Understanding of Dyslexia 3) The Crucial Role of Sensory-Motor Integration and Technology in Addressing the Slow Learning Process of Dyslexic Students 4) Incorporating Technology in Dyslexia Education and Benefits 5) Challenges in Integrating Technology into Classrooms 6) Envisioning the Future of Dyslexia Teaching in Malaysia and Desired Improvements.

Table 4.1: Thematic Analysis

Themes	Sub-theme	Interviews extract to support the mapping
Experiences and Perspectives on Teaching Dyslexic Students in Malaysia	• Transformative Experience • Rewarding and Difficult • Need for Awareness and Understanding • Tailored Approaches and Collaboration • Strengths-Based Approach	"It has been a truly transformative experience for me to teach dyslexic..." Participant 1 "Teaching dyslexic students in Malaysia has been rewarding and difficult at the same time." Participant 2 "It has brought to light the necessity for educators and the general public to have a greater awareness of and understanding of dyslexia." Participant 3 "I have come across students with various learning styles, and each one required a tailored approach and collaboration" Participant 4 "My experience highlighted the significance of using a strengths-based approach and concentrating on their special talents rather than their weaknesses." Participant 5
Addressing Limited Awareness and Understanding of Dyslexia	• Awareness Campaigns and Workshops • Multi-Faceted Approach • Collaboration and Communication • Informational Sessions and Workshops • Proactive Outreach and Collaboration	"I actively participate in awareness campaigns and workshops for parents and educators in order to address the issues associated with limited awareness and understanding." Participant 1 "A multifaceted strategy is needed to address limited awareness and understanding." Participant 2 "I collaborate with parents and traditional educators through routine communication channels to overcome limited awareness and understanding." Participant 3 "I organize informational sessions and workshops for parents, teachers, and school staff in order to address the issues associated with limited awareness and understanding." Participant 4 "I take part in proactive outreach efforts to address the lack of awareness and understanding..." Participant 5

The Crucial Role of Sensory-Motor Integration and Technology in Addressing the Slow Learning Process of Dyslexic Students	• Limited Sensory-Motor Activities Impact Learning • Technology as a Transformative Solution • Meeting Special Needs Through Technology • Reducing Learning Difficulties with Sensory-Motor Support • Empowering Dyslexic Learners Through Technology	"In fact, the lack of sensory-motor activities may be a major factor in the slow learning progress of dyslexic students." Participant 1 "Technology integration is a probably game-changing approach." Participant 2 "Technology integration has the potential to transform the way dyslexic students learn, especially through interactive, multisensory activities." Participant 3 "This fills the gap by encouraging the development of sensory-motor skills, which makes learning less difficult for dyslexic students." Participant 4 "Technology has the ability as a solution." Participant 5
Incorporating Technology in Dyslexia Education and Benefits	• Assistive Reading Software and Interactive tools • Individualized Instruction and Instant Feedback • Educational Apps and Adaptive Features • Improved engagement level and enhanced literacy abilities • Educational Apps and access to information	"I use reading software to help dyslexic students with decoding and comprehension. I also discuss interactive learning tools that..." Participant 1 "technology enables individualized instruction, instant feedback, and the chance to practice skills in a motivating..." Participant 2 "I use online platforms, multimedia resources, and educational apps to incorporate technology into dyslexia education. These resources provide interactive learning opportunities and adaptive capabilities" Participant 3 "Technology improved engagement levels, enhanced literacy abilities, and an increase in students' confidence and independence." Participant 4 "I observed include improved reading fluency, enhanced access to information, and the development of digital literacy skills." Participant 5
Challenges in Integrating Technology into Classrooms	• Availability and Accessibility of Technology Resources	"The availability and accessibility of technology resources is one issue." Participant 1 "Because of the lack of technical support and poor infrastructure, integrating technology into the classroom can be difficult." Participant 2

	• Lack of Technical Support and poor Infrastructure • Learning Curve and Training • Connectivity Problems and Compatibility • Resistance to Change and lack of familiarity	"The learning curve involved in using new technology tools is one difficulty…" Participant 3 "Connectivity problems and device compatibility can make it difficult to integrate technology into the classroom." Participant 4 "One difficulty is the educators' and students' resistance to change and lack of familiarity with technology." Participant 5
Envisioning the Future of Dyslexia Teaching in Malaysia and Desired Improvements	• Diverse Educational System and Improved Specialized Training • Complete structure and Collaboration • Equal Opportunities and Supportive Policies • Teaching environment Opportunities for Educators • Suitable Curriculum and Investment in Technology	"In Malaysia's future, I see an educational system that is more diverse that allows and meets the special needs..." Participant 1 "A complete structure that promotes early identification, suitable interventions, and flexible learning environments...". Participant 2 "In order to ensure equal opportunities and academic success for dyslexic learners, I would..." Participant 3 "In the future, I see a collaborative, innovative, and individualized dyslexia teaching environment in Malaysia…" Participant 4 "I wish for a more suitable curriculum that accepts various learning requirements…" Participant 5

The findings from the interviews offer important new perspectives on Malaysia's dyslexia teaching environment and the contribution of technology to the support of dyslexic students. The information provided by these findings indicates a number of crucial issues that can direct discussions and initiatives aimed at enhancing dyslexia education in the nation.

In Malaysia, different regions and educational settings have varying levels of accessibility and availability of resources and support systems for dyslexic students. While some schools might have trained staff members or specialized support groups for dyslexia, other schools might not have the necessary tools or resources. The disparity between the two groups emphasizes the need for a more uniform and fair approach to dyslexia education across the country. Furthermore, parental involvement and awareness are crucial in helping dyslexic students, but more programs are needed to educate parents and engage them so they can help their children in an effective way.

The interviews with dyslexia teachers also shed light on the difficulties educators face due to the lack of resources, support networks, and opportunities for professional development. The future of education must prioritize accessibility and effectiveness, otherwise, educational gaps will continue to widen[132]. The lack of resources and specialized training may make it more difficult to effectively support dyslexic students. Therefore, it is crucial to close these gaps by making investments in thorough training programs and equipping teachers with the resources they need to meet the special needs of dyslexic students.

The necessity of increasing stakeholder understanding and awareness of dyslexia, including parents and traditional educators, is another important topic of discussion. The interviews revealed that it can be difficult to give dyslexic students the proper support because of a lack of knowledge and misconceptions about the condition. It is necessary to address this by fostering a better understanding of dyslexia and promoting inclusive practices in schools. To address this, collaborations between dyslexia teachers and mainstream educators are also required, in addition to awareness campaigns and workshops.

The experts all agree during the follow-up interview that sensory-motor skills are crucial for learning, especially for dyslexic students who frequently have difficult and slow learning experiences. They identify one of the main causes of these issues as an insufficient amount of sensory-motor activities in conventional education. These motor and sensory perception coordination abilities are crucial for efficient information processing and cognitive development. The experts all agree that technology offers a revolutionary way to deal with these problems. They emphasize that technology has the potential to revolutionize education by providing interactive, multisensory learning experiences. Technology improves learning by addressing the particular sensory-motor requirements of dyslexic students in a way that is more convenient, usable, and interesting. It serves as a conduit for enhancing the growth of cognitive understanding and sensory-motor abilities. The experts emphasize the potential of technology to significantly ease the learning process for dyslexic students and, in essence, close the gap in traditional education caused by a dearth of sensory-motor activities.

Technology is crucial for discussion in dyslexia education[133]. The findings of the interviews emphasized the importance of technology in dyslexia education. Participants emphasized the importance of using assistive technologies such as reading software, educational apps, and multimedia resources to help dyslexic learners with decoding, comprehension, writing, and organization. They also emphasized the advantages of technology, such as increased student engagement, personalized learning experiences, improved information access, and increased self-confidence.

The study's finding that teachers prioritize computers over mobile phones for teaching and learning aligns with the observation that mobile learning is user-friendly for educators in Malaysia[134]. However, it's important to note that this emphasis on usability might not fully capture the depth of teachers' technological preferences and practices. In these interviews with participants, their perspectives on technology were more encompassing, extending beyond the device to include various technological tools and applications. Their discussions highlighted how technology, in general, including computers and mobile phones, contributes to their teaching strategies and the learning experience. While the study rightly points out the ease of mobile learning, it's essential to consider that participants' focus on integrating technology effectively into their daily teaching plans and processes signifies a broader recognition of the overall impact of technology on education. However, participants also pointed out the difficulties with technology and restricted access to resources were also mentioned.

Major barriers included a lack of infrastructure, poor technical support, limited availability and accessibility of technology resources, and the learning curve involved with using new technology tools. Participants emphasized the significance of tackling these issues in conjunction with IT departments, and school administrators, and the provision of ongoing training for teachers and students. These discussions highlight the importance of making investments in technology infrastructure and support systems to guarantee equal access to technological resources and efficient integration in educational settings.

Overall, the discussions resulting from the findings highlight the significance of developing a welcoming and encouraging learning environment that caters to the particular requirements of dyslexic students in Malaysia. Policymakers, educators, and researchers can collaborate to improve dyslexia support services and enable dyslexic students to thrive academically and beyond by addressing the identified challenges and building on the successes observed.

4.1.2 Results of Observation

The comprehensive observations conducted at the PDM center offered valuable insights into the prevailing pedagogical approaches and the state of technological integration within the learning environment. The predominant trend observed was the prevalence of non-technological practices, indicating a reliance on traditional teaching methodologies. Within this context, the use of technology appeared limited, with a rare focus on computer applications. This observation highlighted that technological integration within the learning framework was in its early stages, suggesting a tentative approach to adopting digital tools and platforms for educational purposes.

Amidst this, one notable aspect that emerged was the center's emphasis on the implementation of multisensory techniques. The pedagogical strategies employed within the PDM center prominently featured interactive and hands-on approaches, meticulously designed to engage multiple senses during the learning process as shown in Figure 4.1. This emphasis is a deliberate effort to diversify teaching methodologies, fostering an immersive and engaging learning environment despite the limited technological utilization.

Figure 4.1: Hands-on Learning Activities for Dyslexic Children

However, the observations distinctly pointed out the reliance on more traditional teaching methodologies, despite the growing acknowledgment of the potential benefits associated with technology-enabled learning. The limited use of computer applications and the relatively early stages of technology integration suggested a cautious approach toward embracing digital advancements for educational purposes.

Table 4.2: Results of Observations

Aspect	Elements Observed	Observations	Implications	Recommendations
Pedagogical Approaches	Teaching methodologies, technology integration	Predominance of non-technological practices. Rare focus on computer applications. Limited integration of technology, especially digital tools and platforms	Limited exposure to technology may hinder digital literacy skills development. Potential for enhanced learning experiences through technology	Introduce more digital tools and platforms to enhance digital literacy skills. Encourage the use of technology to enrich learning experiences
Technological Integration	Digital tools, computer applications	Early stages of technology integration. Limited use of computer applications. Cautious approach to embracing digital advancements for educational purposes	Potential for growth and expansion in digital integration. Need for more robust digital infrastructure and support systems	Invest in training and development programs for educators to effectively integrate technology. Implement strategies to gradually increase technology use in educational practices
Multisensory Techniques	Interactive learning tools, hands-on activities, sensory engagement	Emphasis on interactive and hands-on approaches. Design to engage multiple senses during the learning process. Diversification of teaching methodologies through multisensory techniques	Enhanced engagement and retention through multisensory learning. Catering to diverse learning styles and preferences	Continue to integrate multisensory techniques in teaching practices. Explore further innovative multisensory approaches

Commitment to Holistic Learning	Holistic learning environment, innovative teaching methods	Emphasis on providing a holistic and immersive learning experience. Willingness to explore innovative ways to enrich the learning process	Focus on overall development and well-being of learners. Potential for fostering creativity and critical thinking skills	Maintain a holistic approach to education. Encourage exploration of innovative teaching methodologies
Potential for Further Exploration and Implementation	Technological advancement, inclusive learning environment	Need for further exploration and strategic implementation of technology in pedagogical approaches. Value of multisensory techniques in fostering an inclusive and engaging learning environment for dyslexic learners	Opportunities for research and development in educational technology. Importance of inclusive and engaging learning environments	Support research initiatives in educational technology. Promote inclusive practices in education

The findings highlighted the center's commitment to providing a holistic and immersive learning experience through interactive and multisensory techniques. Although the adoption of technology appeared at its preliminary phase, the observed emphasis on engaging teaching methods signified a willingness to explore innovative ways to enrich the learning process.

This insightful exploration of the PDM center's teaching landscape provides a foundational understanding of the current state of technology integration within dyslexia-focused education. The findings highlight both the potential and the need for further exploration and strategic implementation of technology in pedagogical approaches, while also emphasizing the inherent value of multisensory techniques in fostering an inclusive and engaging learning environment for dyslexic learners.

4.1.3 Result of Systematic Literature Review

In this review, we investigate different publicly available articles that are used for the intervention of pupils with dyslexia. Review findings show that, currently, the interventions are employed to facilitate the learning of pupils with dyslexia in two ways: technological and non-technological. In this digital era, technology is at its peak; but in the past years' non-technological practices have been seeking attention, interest, and adoption by educators, students, or researchers in the current period, possibly due to the base of intervention approaches [93, 94]. A notable finding is that all of the included studies in this review employed the VAKT approaches for intervention in various combinations as shown in Tables 2.1, 2.2, and 2.3. Studies have revealed that different individuals have distinct learning preferences.

According to studies visual learners prefer to process information through images, graphs, charts, and other visual aids [95]. They learn best when they can see and observe information. Auditory learners learn effectively through listening and verbal communication [96]. They grasp information best when it is presented through spoken words, discussion, and lectures. Kinesthetic learners learn by doing and engaging in hands-on activities [97]. They thrive when they can physically interact with the subject matter, such as through experiments or simulations. Tactile learners are similar to kinesthetic learners but specifically learn through touch and physical sensations [98]. They benefit from activities that involve the manipulation of objects or textures. Some of the main characteristics of these interventions are that VAKT approaches create stronger neural connections, neural pathway activation, neurotransmitter release, and improved motor, and sensory processing [57]. Incorporating the VAKT approach into teaching practices can maximize brain engagement and optimize the learning experience for students [99]. By stimulating multiple sensory channels and promoting neural plasticity, these strategies support the brain’s natural capacity for learning and adaptation.

The current literature review shows the formation of interventions has two main stages: the development and deployment stages as shown in Fig. 9. In-depth, the development stage mainly focused on the utilized sensory modalities and different learning and teaching approaches. This study shows that the VAKT approach is utilized and all four types of modalities are used with different combinations to develop a learning and teaching intervention for pupils with dyslexia. As mentioned in the introduction section, dyslexia is a learning disorder in which they have difficulty how to process information. Different information is processed in different areas of the brain as shown in Fig. 3. The researchers utilized various modalities with different combinations because it helps to evoke the different areas in the brain of dyslexia pupils [99]. To utilize these combinations of modalities, various approaches are used by researchers non-technological, apps/games, and haptics as discussed in the individual study section.

The "Apps/Games" category includes technological innovations like educational games and mobile apps. These interventions make use of technology-based learning to offer individualized instruction, involve dyslexic students, and provide chances for practice and reinforcement. Interventions utilizing tactile feedback devices and touch-sensitive interfaces fall under the "Haptics" category. These interventions emphasize sensory-based learning, promoting kinesthetic learning and enhancing the multisensory experiences of dyslexic learners. The "Non-Technological Interventions" section, on the other hand, includes interventions that do not use technology. This group includes well-known strategies like explicit instruction, phonics-based instruction, and multisensory teaching. With a focus on multiple aspects of the development of reading and language skills, these evidence-based interventions have been widely used to address dyslexia challenges.

Most of the non-technological approaches utilized VAKT modalities with different combinations some of the researchers used all four modalities to evoke all of their senses, but they do not offer tactile or kinesthetic feedback and guidance. When teaching pupils with dyslexia, the commonly employed non-technological approaches failed to provide the primary training components—feedback and guidance—that were not always given in the best way. The instructor usually gives feedback and guidance during these interventions in visual and auditory forms, which does not train the motor cortex and somatosensory cortex areas of the brain, which are responsible for kinesthetic and tactile processing [135]. Somehow there are tactile and kinesthetic-based interventions that use the motor cortex and somatosensory cortex area of the brain, but they are not used to their full potential due to the absence of aspects that provide feedback and guidance. In these non-technological approaches, all the multisensory interventions are implemented in different modules which are very slow and difficult teaching strategies.

Particularly in a crisis, pandemic, or emergency, such as the current global COVID-19 problem, technology has proven to be important. Regarding the intervention development based on technology, the researchers utilized technology to help pupils with dyslexia in learning. Researchers introduce different apps and game approaches according to the needs of dyslexic children's learning. These apps and games have different reading, writing, pronunciation, and spelling practices which improve the learning of dyslexic children. Researchers mostly concentrate on the games and apps that have primarily focused on VAKT-based interventions. For these interventions, the researcher made extensive use of the visual, auditory, and tactile senses. In these interventions, tactile kinesthetic functions are not exploited; rather, the tactile was only used to enter data and not for its sensation function. Most of the games and apps are mobile-based in which the touch screen completely lacks in providing tactile feedback. A user can not feel any guidance through the mobile touch screen. Apps and games completely lack to use of the brain area which processes tactile and kinesthetic information. So these apps and games practices use visual, and auditory as a learning intervention that practices only the visual and auditory information processing area.

The current literature review shows that some practices used tactile and kinesthetic as an intervention but these interventions are based on non-technological practices. The employment of haptic technology to aid pupils with dyslexia in their learning is quite unusual.

Table 4.3: Results of Systematic Literature Review

Key Aspects and Interventions	Description	Main Findings	Notable Approaches
Technological Interventions	Employed to facilitate learning through technology-based approaches like educational games and mobile apps.	Offer individualized instruction. Provide chances for practice and reinforcement.	Educational games, mobile apps
Non-Technological Interventions	Include well-known strategies like explicit instruction, phonics-based instruction, and multisensory teaching, focusing on reading and language skills development.	Focus on multiple aspects of reading and language skills. - Widely used to address dyslexia challenges.	Explicit instruction, phonics-based instruction, multisensory teaching
VAKT Approaches	Utilized in all included studies, indicating a commonality in employing Visual, Auditory, Kinesthetic, and Tactile modalities in interventions for dyslexia.	Create stronger neural connections. - Activate neural pathways. - Improve motor and sensory processing.	Visual aids, auditory learning, hands-on activities, tactile feedback
Learning Preferences	Studies show distinct learning preferences, with visual, auditory, kinesthetic, and tactile learners benefiting from different types of interventions.	Visual learners prefer processing information through images, graphs, and charts. - Auditory learners learn effectively through listening and verbal communication.	Kinesthetic learners engage in hands-on activities. Tactile learners benefit from tactile sensations.

Neural Processing	VAKT approaches create stronger neural connections, activate neural pathways, and improve motor and sensory processing, enhancing the learning experience.	Incorporating VAKT approach can maximize brain engagement and optimize learning. - Stimulating multiple sensory channels promotes neural plasticity.	VAKT approaches strengthen neural connections, improve sensory processing
Technology vs. Non-Technology	While technology-based interventions are prevalent, non-technological approaches are gaining attention, possibly due to their effectiveness and established practices.	Non-technological approaches offer ordinary classroom instruction and practice. - Technology-based interventions provide engaging and interactive learning experiences.	Technology-based interventions, non-technological approaches

4.1.4 Thematic Analysis, Keyword Analysis, and Validation of Factors through Systematic Literature Review

This section presents a comprehensive analysis categorized into two parts: (i) conducting a keyword analysis to identify the factors, and (ii) validating the identified factors using a Systematic Literature Review (SLR).

a) Identification of Factors: Through detailed interviews and observations, several factors were identified as contributing to the "inaccessible" elements for dyslexic users when accessing learning materials. These factors were derived following three rounds of thorough review, which included analyzing the interview and observation data. The identification process utilized sentences, keywords, and emotions to pinpoint these factors.

b) Systematic Data Collection:

Interviews: Conducted with 5 experts in dyslexia education.

Observations: Carried out at the PDM center.

Systematic Literature Review (SLR): Reviewed 34 peer-reviewed articles focusing on educational technology for dyslexic learners.

c) Validation through Keyword Analysis: A keyword analysis was conducted on the interview transcripts and observation notes to identify recurring themes and factors. The top five key elements that emerged were:

1. Technology
2. Multisensory techniques
3. Haptic technology for kinesthetic and tactile
4. Tailored approach
5. Feedback and guidance

Table 4.2 presents a comprehensive synthesis of factors affecting the accessibility of educational technology for dyslexic learners, as derived from expert interviews, site observations, and SLR.

Table 4.2 not only details the key factors affecting the accessibility of educational technology for dyslexic learners, but also highlights elements essential for the development of a conceptual model, as identified through expert interviews, site observations, and SLR. The identified factors were further validated through an SLR, where the findings from the literature were cross-referenced with the observed data. This triangulation process ensured the robustness of the identified factors.

Table 4.4: Elements Extraction from Interviews, Observation and SLR

Factors	Experts Interviews	Site Observation	SLR	Elements Extracted
Prevalence use of non-technological interventions	lack of technical support and poor infrastructure, integrating technology into the classroom can be difficult	Non-technological methods dominated.	In the past years' non-technological practices have sought attention, interest, and adoption by educators, students, or researchers in the current period, possibly due to the base of intervention approaches	Technology
Rare use of multisensory technique through technology:	Technology can close the gap in conventional education by providing interactive, multisensory activities that fulfill various learning styles	Multisensory techniques prominently employed but with non-technological interactive, hands-on activities	Apps and games completely lack to use of the brain area which processes tactile and kinesthetic information.	Multisensory techniques
Inability to add kinesthetic and tactile in technological intervention	Participant 2: "… I utilize specialized software and apps made to assist dyslexic students … benefit from visual and auditory support for reading, writing, and spelling.	Using computer applications but mostly used the visual and auditory modalities.	In technological interventions, tactile kinesthetic functions are not exploited; rather, the tactile was only used to enter data and not for its sensation function.	Haptic technology for kinesthetic and tactile
Inability to provide the optimal tailored approach:	"In Malaysia's future, I see an educational system that is more diverse that allows and meets the special needs"	Emphasizing the inherent value of multisensory techniques in fostering an	In non-technological approaches, all the multisensory interventions are implemented in different modules which are very slow and difficult teaching strategies.	Tailored approach

	“I wish for a more suitable curriculum that accepts various learning requirements”	inclusive and engaging learning environment for dyslexic learners.		
Inability to provide optimal feedback and guidance:	“crucial to understand each student's specific needs… strengthened my belief that dyslexic learners require specialized support”	Feedback and guidance to each student are difficult for the instructor.	Most of the games and apps are mobile-based in which the touch screen completely lacks in providing tactile feedback. A user can not feel any guidance through the mobile touch screen.	Feedback and guidance

d) Discussion and Implications:

The following are the five factors:

4.1.4.1 Prevalence of Non-Technological Interventions

Experts have noted challenges in integrating technology due to technical and infrastructure limitations. Despite the known benefits of educational technology, these barriers can lead to a reliance on traditional, non-technological teaching methods.

Observations suggest that non-technological methods are predominant, which could be due to the aforementioned barriers or a preference for established practices.

The literature review highlights a resurgence of interest in non-technological approaches, perhaps indicating a gap between available technology and its effective implementation for dyslexic learners.

4.1.4.2 Rare Use of Multisensory Techniques through Technology

The expert interviews suggest an awareness of the potential benefits of multisensory educational tools that cater to various learning styles, but there's an implication that such tools are not being utilized to their full potential.

On-site observations indicate that while multisensory techniques are employed, they are not typically integrated with technological tools, which could enhance their effectiveness and appeal.

The literature review indicates a lack of multisensory integration in educational apps and games, particularly in the stimulation of tactile and kinesthetic senses, which are crucial for dyslexic learners.

4.1.4.3 Inability to add Kinesthetic and Tactile in Technological Intervention

Experts acknowledge the existence of software apps designed to assist learners with dyslexia, but they emphasize that these tools often neglect the tactile and kinesthetic components of learning. Observations confirm that technology used in educational settings tends to focus on visual and auditory modalities, with little to no tactile or kinesthetic interaction. Literature highlights this point by noting that technological interventions frequently fail to incorporate tactile functions, such as those provided by touch screens, for sensory learning.

4.1.4.4 Inability to Provide the Optimal Tailored Approach

From the interviews, there is a call for an educational system that is more inclusive and tailored to the diverse needs of learners with special requirements like dyslexia. Observations highlight the difficulty instructors face in providing individualized feedback, suggesting a disconnect between the ideal of personalized education and the reality. Literature suggests that current multisensory interventions are not well integrated into technology, leading to slow and potentially ineffective teaching strategies.

4.1.4.5 Inability to Provide Optimal Feedback and Guidance

Experts stress the importance of specialized support for dyslexic learners, highlighting the necessity for effective feedback mechanisms. Site observations reveal that it's challenging for instructors to provide tailored feedback to each student, which is compounded by the limitations of the current technological tools. The literature points out that many educational games and apps are mobile-based, where touch feedback is minimal, and they lack complex feedback mechanisms that cater to the nuanced needs of dyslexic learners.

4.1.5 Identification of the Elements

4.1.5.1 Technology

The discussion around the "Technology" element calls for a critical evaluation of current educational technologies, with an emphasis on making them more accessible and effective for all users, including those with dyslexia. It suggests a need for ongoing research, development, and training to bridge the gap between the potential of educational technology and its current application.

In the interviews, experts might express positivity about the potential of technology to transform learning for dyslexic students. Yet, observations could reveal a lack of effective implementation of these technologies in the classroom, with issues such as inadequate teacher training and insufficient infrastructure. The literature would provide a broader critique of the role and effectiveness of technology in educational settings, calling for improved design, deployment, and utilization of technological resources to truly support and enhance the learning of dyslexic individuals.

4.1.5.2 Multisensory Techniques

This element acknowledges the importance of engaging multiple senses to enhance learning experiences. Multisensory techniques are crucial for dyslexic learners as they often benefit from using visual, auditory, kinesthetic, and tactile inputs to process information. The literature suggests that while the value of multisensory approaches is recognized, their incorporation into technology-based learning is not yet widespread or fully realized.

The interviews likely reveal that experts are aware of the benefits of engaging multiple senses to aid dyslexic learners, as it can lead to better retention and understanding of information. Despite this knowledge, classroom observations indicate that such techniques are rarely incorporated into technology-based learning tools. The literature echoes the importance of these techniques but criticizes the current educational technologies for their insufficient multisensory capabilities, suggesting that there is a missed opportunity to enhance learning for dyslexic individuals.

4.1.5.3 Haptic Technology for Kinesthetic and Tactile

Haptic technology refers to any technology that can create an experience of touch by applying forces, vibrations, or motions to the user. The literature review points out that current educational technologies rarely exploit haptic feedback, which is a significant omission given the potential benefits for dyslexic learners who may rely more on tactile and kinesthetic learning.

According to the interviews, there's an understanding among experts that haptic feedback is crucial for learning that involves physical movement and touch, which can be particularly beneficial for dyslexic learners. However, in practice, as observed in classrooms, this kind of technology is rarely found or used, indicating a gap between knowledge and practice. The literature review confirms that educational applications lack in providing kinesthetic and tactile feedback, which is an essential component for comprehensive multisensory learning.

4.1.5.4 Tailored Approach

A tailored approach in educational technology implies customization to meet the individual learning needs of students. The research indicates that educational apps and interventions often lack this personalization, which is particularly important for learners with dyslexia who may require a different approach compared to their peers.

Expert interviews would have highlighted the need for educational interventions to be individualized, catering to the unique learning profiles of dyslexic students. However, observations might show that the technology used in educational settings is not personalized, with a one-size-fits-all approach prevalent. Literature critiques this by highlighting the need for technology to adapt to various learning styles and abilities, ensuring that each dyslexic learner receives an educational experience that is suited to their needs.

4.1.5.5 Feedback and Guidance

Feedback and guidance are essential for learning, especially for dyslexic learners who may need more frequent and specific input to guide their learning process. The extracted element here suggests that technology-based learning tools often fall short in providing adequate feedback, possibly due to a lack of sensitivity to the nuanced needs of dyslexic users or limitations in the technology itself.

The expert interviews suggest that personalized feedback and guidance are crucial for the learning process, especially for those with dyslexia who may benefit from more frequent and specific feedback. Classroom observations might show that current technological interventions fall short in this area, with generic feedback that does not cater to the individual needs of dyslexic learners. The literature review likely reflects this gap, emphasizing the importance of interactive and adaptive feedback mechanisms in educational technology.

4.2 Conceptual Model HapticLearn 1.0 Formation

The conceptual model depicted in Figure 4.2, HapticLearn 1.0, represents an innovative conceptual model designed to guide the development and deployment of learning and teaching interventions with a focus on multisensory engagement for learners, particularly those with dyslexia. Each component within HapticLearn 1.0 symbolizes its critical importance in achieving the objectives of this study. At the development stage, the model emphasizes the importance of incorporating various modalities—visual, auditory, kinesthetic, and tactile—ensuring that learning materials cater to different sensory processing preferences. The approaches used, such as apps and games, are integrated with haptic technology, which is crucial for creating a tactile and kinesthetic learning experience.

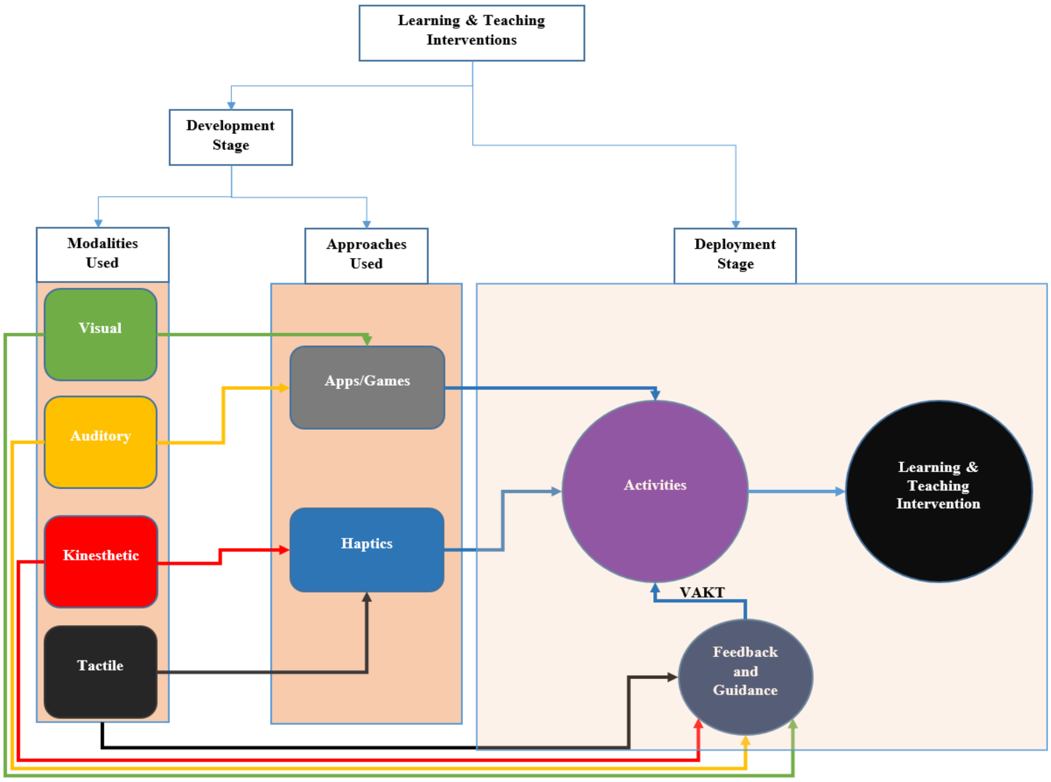


Figure 4.2: HapticLearn 1.0 Model

By focusing on haptic technology and multisensory techniques, HapticLearn 1.0 diverges from traditional design models that might prioritize visual and auditory information. It is an innovative step towards creating accessible and effective learning platforms for dyslexic learners, providing a rich, interactive experience that leverages touch and movement as primary conduits for learning.

As the model progresses to the deployment stage, it translates these multisensory approaches into practical activities that embody the VAKT learning style. This ensures that educational content is not only diverse in its sensory appeal but is also actively engaging learners through interactive methods. A critical component of HapticLearn 1.0 is the feedback and guidance system, which is closely interlinked with the VAKT activities. This system is designed to provide real-time, personalized feedback to learners, an essential feature for facilitating effective learning and for making adjustments to teaching strategies based on learner responses.

HapticLearn 1.0 positions itself as a comprehensive model that bridges the gap between theoretical multisensory educational practices and their practical application, aiming to enhance the learning experience and improve the educational outcomes for dyslexic learners through the thoughtful use of haptic technology. HapticLearn 1.0 is not just a theoretical construct; it serves as a practical guide for designers aiming to create educational applications that are truly accessible. It provides the foundational knowledge necessary for designers to construct platforms that are not only accessible to dyslexic learners but also enhance the learning process through the strategic use of design elements that engage multiple senses. This model, therefore, contributes a new perspective to the field of educational technology design, with a unique focus on the multisensory and tactile dimensions of user interaction.

4.3 Verification of HapticLearn 1.0 using Expert Evaluation

The HapticLearn 1.0 model underwent a rigorous verification process involving five IT experts with diverse professional backgrounds, including software engineering, game development, virtual reality development and research, and IT product management. These experts, each with a minimum of three years of experience, evaluated the model based on a set of criteria designed to measure the relevancy, readability, understandability, contribution, and importance of the elements within the model.

The evaluation criteria were chosen to ensure that the model could be easily understood and implemented by practitioners in the field, that it was relevant to the needs of dyslexic learners in educational technology, and that it made a significant contribution to the current body of knowledge. Relevancy assessed how well the elements of the HapticLearn 1.0 model align with the needs of multisensory learning approaches. Readability evaluated the clarity of the presentation of the model, while understandability looked at how easily those in the field could grasp the model's concepts. Contribution examined the extent to which the HapticLearn 1.0 model adds value to existing educational technology, and importance gauged the significance of the model in the context of current and future technology design.

The outcome of this expert evaluation was positive, with the overall result surpassing the 80% threshold as shown in Table 4.3. This high level of approval indicates a strong consensus among the experts that the HapticLearn 1.0 model is a valuable and effective tool for guiding the development of accessible educational technology, particularly for those with dyslexia.

Table 4.5: Summary of Expert Evaluation Result

Criteria	Description	Evaluation Questions	Evaluation Result
Relevancy	Assesses how closely the model aligns with the needs and goals of the target users and stakeholders.	Determine the relevance of the proposed elements (in the model) in designing a haptic-based application/game for a dyslexic user.	>=80%
Readability	Evaluates the ease with which the content of the model can be read and understood by its intended audience	Do you find the model is readable?	100%
Understandability	Measures how easily the concepts and components of the model can be comprehended.	Do you find the terms used in the model are easy to understand?	100%
Contribution	Assesses the value that the model adds to the existing body of knowledge and practice.	Do you able to relate the contribution of the elements in the model?	>=80%
Importance of the elements	Examines the significance and necessity of each component within the model.	Do you agree the elements stated in the model are important in designing ICT applications for dyslexic children?	100%

The model's robust validation by experts with substantial experience and varied specializations lends credibility to its application and framework and suggests that it could serve as a reliable reference in the field of educational technology design.

4.4 Summary

In summary, it is possible to say that the early results gained from the interview, observation, and SLR shed light on the challenges that children with dyslexia experience while they are utilizing technology for their educational purposes. There are a number of factors that have been recognized as being a barrier to the learning of children with dyslexia. With the assistance of these interviews, observations, and a comprehensive examination of the relevant literature, a variety of elements that have the potential to improve the learning experience of children who have dyslexia were found.

Technology, multisensory techniques, haptic technology for kinesthetic and tactile learning, a tailored approach, and feedback and guidance are the five components that are contributing to the learning of children who have dyslexia, according to the final results. A conceptual model was developed on the basis of these elements, and a comprehensive expert validation was carried out to determine whether or not the design elements were suitable and accurate for use as the primary component of the conceptual model for children who have dyslexia.

The components of the model have been evaluated with regard to their relevance to the learning of children with dyslexia, the relative importance of the elements in relation to their contribution, the importance of the elements based on their contribution, the readability of the model, and the designers' ability to understand the fundamental concepts that underlie the model. The reviews that were received from the group of industry specialists were positive affirmations that the representation of HapticLearn 1.0 is at the most appropriate level, containing the essential components that the designer needs in order to develop a technology-based learning platform for children who have dyslexia.

CHAPTER 5

VALIDATION OF THE MODEL (HapticLearn 1.0)

The section is divided into three main components: 1) the description of the prototype in conjunction with HapticLearn 1.0; 2) the results of the pre and post-test of the control and experimental group and the evaluation of the prototype to serve as the evaluation of HapticLearn 1.0; and 3) the discussion of the findings. The architecture of the developed prototype and the mapping of the prototype features reflecting components of HapticLearn 1.0 were described in the first component. The second component, the performance of the control and experimental group in the pre and post-test, and the result of the prototype evaluation is divided into five sections. The first section is to evaluate the ability to remember in both the control group and the experimental group. The second section evaluates the ability to understand in the control group and also the experimental group. The third section is a performance change comparison between the control and experimental groups. The fourth section is the average percentage change in remembering and understanding tasks. The last section is a summary of key observations for remembering and understanding tasks.

The chapter ends with a discussion summarizing the effectiveness of HapticLearn 1.0 as a solution to overcoming accessible learning problems for children with dyslexia. The section serves as an answer to the last research question of the study.

5.1 Development of Prototype HapticLearn 1.0 and Training Phase

The development process of the HapticLearn 1.0 prototype involved a meticulous approach and development tools to ensure a comprehensive and engaging learning environment for dyslexic individuals:

5.1.1 Development Tools

5.1.1.1 Interactive Learning Activities using Unity

The Unity game development environment facilitated the creation of diverse learning activities. The activities were carefully crafted within the Unity game development environment, renowned for its interactive and adaptable features, fostering an immersive learning atmosphere.

5.1.1.2 Multisensory Approach using Blender

Blender, with its sophisticated capabilities, enabled the creation of visually stimulating content, aligning with the multisensory learning needs of dyslexic individuals. The emphasis on high-quality visual representation aimed to cater to diverse learning preferences among students.

5.1.1.3 Tactile Learning Experience using Haptic Device

Integrating a haptic device "Touch X" into the learning framework was a deliberate step to provide a tactile learning experience. This inclusion allows learners to not only see but also physically feel and interact with the educational material, fostering a deeper understanding and memory retention.

5.1.1.4 Accessibility and Inclusivity

The HapticLearn 1.0 prototype was designed with accessibility in mind, ensuring that individuals with dyslexia could access and benefit from the learning content equally. By incorporating innovative technology and tailored content, it aimed to bridge educational gaps and create an inclusive learning environment.

Overall, the HapticLearn 1.0 prototype's development process aimed to merge technological innovation with educational efficacy, emphasizing engagement, accessibility, and effectiveness in catering to the specific learning needs of dyslexic learners.

5.1.2 Architecture of Prototype

The architecture presented in Figure 5.1 details the structure of HapticLearn 1.0, designed to deliver a multisensory educational experience. At the heart of user interaction is the haptic device, which is essential for translating user-generated motions and forces into a digital format that can be processed by the system.

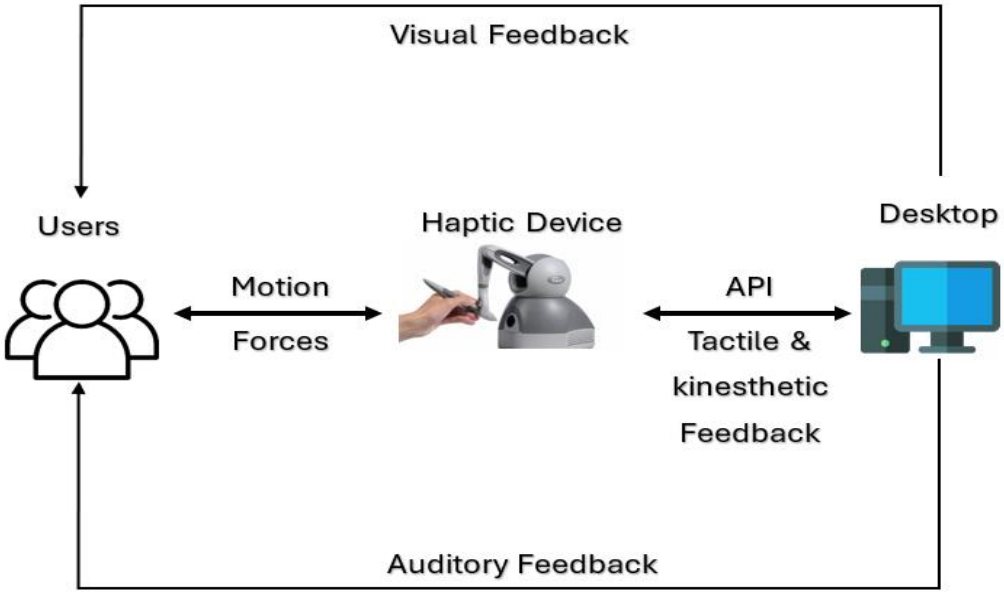


Figure 5.1: Architecture of the Prototype

Users interact with the haptic device by applying various forces and motions. The device captures these physical inputs and communicates them to a desktop computer via an Application Programming Interface (API). This API is crucial as it interprets the analog inputs into a digital signal that the software running on the desktop can understand and manipulate.

The desktop, equipped with the necessary software, likely a Unity-based application, processes these inputs. It generates visual feedback, which is displayed to the user, allowing them to see the outcome of their interactions. Auditory feedback is also provided, augmenting the sensory experience with contextual sounds that correspond to the user’s actions.

Additionally, the desktop system is responsible for generating tactile and kinesthetic feedback, which is sent back to the user through the haptic device. This feedback is precise and nuanced, made possible by the integration of specialized haptic APIs. These APIs enable the haptic device to simulate various textures, resistances, and other physical sensations, thus providing a realistic touch-based experience.

This architecture is reflective of an interactive learning system where feedback loops are integral to the user experience. It allows for real-time adjustments and responses to user actions, creating an immersive and responsive environment. The system is designed to support a dynamic educational experience, making the interactions within HapticLearn 1.0 feel authentic and engaging, and effectively bridging the gap between digital and physical learning tools.

5.2 Training Phase

During the training phase, the experimental group underwent a comprehensive training program with HapticLearn 1.0 spanning 18 days. Each student within the group received focused training sessions lasting 15 minutes per day. This structured approach ensured consistent exposure to the interactive educational content and allowed for the gradual development of cognitive skills. Throughout this period, participants engaged with the full suite of activities outlined in Section 3.2.8, each meticulously designed to target specific learning outcomes.

The 15-minute sessions were carefully calibrated to maximize engagement without overloading the students, providing a balanced rhythm of learning that was tailored to the attention spans and needs of dyslexic learners. The sequence and frequency of the activities were strategically planned to reinforce learning concepts and skills progressively over the 18-day training sessions.

Each session was an opportunity to interact with the innovative features of the HapticLearn 1.0 prototype, including tactile and kinesthetic feedback through the haptic device, visual stimuli rendered via Blender in Unity, and auditory cues integrated through Unity. This immersive, multisensory approach aimed to enhance memory retention, shape and letter recognition, and numeracy skills, all critical components of the learning objectives for children with dyslexia.

This combination of tools, activities, and technologies was helpful in developing a prototype that was educational, engaging, and responsive to the needs of dyslexic children.

The implementation of the HapticLearn 1.0 prototype was a multi-faceted process. Here's how each activity was implemented:

5.2.1 Implementation of Alphabet Shape Exploration

In implementing this activity, Unity scripts were designed to respond to user interaction with each alphabet character. The scripts triggered auditory feedback that pronounced the selected letter, reinforcing cognitive connections. The haptic device was programmed to provide physical resistance when the user's stylus strayed from the letter's path, using Unity's physics engine to simulate boundary lines and giving the learner real-time guidance on proper letter formation as shown in Figure 5.2.

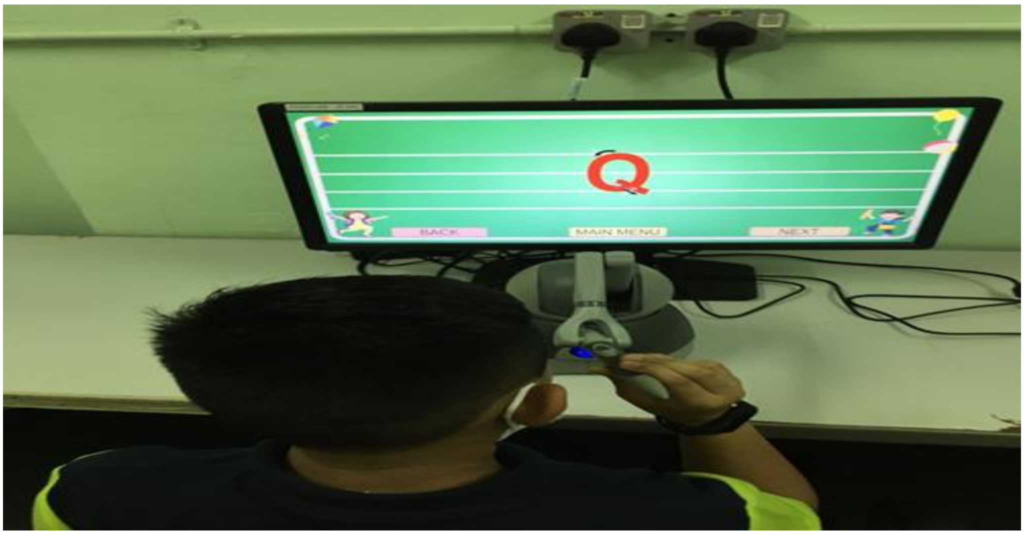


Figure 5.2: Alphabet Shape Exploration Activity

5.2.2 Implementation of Alphabet Painting

Expanding on the shape exploration, this activity transformed alphabet models created in Blender to have open centers as shown in Figure 5.3. Unity's graphical interface allowed users to 'paint' within these structures, with the haptic device delivering force feedback if the stylus moved outside the virtual lines. This not only reinforced the spatial constraints of letter structures but also encouraged precise motor control and memory retention.

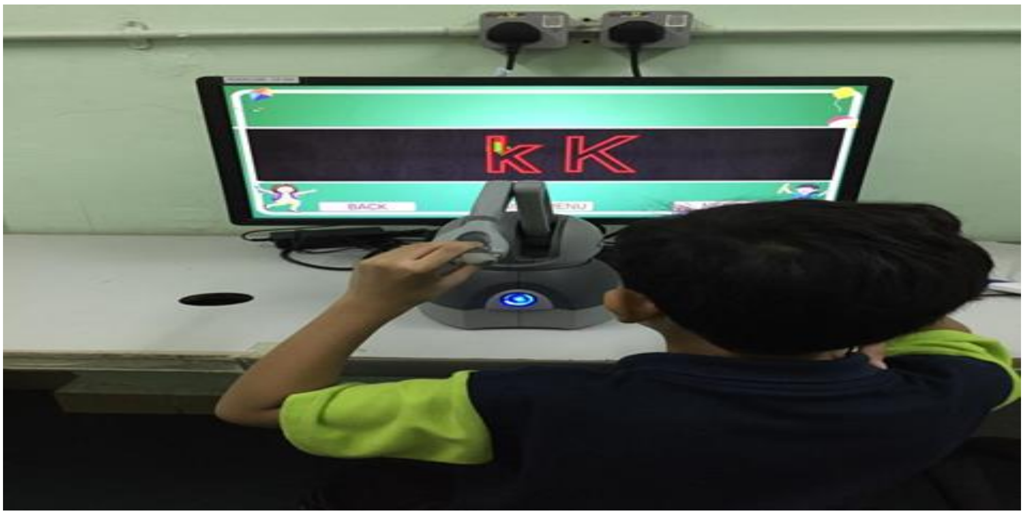


Figure 5.3: Alphabet Painting Activity

5.2.3 Implementation of Digit Exploration

For digits, the implementation mirrored the alphabet shape exploration, with the Unity engine recognizing user interaction with digit models designed in Blender as shown in Figure 5.4. The haptic feedback was fine-tuned to guide the user through the shape of each number, providing a tactile understanding of numerical formation critical to cognitive learning.

Figure 5.4: Digit Shape Exploration Activity

5.2.4 Implementation of Digit Painting

Building upon the digit exploration, this painting activity required additional Unity scripting to recognize correct and incorrect painting paths within the digit structures. The haptic feedback was crucial in guiding the user's hand, ensuring they followed the correct form and order of strokes for each number as shown in Figure 5.5.

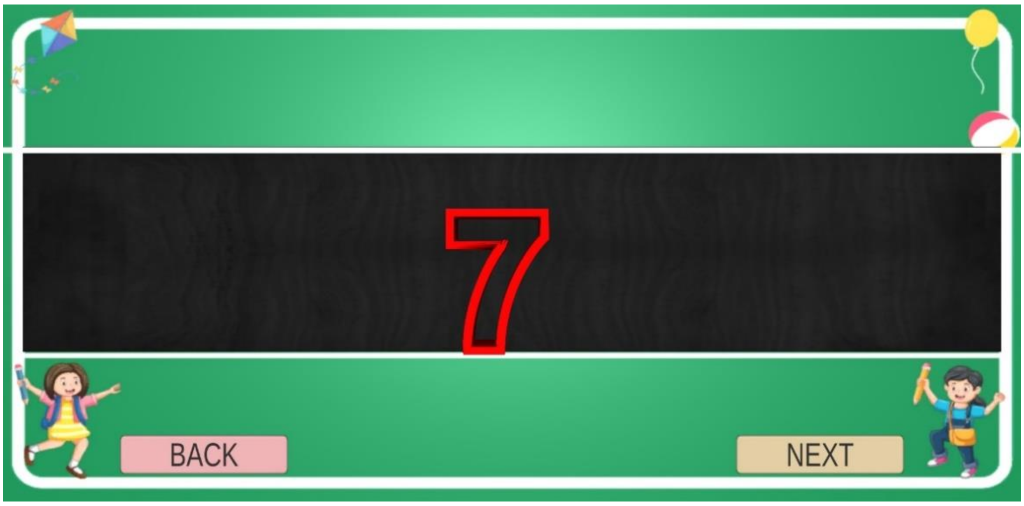


Figure 5.5: Digit Painting Activity

5.2.5 Implementation of Shapes Counting

This activity combined Unity's interaction detection with haptic feedback to create a counting game as shown in Figure 5.6. Users counted shapes by pointing at them with the stylus, receiving corrective force feedback if the count was incorrect. Only upon a correct count would the painting feature unlock, blending the cognitive challenge of counting with the reward of painting.

Figure 5.6: Shapes Counting Activity

5.2.6 Implementation of Shape Coloring

The final activity focused on the coloring of geometric shapes as shown in Figure 5.7. Each shape began with a visual and auditory introduction of its name, implemented through Unity's audio-visual systems. As the user painted, the name of the shape would progressively fill its interior, a feature achieved through Unity's scripting and graphical capabilities. The haptic feedback not only guided the painting process but also reinforced the association between the shape and its name.

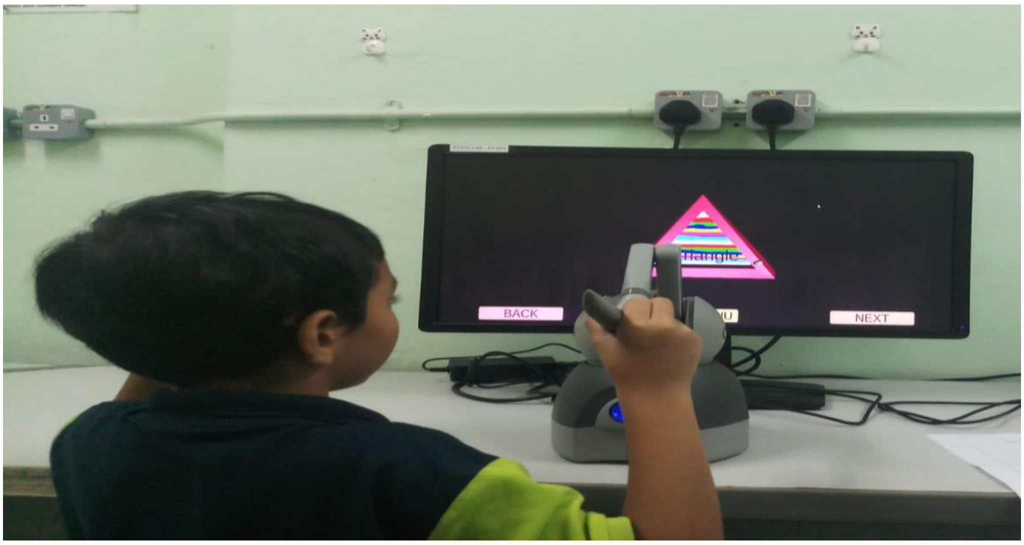


Figure 5.7: Shape Coloring Activity

By the conclusion of the training phase, the experimental group had experienced a rich interactive learning activities, each of which contributed to the development of a comprehensive educational experience.

5.3 Analysis

5.3.1 Results and Analysis of Pre and Post-Test

The analysis presented here seeks to shed light on the cognitive development of dyslexic children, with a specific focus on their cognitive skills related to remembering and understanding. This study aimed to assess the effectiveness of a targeted training intervention designed to improve the cognitive skills of dyslexic children, specifically concentrating on their capacity to remember and understand information. The analysis considered both pre-training and post-training data from two groups: a control group and an experimental group as shown in Figure 5.8.

Figure 5.8: Pre-test and Post-test Activities

The primary objective of this analysis is to determine whether the training program led to significant improvements in the cognitive skills of the experimental group when compared to the control group. To achieve this, we have examined pre-test and post-test scores for both groups across the remembering and understanding tasks, as well as the overall total scores. Appendix C contains the raw results.

The findings from this analysis will not only contribute to our understanding of the cognitive development of dyslexic children but may also inform educational practices and interventions tailored to their specific needs. The outcomes of this study could have far-reaching implications for educators, parents, and researchers working with dyslexic children, as they seek effective methods to improve cognitive skills and enhance the overall learning experience for this unique population.

This analysis, therefore, represents a valuable step towards addressing the challenges faced by dyslexic children, with the potential to guide the development of more effective interventions and educational strategies.

5.3.1.1 Results and Analysis of Tasks for Remembering

In the analysis of the remembering tasks within the Experimental Group, it becomes evident that the haptic-based training program had a pronounced and positive effect on participants' remembering skills. Task REM 1 displayed a moderate initial score of 91.2%, which significantly improved to 99.1% after the 4-week training program, resulting in a notable 7.9% increase as shown in Table 5.1. This enhancement in Task REM 1's performance can be attributed to several factors. The haptic device provided an immersive learning experience, allowing participants to physically engage with and explore alphabet shapes, leading to better retention and recall. The tactile feedback offered by the haptic device, coupled with its capacity to provide immediate corrective feedback when participants deviated from the correct path, contributed to a deeper understanding of the shapes and, consequently, improved remembering.

Table 5.1: Pre-Test and Post-Test Results of Remembering Tasks

Task	Control Group (Pre-Test)	Control Group (Post-Test)	Experimental Group (Pre-Test)	Experimental Group (Post-Test)
REM 1	94.00%	92.30%	91.20%	99.10%
REM 2	72.90%	78.20%	68.20%	92.30%
REM 3	74.70%	80.20%	81.50%	94.40%

Task REM 2 initially displayed a lower score of 68.2% but showed the most substantial improvement, with an impressive 24.1% increase, reaching 92.3% after the training intervention as shown in Table 5.1. Task REM 2's remarkable improvement can be attributed to its potential for substantial enhancement. The haptic device's immersive and multisensory approach likely had a substantial impact on participants. By allowing them to engage with the shapes physically and receive immediate feedback through force feedback, the haptic device reinforced remembering skills significantly. The force feedback feature, in particular, played a crucial role in guiding participants, enabling them to learn more effectively and remember the shapes more accurately.

Task REM 3 had an initial score of 81.5%, which improved to 94.4% in the post-test, demonstrating a 13.0% increase in performance as shown in Figure 5.9. The positive change observed in Task REM 3 can be attributed to the haptic device's ability to engage participants actively in the learning process. The tactile feedback and force feedback aspects of the device likely made the exploration of alphabet shapes more interactive and memorable, contributing to improved remembering. The haptic device's capability to provide immediate corrective feedback likely played a key role in helping participants remember the information more effectively.

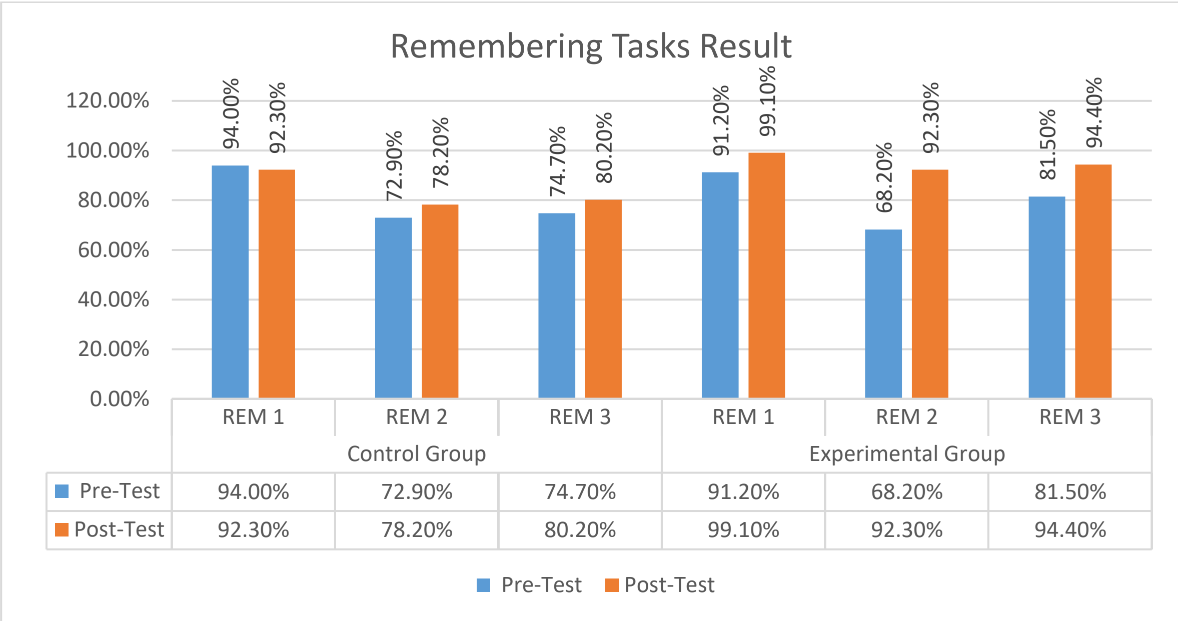


Figure 5. 9: Remembering Tasks Result

Conversely, in the analysis of the remembering tasks within the Control Group, the results presented a different pattern. Task REM 1 in the control group exhibited a slight decrease in performance, starting with a pre-test score of 94.0% and decreasing to 92.3% in the post-test as shown in Figure 5.9. The decrease in Task REM 1's performance may be due to various factors, such as individual differences in learning styles and the specific content of the task. However, in Tasks REM 2 and REM 3, improvements were observed, with increases of 5.3% and 5.6%, respectively. Task REM 2, with an initial pre-test score of 72.9%, improved to 78.2% in the post-test, while Task REM 3, starting with a pre-test score of 74.7%, increased to 80.2% in the post-test as shown in

Figure 5.9. These improvements are likely from the interactive classroom activities.

The impact of the haptic-based training program in the experimental group is more effective as compared to the traditional training program in the control group. While the Experimental Group demonstrated significant improvements in all three remembering tasks, the Control Group's results were more varied, with a slight decline in Task REM 1 but improvements in Tasks REM 2 and REM 3. These findings highlight the effectiveness of haptic-based interventions in enhancing remembering, particularly in specific tasks, and emphasize the value of tailored interventions for individuals with diverse learning abilities. The activities designed to aid users in remembering the shape of each alphabet were effective due to their hands-on and multisensory nature, reinforcing the concept of touch and remembering. The haptic device's realistic touch sensation and capacity to provide immediate feedback contributed to enhanced memory retention and recall.

The haptic-based intervention's engagement of multiple sensory modalities likely played a crucial role in aiding remembering. This multisensory approach, combining visual, auditory, kinesthetic, and tactile modalities, has been shown to be highly effective in enhancing remembering skills by providing diverse and memorable stimuli to the participants. By incorporating tactile, and kinesthetic feedback, the haptic-based training program maximized participants' engagement and memory retention, ultimately contributing to improved performance in remembering-related tasks.

5.3.1.2 Results and Analysis of Tasks for Understanding

In the analysis of understanding tasks within the Experimental Group, it is evident that the haptic-based intervention had a substantial and positive impact on participants' understanding skills. Task UND 1, which required participants to write the lowercase alphabet corresponding to a given uppercase alphabet, displayed a significant improvement, increasing from an initial score of 72.0% to an impressive 95.1% as shown in Figure 5.10. This remarkable 23.1% increase can be attributed to several factors. The haptic device provided a multisensory learning experience that allowed participants to physically engage with alphabet shapes, reinforcing the concept of writing within a four-line structure. The tactile feedback from the haptic device offered a realistic sensation, making the exploration of alphabet shapes more engaging and memorable. Moreover, the immediate corrective feedback provided through force feedback when a participant deviated outside the boundaries of the alphabet ensured a clear understanding of writing, contributing to improved comprehension. The tactile feedback likely contributed to this substantial improvement.

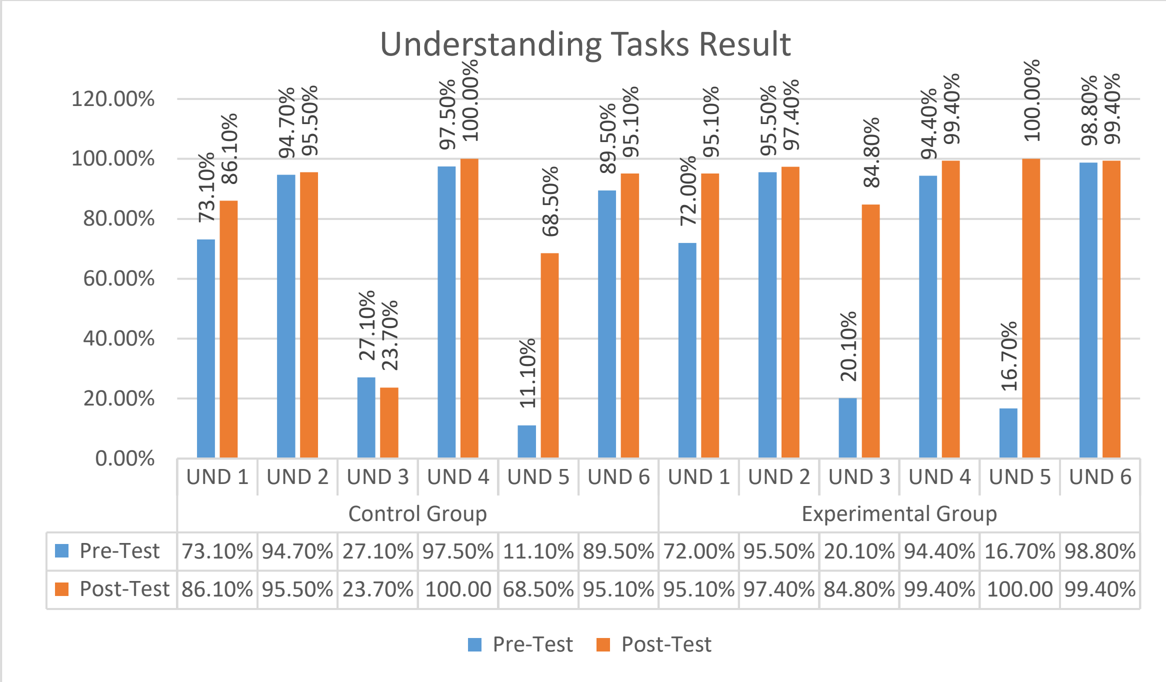


Figure 5.10: Understanding Tasks Result

Task UND 2, which required participants to match lowercase and uppercase alphabets through lines, started with a high initial score of 95.5% and experienced a minor improvement, reaching 97.4% with a 1.9% increase as shown in Table 5.2. While the percentage increase may seem modest, several factors contributed to this improvement. Participants with higher initial scores might have had a more advanced understanding of alphabet shapes and writing structures, leaving less room for substantial improvement. However, the haptic-based intervention still played a role in refining their comprehension by providing additional multisensory reinforcement and immediate corrective feedback. Although the increase in performance for Task UND 2 was smaller than for other tasks, it underlines the effectiveness of the haptic-based approach in further enhancing comprehension skills even for participants who already exhibited strong initial performance.

Table 5.2: Pre-test and Post-test Results for Understanding Tasks

Task	Control Group (Pre-Test)	Control Group (Post-Test)	Experimental Group (Pre-Test)	Experimental Group (Post-Test)
UND 1	73.1%	86.1%	72.0%	95.1%
UND 2	94.7%	95.5%	95.5%	97.4%
UND 3	27.1%	23.7%	20.1%	84.8%
UND 4	97.5%	100.0%	94.4%	99.4%
UND 5	11.1%	68.5%	16.7%	100.0%
UND 6	89.5%	95.1%	98.8%	99.4%

Task UND 3, which involved matching numbers from 1 to 9 with corresponding shapes, initially faced challenges with a score of 20.1% but exhibited a remarkable transformation, improving to 84.8% as shown in Table 5.2. This significant 64.7% increase can be attributed to the engaging and interactive activities that focused on understanding number-symbol relationships. The haptic device's tactile feedback, visual instructions, and auditory cues made learning more interactive, engaging, and memorable, thereby enhancing understanding. The haptic device's force feedback feature was particularly beneficial. It guided participants towards making correct matches by applying a tangible force when an incorrect match was attempted, thus providing immediate corrective feedback. This not only helped in teaching the concept of number-symbol correspondence within a multisensory framework but also ensured that users could quickly understand and learn from their mistakes. The multisensory approach, combining tactile, visual, and auditory elements, created a rich learning environment that significantly enhanced understanding and retention.

Task UND 4, which involved matching shape names to the correct shapes, began with a high score of 94.4% and displayed modest growth, reaching 99.4%, resulting in a 4.9% increase as shown in Figure 5.10. Task UND 4's initial high score indicated that participants had a strong grasp of the understanding skills required for this task. While the increase was moderate compared to other tasks, the haptic-based intervention further reinforced their understanding.

Task UND 5, a writing task, required participants to write uppercase alphabets in a four-line structure. It started with a very low initial score of 16.7% but underwent a substantial improvement, achieving a perfect score of 100.0% in the post-test, representing an impressive 83.3% increase. The system's ability to provide corrective feedback through force feedback when a participant deviated outside the boundaries of the four-line structure played a crucial role. This feature ensured that users received immediate feedback when they made errors, facilitating writing understanding and the learning process.

Task UND 6, which involved counting random shapes and writing the number of shapes in small boxes numbered from 1 to 9, had a high initial score of 98.8% and showed minimal change, increasing to 99.4% with a 0.6% change. Participants with high initial scores may have achieved a peak in their understanding ability for this task. Nonetheless, the haptic-based intervention continued to provide support for reinforcing the concept of counting and shape recognition.

In the Control Group's understanding tasks, Task UND 1 demonstrated a positive change, with a 13.0% improvement, likely due to the engagement and motivation of some participants as shown in Figure 5.10. Task UND 2 displayed only minor growth, suggesting that participants with higher initial scores may have had less room for improvement. Task UND 3 faced challenges, with a decline of -3.4%, indicating potential individual differences and challenges within the content of the task. Task UND 4 showed a modest 2.5% improvement, likely indicating that participants had a strong grasp of the comprehension skills required for this task. Task UND 5 exhibited a notable 57.4% increase. Task UND 6 showed little increase, implying that participants with high beginning scores may have met an upper limit in their understanding ability for this task. These diverse responses in the Control Group highlight the importance of considering participants' initial abilities, motivation, and task content when implementing haptic-based interventions to enhance understanding, reinforcing the need for tailored interventions to address cognitive skill deficits effectively.

5.3.1.3 Performance Change Comparison between Control and Experimental Group

The Table 5.3 provides a detailed comparison of the performance percentage changes in cognitive skill improvements between the control and experimental groups, broken down by specific remembering (REM) and understanding (UND) tasks. It allows for a quick assessment of which tasks showed the most substantial differences in improvement between the two groups.

Table 5.3: Performance Percentage Change Comparison between Control Group and Experimental Group

Task	Control Group Percentage Change	Experimental Group Percentage Change
REM 1	-1.7%	7.9%
REM 2	5.3%	24.1%
REM 3	5.6%	13.0%
UND 1	13.0%	23.1%
UND 2	0.9%	1.9%
UND 3	-3.4%	64.7%
UND 4	2.5%	4.9%
UND 5	57.4%	83.3%
UND 6	5.6%	0.6%

Table 5.3 highlights the tasks where the experimental group had a significantly higher percentage change compared to the control group, indicating the effectiveness of the training program. The analysis reveals the following key insights:

The data highlights task-specific variations in percentage changes. In remembering tasks (REM 1, REM 2, and REM 3), the experimental group consistently outperforms the control group. The most notable difference is observed in REM 2, with the experimental group exhibiting a remarkable percentage change of 24.1%, compared to the control group's 5.3% as shown in Figure 5.11. This indicates the prominent impact of the training program on specific remembering-related tasks. In understanding tasks (UND 1 to UND 6), task-specific differences are even more apparent. UND 3, in particular, stands out with the experimental group displaying a substantial percentage change of 64.7%, while the control group demonstrates a decrease of -3.4%. This stark difference suggests that the training program had a transformative effect on understanding-related cognitive skills, especially in task UND 3.

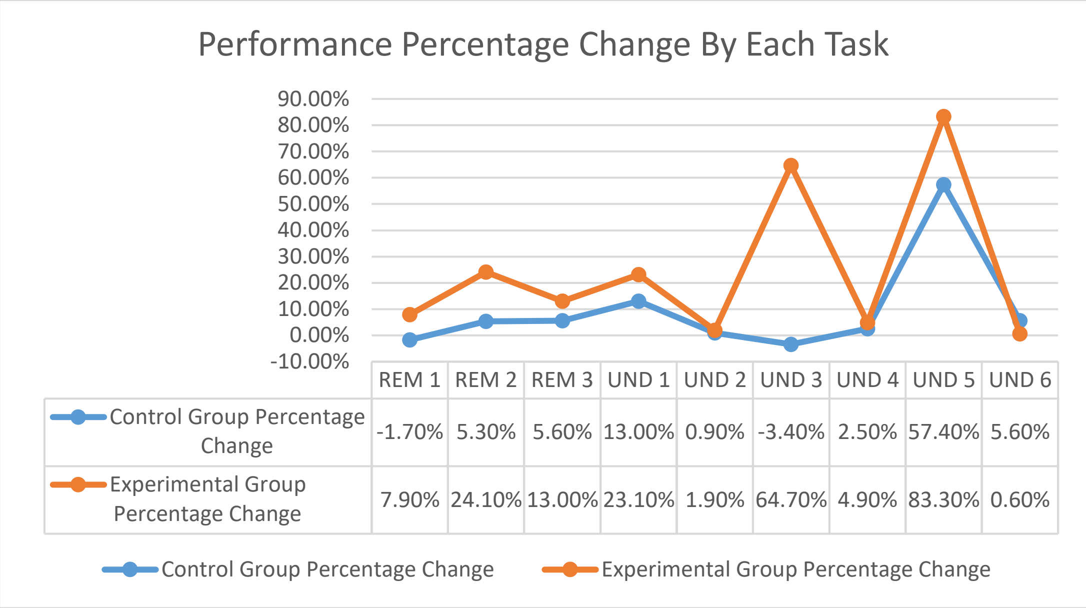


Figure 5.11: Performance Percentage Change

The interactivity of the haptic-based activities encouraged active engagement and participation. Users were not passive observers but actively involved in shaping and exploring alphabets. Interactivity is known to enhance learning, understanding, and remembering. Haptic devices can often be customized to suit individual learning preferences and abilities. The ability to tailor the learning experience to each participant's needs may have played a role in improving results.

5.3.1.4 Average Percentage Change in Remembering and Understanding Tasks

The Table 5.4 presenting the average percentage change in remembering and understanding tasks for both the control and experimental groups offers a concise summary of the overall improvements in cognitive skills.

Table 5.4: Average Percentage Change in Remembering and Understanding Tasks

Task Type	Control Group Average Percentage Change	Experimental Group Average Percentage Change
Remembering	3.53%	14.97%
Understanding	12.58%	27.28%

This analysis explores the implications of the average percentage changes and their significance:

On average, the experimental group demonstrated a 14.97% increase in remembering task performance, while the control group showed a more modest 3.53% improvement as shown in Table 5.4 and Figure 5.12. This significant difference indicates that the experimental group experienced substantially greater improvements in remembering-related tasks, highlighting the positive impact of the training program.

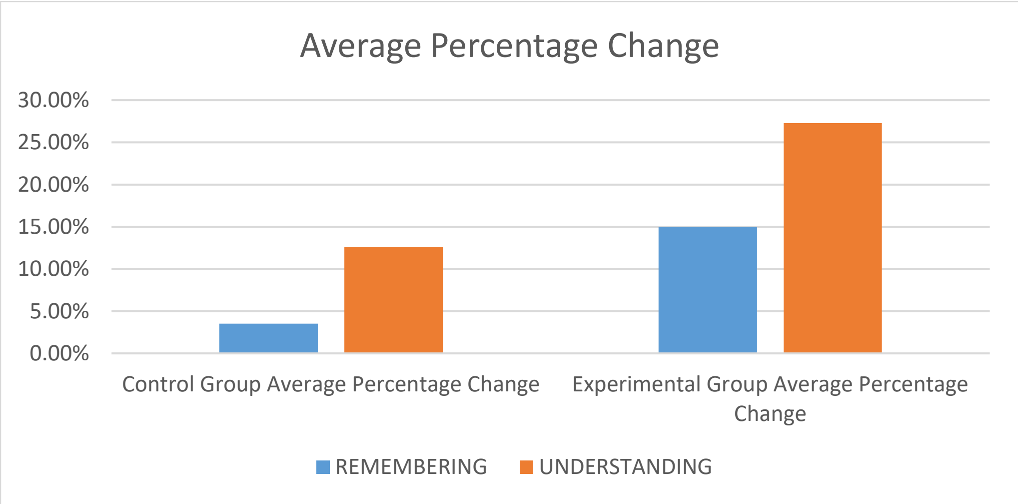


Figure 5.12: Average Percentage Change

Similarly, the experimental group exhibited an average percentage change of 27.28% in understanding tasks, whereas the control group showed an average change of 12.58% as shown in Table 5.4. The higher average percentage change in the experimental group highlights the training program's effectiveness in enhancing understanding-related cognitive skills.

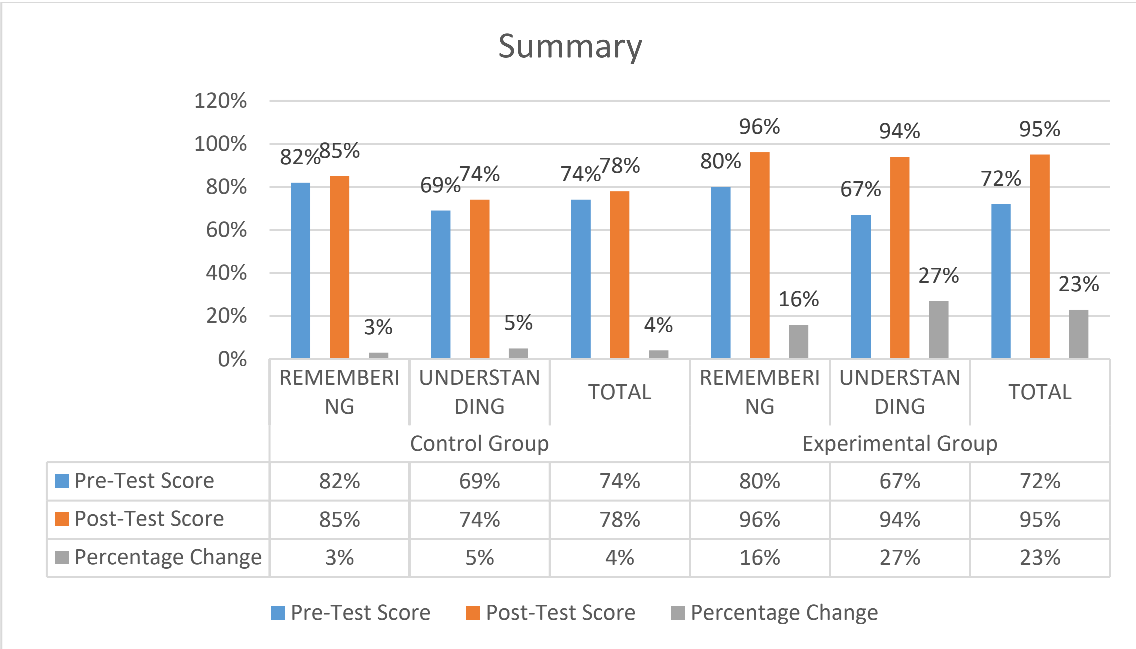
5.3.2 Summary of Key Observations for Remembering and Understanding Tasks

The Table 5.5 presents a comprehensive overview of the performance results for both the Control Group and the Experimental Group across remembering and understanding tasks. Here is a detailed discussion of the statistics provided in the Table 5.5:

Table 5.5: Summary of Key Observations for Remembering and Understanding Tasks

Group	Task	Pre-Test Score	Post-Test Score	Percentage Change	Key Observations
Control Group	Remembering	82%	85%	3%	Modest improvement in routine classes
	Understanding	69%	74%	5%	
	Total	74%	78%	4%	
Experimental Group	Remembering	80%	96%	16%	Significant improvement with training
	Understanding	67%	94%	27%	
	Total	72%	95%	23%	

In remembering tasks, the Control Group started with a pre-test score of 82% and achieved a post-test score of 85%, reflecting a 3% increase as shown in Figure 5.13. This modest improvement suggests that traditional classroom methods and non-technological approaches contributed to a small but positive change in remembering-related skills. For understanding tasks, the Control Group began with a pre-test score of 69% and improved to a post-test score of 74%, resulting in a 5% increase as shown in Table 5.5. This more notable enhancement indicates that conventional teaching methods were more effective in promoting understanding skills among participants. In the combined analysis of remembering and understanding tasks, the Control Group exhibited a 4% overall improvement, emphasizing the overall effectiveness of non-technological approaches in enhancing learning outcomes.



	Control Group: REMEMBERING	Control Group: UNDERSTANDING	Control Group: TOTAL	Experimental Group: REMEMBERING	Experimental Group: UNDERSTANDING	Experimental Group: TOTAL
Pre-Test Score	82%	69%	74%	80%	67%	72%
Post-Test Score	85%	74%	78%	96%	94%	95%
Percentage Change	3%	5%	4%	16%	27%	23%

Figure 5.13: Summary of Results

The Experimental Group demonstrated a substantial 16% improvement in remembering tasks. Commencing with a pre-test score of 80%, the group achieved an impressive post-test score of 96%. This remarkable increase highlights the significant impact of the innovative haptic-based training program on remembering-related skills. The haptic device's multisensory approach, combining visual, auditory, kinesthetic, and tactile elements, likely played a pivotal role in enhancing remembering retention. In the understanding tasks, the Experimental Group excelled with an outstanding 27% increase in performance. The pre-test score of 67% surged to a post-test score of 94%. This substantial difference emphasizes the effectiveness of the haptic-based training program in boosting participants' ability to understand and process information. The force feedback feature of the haptic device likely contributed significantly to this improvement. Overall, the Experimental Group demonstrated a remarkable 23% improvement when combining remembering and understanding tasks. This emphasizes the significant advantages of haptic-based interventions for remembering and understanding skills and highlights the efficacy of haptic technology in enhancing learning outcomes.

In summary, the statistics in Figure 5.13 highlight the considerable benefits of haptic-based interventions over traditional teaching methods. The Experimental Group exhibited substantial improvements in both remembering and understanding tasks, significantly outperforming the Control Group. These findings underline the pivotal role of haptic technology in enhancing remembering and understanding skills and the value of tailored interventions for diverse learning needs.

The use of a haptic device allowed participants to receive tactile feedback when exploring the shapes of alphabets. This tactile and kinesthetic feedback provided a physical sensation that helped users understand and remember the shape of each alphabet. The force feedback from the stylus allowed users to feel the contours and boundaries of the alphabet, enhancing their sensory experience. The integration of corresponding auditory cues and visual with each selected alphabet added a multisensory dimension to the learning process. Auditory and visual cues can reinforce the memory and recognition of alphabet shapes by engaging all the senses touch, kinesthetic, visual, and hearing. This combination of multisensory feedback likely contributed to improved learning outcomes.

The low latency between user actions and haptic feedback ensures that participants receive immediate responses when touching or exploring alphabet shapes. This quick feedback loop contributes to effective learning.

5.4 Discussion

The findings show that introducing haptic-based intervention to the learning process of dyslexia is more effective than ordinary classroom interventions. The experimental group that intervenes with the haptic-based game activities showed significant improvement compared to the control group that intervenes with ordinary classroom interventions. The Control Group showed modest improvements in both remembering and understanding tasks. These improvements were likely a result of ordinary classroom instruction. In contrast, the Experimental Group demonstrated significant improvements in both task categories. Their remarkable percentage changes indicate the effectiveness of haptic-based training in enhancing cognitive skills.

The success of haptic-based interventions in improving cognitive skills for individuals with dyslexia goes beyond the individual properties of the haptic device and the designed learning activities. A strong and successful learning experience is produced by the interaction of these components.

Previous research has established the potential benefits of multisensory learning for dyslexic individuals, particularly emphasizing visual and auditory modalities [136, 137]. Previous studies also shown that incorporating visual and auditory cues can significantly improve reading and comprehension skills among dyslexic learners [138, 139]. However, the integration of haptic feedback into learning interventions remains relatively underexplored [4]. Our study extends this body of work by incorporating tactile and kinesthetic feedback, providing a more comprehensive multisensory learning experience. The tactile feedback from the haptic device makes the learning process more engaging and memorable, allowing participants to physically feel and internalize the shapes of the alphabet. The tactile feedback helps users not only remember the shapes but also understand the subtle contours and boundaries of each alphabet. The incorporation of tactile and kinesthetic feedback is particularly effective for dyslexic individuals, who often prefer interactive and sensory-rich learning environments.

Furthermore, the integration of auditory cues with the alphabet shapes adds depth to the learning experience, reinforcing memory and recognition [140]. This multisensory approach aligns with previous findings that dyslexic individuals benefit from engaging multiple senses during learning. Previous studies have demonstrated the effectiveness of multisensory learning strategies in improving phonological processing [137]. However, our study uniquely highlights the importance of kinesthetic movements, which were encouraged by the haptic device. Dyslexic individuals often benefit from physical and interactive approaches to learning and the force feedback from the stylus guided participants to stay within the boundaries of the alphabet, teaching the concept of writing within the four-line structure. These kinesthetic and tactile elements ensures that the learning is not abstract but grounded in practical experience.

The effectiveness of haptic-based interventions in enhancing cognitive skills for individuals with dyslexia isn't solely attributed to tactile feedback, auditory cues, and kinesthetic engagement. Visual appearance also plays a significant role in shaping the learning experience.

The visual aspects of the learning activities, particularly the appearance of alphabets, digits, and shapes, are designed to be visually appealing and engaging. Visual stimuli are known to capture attention and facilitate learning. In the case of dyslexic individuals, who may have varying degrees of visual processing strengths, the visual appeal of the activities can enhance their motivation and focus.

When participants open an alphabet activity and are presented with a visually attractive representation of an alphabet, their initial engagement is often heightened. This visual appeal creates a positive first impression and encourages participants to delve into the activity with curiosity. For individuals with dyslexia, who may have experienced challenges and frustrations with traditional learning materials, the visually engaging aspect of haptic-based interventions can be a welcome change.

Previous work has emphasized the visual and auditory aspects of learning interventions for dyslexic individuals [4, 141]. Our study introduces the significant role of tactile and kinesthetic feedback. The visually appealing and engaging learning activities, combined with immediate error correction, make the learning process tangible and understandable for dyslexic learners. This holistic approach to multisensory learning is a novel contribution to the field.

In addition, the immediate error correction provided by the haptic device is invaluable. Previous studies have noted the challenges dyslexic individuals face with accuracy in writing and understanding structures [142]. The real-time feedback helps them correct errors and learn from their mistakes, contributing to a more effective learning process. This feature ensures that participants receive guidance when they need it the most, further enhancing their understanding. Research supports the concept that immediate feedback can significantly enhance learning outcomes for students with learning disabilities [143].

The designed learning activities align perfectly with the properties of the haptic device. The activities are structured to improve both the remembering and understanding of alphabets, digits, and shapes. By allowing participants to feel and paint these elements, they are reinforcing their remembering and comprehension of these structures. Additionally, understanding the concept of writing within the four-line structure is a critical skill, and these activities make this concept tangible and understandable.

Additionally, our work highlights the importance of integrating cognitive and motor skill development within haptic-based interventions. Previous studies, have shown that motor skills play a crucial role in cognitive development and learning in children with dyslexia [144]. By incorporating these elements into our haptic-based interventions, we provide a more well-rounded educational experience that addresses both cognitive and motor deficits observed in dyslexic individuals.

In conclusion, the success of haptic-based interventions for individuals with dyslexia is a testament to the thoughtful combination of tactile feedback, multisensory integration, kinesthetic involvement, and immediate error correction. This synergy creates a highly effective learning environment that caters to the unique needs of dyslexic individuals. By addressing their preferences for interactive and multisensory learning, haptic-based interventions have the potential to significantly enhance the cognitive skills of individuals with learning difficulties, and these findings open up exciting possibilities for innovative and inclusive educational approaches in the future.

5.5 Summary

A prototype has been developed and is mapped to match the design elements of the conceptual model. The prototype validation results show a modest improvement of 3% in remembering, 5% in understanding, and an overall 4% change in the performance of the control group which follows the routine classes. On the other hand, a significant improvement of 16% in remembering, 27% in understanding, and overall 23% in performance change occurs in the results of the experimental group who attended the training session. The reported results are at a satisfactory level.

This shows that efficiency and effectiveness exist in the HapticLearn 1.0 for children with dyslexia. A huge improvement could be seen in all results, thus indicating that the developed prototype made a big difference in enhancing the learning accessibility of children with dyslexia. Adding on to this, the remembering tasks result shows the ability of the children with dyslexia to recall the information. The understanding tasks result shows the ability of the children with dyslexia to grasp the concept. it can be said that the prototype offers an accessible learning environment for children with dyslexia, facilitating cognitive development.

A discussion on the results of pre and post-tests and validation of the prototype has been highlighted. The achievement of the prototype in fulfilling the identified problems faced by children with dyslexia is also described. HapticLearn 1.0 significantly improves learning accessibility due to components in the model reflecting the sensory-motor skills and cognitive skills of children with dyslexia. In conclusion, a design environment resembling the expectations, imagination, experience, and knowledge of children with dyslexia provides a better learning environment.

CHAPTER 6

CONCLUSION

This chapter describes the overall success of the research in finding a solution to the research questions and achieving the research objectives. It also summarizes the advantages and disadvantages of using HapticLearn 1.0 to improve learning accessibility for dyslexic children. Aside from that, the research contribution and the prototype's limitations have been highlighted in order to learn about the findings' weaknesses. The section is followed by a conclusion, which summarizes the entire research. Finally, the chapter discusses potential research in the future.

6.1 Research Summary

6.1.1 The Findings of the Research in Achieving the Research Questions

This section describes the achievement of the research in devising the solutions for the generated research questions. The research questions are listed below:

1) What are the haptic interventions practiced on dyslexic children in Malaysia?

Our research has revealed that the state of haptic interventions for dyslexic children in Malaysia is still in its formative stage. Through an extensive literature review, methodical observations at dyslexic centers, and in-depth interviews with educational experts and technologists, we have identified a distinct gap in the deployment of haptic technology in educational settings. Current haptic interventions are primarily manifested through non-technological means, such as the use of physical objects and materials that provide tactile feedback to the students. These methods, while beneficial, are not complemented by advanced technological solutions that could potentially offer a more nuanced and interactive haptic experience.

Furthermore, our findings suggest that while there is a foundational understanding of the benefits of haptic feedback in learning, particularly for children with dyslexia who may have distinct sensory processing needs, this understanding has not been widely translated into practice within the technological domain. The limited use of technology-based haptic interventions can be attributed to a range of factors, including insufficient infrastructure, a lack of awareness or expertise in developing such interventions, and limited availability of specialized tools that are tailored to the needs of dyslexic learners.

In many of the dyslexic centers we observed, there was a clear reliance on traditional teaching aids and a noticeable absence of interactive, haptic-enabled devices that could stimulate learning through touch, motion, and physical interaction. This is in contrast to more technologically advanced educational environments, where haptic devices are used to enhance learning by simulating real-world experiences or by providing immediate feedback to the learner.

The interviews with experts in the field also highlighted a sense of untapped potential in the realm of haptic technology. While the experts acknowledged the promise of haptic interventions, they also expressed concerns regarding the readiness of educational institutions to adopt such technologies, the training required for educators to effectively incorporate them into their teaching, and the overall cost implications.

Despite these challenges, the initial stages of haptic intervention in Malaysia offer a fertile ground for innovation and growth. The research conducted lays a foundation for further exploration into how haptic technology can be developed and integrated into learning programs for dyslexic children. There is a clear opportunity to build upon the existing knowledge and interest in multisensory learning to create more immersive, interactive, and effective educational experiences that can cater to the unique learning styles of dyslexic students. With targeted investment, interdisciplinary collaboration, and a commitment to inclusive education, Malaysia can progress toward more sophisticated and technologically integrated haptic interventions that truly enhance the learning journey for children with dyslexia.

2) How to develop haptic intervention incorporating motor skills and cognitive skills elements for dyslexic children in Malaysia?

Developing a haptic intervention that incorporates motor skills and cognitive skills elements for dyslexic children in Malaysia, our process follows a meticulous and multi-step approach. Initially, the crucial task is the identification of key elements necessary for the intervention. This stage involves extensive research, including thorough observation, interviews with experts, and literature reviews. This foundational research helps in pinpointing the essential aspects, particularly focusing on enhancing motor and cognitive skills.

Our research suggests an innovative approach to help Malaysian children who are dyslexic by developing haptic interventions that combine elements of motor and cognitive skills. The core of our effort is our HapticLearn 1.0 model, which makes strategic use of haptic technologies and multimodal approaches. Our approach is based on the theory that children with dyslexia do better in a multimodal classroom that encourages active participation from all senses.

The HapticLearn 1.0 model emphasizes the importance of technology that extends beyond visual and auditory stimuli. It supports the incorporation of tactile and kinesthetic interactions that simulate physical experiences. This type of haptic technology helps to encourage motor skill development while also engaging cognitive processes including remembering, spatial thinking, and understanding.

The developed model, named HapticLearn 1.0, acts as a crucial guide for designers focusing on educational technology for dyslexic learners. The verification results, as detailed in Table 4.3, demonstrate that designers are capable of comprehending the content of HapticLearn 1.0. The components of HapticLearn 1.0 provide a clear understanding of the role of design elements in creating computer applications tailored for those with dyslexia. With this knowledge, designers are better equipped to incorporate these design elements into their work, thereby enhancing the effectiveness and learning accessibility of computer applications for dyslexic users. This understanding is vital for developing tools that not only engage dyslexic learners but also support their unique learning needs in a more effective manner.

The validation results of the prototype testing, as presented in Table 5.5 and Figure 5.13, are quite telling regarding the effectiveness of the HapticLearn 1.0 model. The scores achieved in categories such as remembering, understanding, and overall performance change in learning are in a favorable range. This indicates that dyslexic users respond positively to HapticLearn 1.0, finding it convincing and beneficial. Notably, there's a visible overall improvement in performance, signifying the development of cognitive skills among these users.

Furthermore, the comparative results from the control group and the experimental group reveal a significant impact of HapticLearn 1.0 on the learning of dyslexic children who participated in the HapticLearn 1.0 training. In contrast, the control group, which did not engage with the HapticLearn 1.0 intervention, did not show similar levels of improvement. This distinction highlights the effectiveness of the HapticLearn 1.0 model in enhancing the learning experience of dyslexic children.

Therefore, it can be concluded that the design of computer applications for dyslexic learners has been substantially enhanced by the development of the HapticLearn 1.0 conceptual model. This model has effectively addressed the contribution and importance of each design element in relation to facilitating the learning process for dyslexic users. By doing so, it has created a more accessible and supportive learning environment, tailored to the unique needs and learning styles of dyslexic individuals.

6.1.2 The Findings of the Research in Achieving the Research Objectives

This section describes the undertaken methods and the generated results in achieving the objectives of the study. The objectives are as listed below:

Objective 1: To study the existing haptic interventions practiced on dyslexic children in Malaysia.

The first objective of our research, which focuses on understanding the haptic interventions practiced on dyslexic children in Malaysia, reveals a landscape that is still evolving. Our comprehensive investigation, including a literature review, observations at dyslexic centers, and in-depth interviews with educational experts and technologists, has uncovered a significant gap in the use of advanced haptic technology within educational settings for dyslexic learners.

Our findings indicate that current haptic interventions in Malaysia predominantly involve non-technological means. These include the use of physical objects and materials that provide tactile feedback, which, while beneficial, lack the depth that more sophisticated technological solutions could offer. Such advanced solutions could provide a more nuanced and interactive haptic experience, enhancing the learning process for children with dyslexia, who often have unique sensory processing needs.

Despite a general understanding of the benefits of haptic feedback in learning, especially for dyslexic children, this knowledge has not been extensively implemented in practice, particularly in the realm of technology-based interventions. The reasons for this limited implementation range from insufficient infrastructure and a lack of awareness or expertise in developing such interventions to the limited availability of specialized tools designed specifically for the needs of dyslexic learners.

In our observations of various dyslexic centers, we noticed a reliance on traditional teaching aids and a notable absence of interactive, haptic-enabled devices. This contrasts starkly with more technologically advanced educational environments, where such devices are used to simulate real-world experiences or provide immediate feedback, thereby significantly enhancing the learning process.

Interviews with field experts highlighted the untapped potential of haptic technology. While acknowledging the benefits, experts also pointed out the challenges faced by educational institutions in adopting these technologies, such as the need for specialized training for educators and the cost implications.

However, the current state of haptic intervention in Malaysia, despite its challenges, presents a fertile opportunity for innovation and growth. Our research lays the groundwork for further exploration into the development and integration of haptic technology in learning programs for dyslexic children. There is immense potential to build on the existing knowledge of multisensory learning and create more immersive, interactive, and effective educational experiences that cater specifically to the learning styles of dyslexic students. With focused investment, cross-disciplinary collaboration, and a dedication to inclusive education, there's a promising path ahead for Malaysia to advance toward more sophisticated and technologically integrated haptic interventions. These interventions could significantly enhance the educational experience and outcomes for children with dyslexia.

Objective 2: To propose an accessibility framework incorporating haptics elements to facilitate the learning process of dyslexic children in Malaysia.

The second objective of our research involves proposing an accessibility framework that integrates haptic elements to enhance the learning experience for dyslexic children in Malaysia. This initiative, centered on the development of the HapticLearn 1.0 model, is a comprehensive response to the unique educational requirements of dyslexic learners. At the heart of this objective is the identification of key haptic elements that are instrumental in supporting the development of motor and cognitive skills in dyslexic children. This involves a deep dive into understanding how tactile feedback and kinesthetic interactions can be effectively utilized within educational tools to create a more engaging and beneficial learning environment.

The HapticLearn 1.0 model is crafted with a strategic emphasis on multimodal learning, recognizing the enhanced outcomes achieved when dyslexic children are engaged through multiple senses. The model goes beyond conventional auditory and visual stimuli, incorporating tactile and kinesthetic elements that mirror real-world experiences. This approach is designed to foster a more immersive learning experience, aiding in the retention and understanding of new information.

Central to the design of the HapticLearn 1.0 model is a user-centered approach, ensuring that the specific needs and learning styles of dyslexic children are at the forefront. The model includes tailored feedback and guidance mechanisms, providing a personalized educational experience that adapts to each learner’s unique requirements.

The validation and refinement of the framework form a crucial part of our research process. Through expert evaluations, the HapticLearn 1.0 model is rigorously assessed to ensure its effectiveness and practicality in the educational context of dyslexic children in Malaysia for framework validation. Feedback from these evaluations is instrumental in fine-tuning the framework, ensuring its relevance and impact.

Finally, the implementation of the HapticLearn 1.0 model entails comprehensive training for educators and its integration into current educational practices. This step is vital to realize the full potential of haptic technology in enriching the learning journey of dyslexic children. Moreover, the model is subject to continuous evaluation and improvement, keeping pace with technological advancements and evolving educational needs.

In summary, through this objective, our research aims to make a significant contribution to the educational landscape for dyslexic children in Malaysia. The HapticLearn 1.0 model is not just a technological intervention but a holistic approach to creating a supportive and effective learning environment tailored to the needs of dyslexic learners.

Objective 3: To evaluate the proposed accessibility framework heuristically with domain experts in Malaysia.

The third objective of our study was established to complement and support the aims outlined in the second objective. This objective involved a meticulous process of validating and verifying the design elements of our HapticLearn 1.0 model, ensuring its effectiveness in improving the accessibility of computer applications for dyslexic learners. To achieve this, we translated the design elements of the HapticLearn 1.0 model into a prototype, which was then tested among dyslexic users. This testing was crucial in providing empirical evidence to affirm that the HapticLearn 1.0 model is not only theoretically sound but also functional and effective in real-world settings.

The verification process of the model involved a panel of experts from industries related to education and technology. These experts evaluated the relationship of the components within the HapticLearn 1.0 model in relation to our study's objective of creating accessible computer applications for dyslexic users. The results, as presented in Table 4.3, indicated positive feedback from these experts. This feedback is significant as it confirms the model’s understandability and applicability from a designer's perspective, validating the role of each design element in meeting the study's objectives.

Following the expert verification, the validation process focused on testing the prototype's functionality based on cognitive development. The results, detailed in Table 5.5 and Figure 5.13, showed positive responses from the test subjects, affirming the success of the prototype, model, and framework validation.

In summary, the successful completion of the third objective demonstrates the practical applicability and effectiveness of the HapticLearn 1.0 model. This achievement marks a significant step in our work to improve the learning accessibility of computer applications for dyslexic learners, ensuring HapticLearn 1.0 has the elements necessary for enhanced learning.

6.2 Contribution of Research

6.2.1 Theoretical Contribution

The theoretical contributions of the research to the field of educational technology and dyslexia research are multifaceted and significant. These contributions reflect upon and extend the current state-of-the-art in several key areas:

6.2.1.1 Reflection on Current State-of-the-Art

HapticLearn 1.0 offers a critical examination and reflection of the existing body of knowledge and practices in the realm of educational technology for dyslexic learners. It provides a comprehensive overview of current methodologies and interventions, highlighting both their strengths and limitations. Current educational practices for dyslexic learners often emphasize multisensory approaches, incorporating visual aids, auditory feedback, and interactive multimedia. These methods have proven beneficial in enhancing reading and comprehension skills, as evidenced by improved phonological processing and reading accuracy in dyslexic individuals who use such tools. However, there are notable gaps, particularly in the integration of tactile and kinesthetic feedback within these interventions. Most existing tools lack the capacity to provide real-time, physical interaction with learning materials, a crucial component for dyslexic learners who benefit from hands-on, experiential learning. Additionally, many interventions do not fully address the development of motor skills alongside cognitive skills, a critical aspect for tasks involving writing and fine motor coordination. By integrating haptic feedback and motor skill activities, HapticLearn 1.0 addresses these gaps, offering a more holistic and effective learning experience. This approach not only supports literacy and linguistic skills but also enhances overall neurodevelopment, providing a more robust educational tool for dyslexic learners.

6.2.1.2 HapticLearn 1.0 – An Improved Knowledge

This model contributes to an enhanced understanding of how haptic technology can be effectively integrated into educational practices. It bridges the gap between theoretical knowledge and practical application, offering an innovative approach to multisensory learning. HapticLearn 1.0 enriches the academic discourse by providing a new perspective on how tactile and kinesthetic feedback can be employed to support dyslexic learners. By utilizing advanced haptic devices, this model enables learners to engage with educational content in a more interactive and immersive manner, which has been shown to improve retention and comprehension significantly. It addresses the shortcomings of traditional methods that often overlook the importance of physical interaction in the learning process. Furthermore, HapticLearn 1.0 incorporates evidence-based strategies from recent studies on neuroplasticity, demonstrating how consistent tactile engagement can facilitate the development of new neural pathways, thereby enhancing cognitive functions. This model also presents practical implications for educators and curriculum developers, suggesting ways to seamlessly integrate haptic technology into existing educational frameworks, thus fostering a more inclusive and effective learning environment for dyslexic students.

6.2.1.3 Latest Accessible Learning Problems & Impact on Dyslexic Children

The research behind HapticLearn 1.0 delves into the latest challenges in accessible learning, particularly focusing on the unique needs of children with dyslexia. It sheds light on how traditional educational methods may fall short in addressing these needs and the potential consequences of these shortcomings. Many conventional teaching approaches rely heavily on text-based instruction and rote memorization, which can be particularly challenging for dyslexic learners who often struggle with reading and processing written information. The model highlights the necessity for more inclusive and adaptable learning tools and methodologies that cater to diverse learning styles and sensory preferences.

In addition, it examines the impact of inadequate support on the academic performance and self-esteem of dyslexic children, emphasizing the long-term effects such as increased dropout rates and reduced career opportunities. By analyzing current gaps in the education system, HapticLearn 1.0 highlights the critical importance of early intervention and the integration of multisensory techniques to enhance learning outcomes. The research also discusses the role of technology in creating more engaging and effective learning experiences, suggesting that tools like haptic devices can provide the tactile and kinesthetic feedback that dyslexic learners need to thrive. This model aims to drive a paradigm shift in educational practices, advocating for a more holistic approach that not only addresses academic skills but also supports the emotional and psychological well-being of dyslexic students.

6.2.1.4 Empirical Evidence on Cognitive Improvement

One of the most critical contributions of HapticLearn 1.0 is the empirical evidence it provides regarding cognitive improvements in dyslexic children. Through prototype testing and validation, the model demonstrates how specific haptic interventions can lead to measurable improvements in cognitive functions such as remembering, understanding, and applying knowledge. This evidence is gathered through rigorous experimental designs, including control and experimental groups, which reveal significant performance gains in tasks requiring memory retention and comprehension among students exposed to haptic-based learning activities.

Moreover, the data showcases improvements not only in academic-related tasks but also in enhancing spatial awareness, fine motor skills, and overall engagement in the learning process. These findings highlight the multifaceted benefits of haptic feedback, illustrating how it can cater to various cognitive domains beyond traditional text-based learning methods. This empirical evidence serves as a significant alert to educators and policymakers about the potential benefits of incorporating haptic-based interventions in educational programs for dyslexic learners. It emphasizes the need for integrating such innovative technologies into mainstream education to provide a more inclusive and effective learning environment. Furthermore, the documented improvements call for further research and investment in developing and refining haptic learning tools to maximize their educational impact.

In summary, the theoretical contributions of HapticLearn 1.0 are substantial, offering new insights and understandings that challenge and extend the current state-of-the-art. By providing a comprehensive, empirically backed model, HapticLearn 1.0 covers the way for more effective, inclusive, and engaging educational experiences for children with dyslexia.

6.2.2 Practical Contribution of HapticLearn 1.0

The HapticLearn 1.0 model makes substantial practical contributions to the field of educational technology, particularly in developing accessible learning applications for children with dyslexia. These contributions are particularly valuable for IT developers and multimedia designers, as well as for the broader educational community.

6.2.2.1 Guidance for IT Developers and Multimedia Designers

HapticLearn 1.0 serves as an invaluable guide for IT developers and multimedia designers who are tasked with creating educational applications. It provides them with a clear framework on how to incorporate haptic feedback and multisensory elements effectively. This model offers insights into the unique learning needs of dyslexic children and demonstrates how technology can be tailored to address these needs. By following the guidelines and principles outlined in HapticLearn 1.0, developers and designers can create more engaging, intuitive, and accessible learning applications that can significantly enhance the educational experience for dyslexic learners.

6.2.2.2 Multisensory Learning and Tailored Educational Experience involving Technology for a Broad Range of Learners

Beyond its immediate impact on dyslexic education, the HapticLearn 1.0 model has the potential to benefit a wide spectrum of learners. While it is specifically designed with the needs of dyslexic children in mind, the principles of multisensory learning and tailored educational experiences are universally applicable. The model's focus on individualized learning strategies and interactive, sensory-rich content can enhance the learning experience for all students, not just those with dyslexia. This broader applicability makes HapticLearn 1.0 a significant tool in the pursuit of more inclusive and effective educational practices.

The practical contributions of HapticLearn 1.0 are thus twofold: it acts as a specialized guide for developers and designers in creating accessible educational technology, and it provides a universally beneficial approach to learning that transcends the specific needs of dyslexic students. This wide-ranging impact highlights the model's importance and utility in the evolving landscape of educational technology.

6.2.3 Technical Contribution of HapticLearn 1.0

The technical contribution of the HapticLearn 1.0 model, particularly in the context of its prototype, is a key aspect of its overall impact. This prototype represents a significant advancement in educational technology, especially for dyslexic learners, and holds potential for commercialization with further enhancement.

6.2.3.1 Prototype Development and Potential for Commercialization

The prototype developed from the HapticLearn 1.0 model is a tangible manifestation of the research and theoretical frameworks that have been explored. It embodies the practical application of haptic technology in an educational setting, tailored specifically for dyslexic learners. The success of the prototype in the testing phases, as shown by positive feedback and improved learning outcomes, highlights its effectiveness and potential as a valuable educational tool.

Looking towards the future, the prototype demonstrates a significant potential for commercialization. With further enhancements and refinements, it can be transformed into a market-ready product. These enhancements might include scaling the technology for wider accessibility, improving user interfaces for greater ease of use, and incorporating additional features based on user feedback. The goal of commercialization would be to make this innovative educational tool available to a broader audience, thereby impacting a larger number of dyslexic learners.

6.2.3.2 Implications for Educational Technology Development

The technical development of the HapticLearn 1.0 prototype also contributes to the broader field of educational technology. It provides a successful example of how specific learning needs can be addressed through targeted technological solutions. This has implications for the development of future educational technologies, encouraging a focus on inclusivity and customization to meet diverse learning requirements.

6.2.3.3 Setting a Benchmark in Haptic Educational Tools

The HapticLearn 1.0 prototype sets a benchmark in the field of haptic educational tools. It showcases the possibilities of integrating sensory feedback into learning environments and paves the way for further innovation in this area. By proving the viability and effectiveness of such tools, it opens doors for other researchers and developers to explore and expand upon this domain.

In summary, the technical contribution of the HapticLearn 1.0 model lies not only in its current prototype form but also in its potential for future development and commercialization. This advancement sets a new standard in educational technology, particularly in the realm of haptic learning tools, and offers a promising path forward for enhancing the educational experiences of dyslexic students.

6.3 Research Limitations

While the study provides valuable insights and contributions to the field of educational technology and dyslexia, it is important to acknowledge certain limitations that could direct future research. These limitations highlight areas where the study could be expanded to deepen our understanding and application of haptic interventions for dyslexic learners:

6.3.1 Investigation of Basic Neural Mechanisms and Signal Processing

A significant limitation of the current study is the lack of investigation into the basic neural mechanisms and the intricacies of signal processing, particularly how these aspects are involved in learning through haptic approaches. Understanding the neurological and signal processing pathways, including live signal analysis, is crucial. This investigation would offer a deeper understanding of the interaction between haptic stimuli and neural responses in dyslexic learners. Exploring these areas could lead to more refined and targeted interventions, maximizing their efficacy and providing insights into real-time adaptation of haptic feedback based on learner responses.

6.3.2 Generalizability Beyond Specific Demographics

The study's findings are primarily relevant to the specific demographics it focuses on, which limits the generalizability of the results. Expanding the study to include a more diverse range of participants from various backgrounds could enhance the applicability and relevance of the findings to a broader population. This would allow for a more inclusive understanding of the efficacy of haptic interventions across different demographic groups.

Including participants from different age groups could provide insights into how the effectiveness of haptic interventions varies across the developmental spectrum. Younger participants may respond differently to haptic stimuli compared to older individuals, highlighting the need for age-appropriate interventions. Additionally, including participants with varying levels of dyslexia severity could reveal whether haptic interventions are equally effective for individuals with mild, moderate, or severe dyslexia.

6.3.3 Evaluation of Long-Term Impact

Another limitation is the study's focus on the immediate outcomes of interventions, without a longitudinal evaluation of their lasting impact. To develop evidence-based practices, it's essential to understand how these interventions affect learning over an extended period. Long-term studies could provide valuable data on the sustainability and long-term effectiveness of haptic interventions in educational settings.

Addressing these limitations in future research endeavors could significantly enrich the field of educational technology for dyslexic learners. Delving into neural mechanisms, signal processing, broader demographic applicability, and long-term efficacy will not only provide a more comprehensive understanding of haptic interventions but also pave the way for more effective, adaptive, and universally applicable educational tools and practices.

6.4 Future Research Directions

Building upon the findings and limitations of the current study, several future research directions can be identified to further enhance our understanding and application of educational interventions for dyslexic learners. These directions not only aim to deepen the existing knowledge base but also seek to broaden the scope and applicability of research in this field:

6.4.1 Exploring Multisensory Interventions and Brain Processing

Future research should delve into how multisensory interventions, particularly those involving haptic technology, impact brain processing in individuals with dyslexia. This exploration would involve studying the neural correlates and changes in brain activity as a result of multisensory stimulation. By understanding the neurological foundations, researchers can refine these interventions to be more targeted and effective. Such studies could involve neuroimaging techniques like MRI or EEG to observe brain function changes in real-time during the application of multisensory interventions.

Additionally, research could examine which specific sensory modalities—such as touch, sight, and sound—most effectively engage the brain regions associated with reading and writing. By mapping the neural pathways activated by haptic feedback, researchers could identify how these stimuli enhance cognitive processes like memory, attention, and phonological processing.

Furthermore, investigating individual differences in brain responses to multisensory interventions could provide insights into personalized learning approaches. Some dyslexic individuals might benefit more from certain types of sensory input than others, and tailoring interventions to these preferences could optimize educational outcomes.

Finally, integrating behavioral assessments with neuroimaging data can offer a comprehensive view of how multisensory interventions translate into practical improvements in reading and writing skills. This holistic approach would ensure that the neurological benefits observed in the lab are mirrored by tangible academic progress, guiding the development of more effective, evidence-based educational tools for dyslexic learners.

6.4.2 Expanding Studies to Diverse Populations and Languages

There is a critical need to expand research to include a wider array of populations and languages. This expansion will help overcome cultural and linguistic biases inherent in the current research. By studying the effects of dyslexia and the efficacy of interventions across different languages and cultural contexts, researchers can develop more universally applicable and culturally sensitive educational tools and strategies. This approach also helps in understanding the unique challenges faced by dyslexic learners in different linguistic environments.

6.4.3 Conducting Longitudinal Studies

To truly assess the long-term effectiveness and sustainability of learning interventions for dyslexia, it is essential to conduct longitudinal studies. Such studies would track the progress of individuals over an extended period, providing valuable insights into the lasting impacts of these interventions. Longitudinal research can help determine the durability of the improvements in learning and whether any adjustments or continued interventions are necessary over time. This approach is critical in developing evidence-based practices that ensure long-term support and success for dyslexic learners.

By pursuing these future research directions, the field can move towards more comprehensive and inclusive educational practices. Understanding brain processing changes, expanding research to diverse populations, and assessing long-term outcomes are key steps in evolving and improving the support provided to individuals with dyslexia. These efforts will contribute significantly to the development of effective, equitable, and sustainable educational interventions.

6.5 Summary

In this chapter, we meticulously addressed and provided answers to two critical research questions underpinning our study. The first question was regarding the current state of haptic interventions for dyslexic children in Malaysia. Our investigation revealed that while some interventions exist, they are primarily non-technological and there's a notable gap in utilizing advanced haptic technologies. The second question focused on developing an accessible framework with integrated haptic elements for dyslexic children. In response, we successfully developed the HapticLearn 1.0 model, a comprehensive framework designed and implemented to enhance learning experiences for dyslexic learners through haptic technology.

The fulfillment of these research questions led us to achieve our set objectives. The first objective involved a deep exploration of existing haptic interventions in Malaysia. Through interviews, observations, and literature reviews, we gained a thorough understanding of the current practices and their effectiveness. The second objective was achieved with the development of the HapticLearn 1.0 model, a guiding tool for developers and designers to create accessible educational technology for dyslexic learners. The third objective, centered on validating and verifying the effectiveness of the HapticLearn 1.0 prototype, confirmed its potential and usability in real-world scenarios.

The theoretical contribution of our study lies in enhancing the understanding of haptic technology’s role in dyslexic education, offering new perspectives for future research. Practically, the HapticLearn 1.0 model emerged as a significant guide for creating effective learning tools. On the technical front, the potential of the HapticLearn 1.0 prototype for future commercialization marks an advancement in educational technology.

However, the study faced limitations, including the lack of an in-depth exploration of the neurological basis of haptic learning, limited generalizability beyond specific demographics, and the absence of long-term impact studies.

Future research directions involve a deeper investigation into the neurological effects of multisensory interventions, expanding the study to diverse populations and languages, and conducting longitudinal studies to understand the long-term effectiveness of these interventions.

In summary, this chapter provided an extensive overview of our research journey, from answering key questions to achieving objectives, recognizing contributions and limitations, and outlining future research avenues. The insights from this study illuminate the current landscape of haptic technology in dyslexia education and set a foundation for future advancements in this important field.

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Appendix A

Interview Questions

No.	Potential Questions
1	Can you share your experiences and perspectives on teaching dyslexic students in Malaysia?
2	How do you address the challenges of limited awareness and understanding of dyslexia among stakeholders, including parents and mainstream educators?
3	How do you incorporate technology in dyslexia education, and what benefits have you observed?
4	What challenges do you encounter in integrating technology into classrooms, and how do you address them?
5	How do you envision the future of dyslexia teaching in Malaysia, and what improvements would you like to see?
6	What is the extent of teacher knowledge about technology in dyslexic pupils' learning?
7	How do you think we can support dyslexic students better?
8	What are the perceived barriers to providing support for dyslexic pupils?

Appendix B

Expert Review Form

Dear esteemed Experts,

I'm Salman Javed, a Master's student of Universiti Tunku Abdul Rahman (UTAR). Currently, we are in the mid of conducting an expert review of our proposed model. We are grateful for your participation in this evaluation, which plays a crucial role in our ongoing efforts to improve the effectiveness of our model.

About the Model

Our model, titled "HapticLearn 1.0" is designed to address the unique learning needs of dyslexic students by integrating visual, auditory, kinesthetic, and tactile modalities. This comprehensive approach combines computer games and haptic devices to create a multisensory learning environment that promotes engagement, inclusivity, and personalized learning experiences. The model incorporates various learning activities, feedback and guidance mechanisms, and assessment tools to support the continuous improvement of dyslexic students' educational outcomes.

Your Role as an Evaluator

As part of this heuristic evaluation, we aim to gather expert feedback to identify strengths, weaknesses, and areas for improvement within our model's design and implementation. As an experienced IT developer expert, your insights and expertise are invaluable in helping us assess the technological aspects of our model. We kindly request that you evaluate the model with a critical eye and provide constructive feedback that can guide our ongoing development efforts.

Heuristic Evaluation Questionnaire

The attached questionnaire contains six questions tailored to assess specific aspects of our attached model from an IT developer perspective. We kindly request your honest and comprehensive feedback on each question.
Your contribution to this evaluation will significantly contribute to our research.
Thank you for your time and expertise.

Sincerely,
Researcher: Mr. Salman Javed
Affiliation: Master in Computer Science Student, Faculty of Information and Communication Technology

Universiti Tunku Abdul Rahman
Jalan Universiti, Kampar 31900, Perak, Malaysia
Contact: 0106650637
Email: salmanjaved637@gmail.com
Address: Faculty of Information and Communication Technology Universiti Tunku Abdul Rahman Jalan Universiti, Kampar 31900, Perak, Malaysia

EXPERT/REVIEWER DETAILS

Name *:	
Age:	
Highest education level *:	
Working Experience * (# of years):	

Based on the proposed design modal (as depicted in the given handout), please select your choice.

1. Determine the relevance of the proposed elements (in the model) in designing a haptic-based application / game for a dyslexic user (Tick the suitable box):

Elements	**Level of Relevance**		
	Very Relevant	**Somewhat Relevant**	**Not Really Relevant**
Visual			
Auditory			
Kinesthetic			
Tactile			
Feedback and Guidance			

2. Do you able to relate the contribution of the elements in the model?

	Yes
	No

3. Do you find the model is readable?

	Yes
	No

4. Do you find the terms used in the model are easy to understand?

	Yes
	No

5. Do you agree the elements stated in the model are important in designing ICT applications for dyslexic children?

	Yes
	No

6. Please provide further comments:

Model:

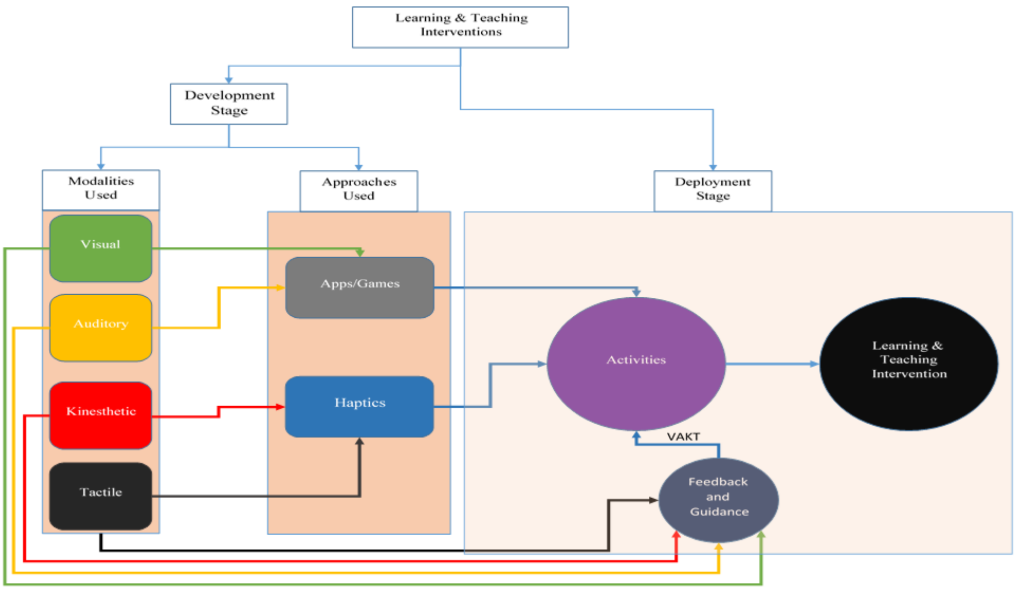

Figure 1.0 HapticLearn 1.0 Model

Appendix C

Prototype Validation Test Results

S No.	Groups	Pre-Test Result	Post-Test Result	Pre-Test Result	Post-Test Result	Pre-Test Result	Post-Test Result	Pre-Test Result	Post-Test Result	Pre-Test Result	Post-Test Result	Pre-Test Result	Post-Test Result	Pre-Test Result	Post-Test Result	Pre-Test Result	Post-Test Result
	Marks	26		26		9		26		26		26		9		3	
		REM 1	REM 1	REM 2	REM 2	REM 3	REM 3	UND 1	UND 1	UND 2	UND 2	UND 3	UND 3	UND 4	UND 4	UND 5	UND 5
	Groups	Marks	Marks	Marks	Marks	Marks	Marks	Marks	Marks	Marks	Marks	Marks	Marks	Marks	Marks	Marks	Marks
Participant 1	Control	25	26	20	21	9	9	26	24	26	26	16	0	9	9	3	3
Participant 2	Control	25	23	23	15	6	9	21	26	26	26	19	7	9	9	0	3
Participant 3	Experimental	26	26	24	26	9	8	26	26	26	26	17	25	9	9	0	3
Participant 4	Experimental	26	26	26	26	9	9	26	26	26	26	1	26	5	9	3	3
Participant 5	Experimental	26	26	0	26	7	8	10	26	22	22	10	12	9	9	0	3
Participant 6	Experimental	24	26	21	19	7	8	12	18	20	24	0	19	9	9	0	3
Participant 7	Experimental	22	25	19	24	7	9	20	26	24	26	0	24	9	9	0	3
Participant 8	Control	24	25	21	23	7	7	5	23	24	26	0	21	9	9	0	3
Participant 9	Control	25	26	26	26	7	6	26	26	22	26	0	22	9	9	0	1
Participant 10	Control	24	23	19	25	3	7	2	8	15	19	0	9	7	9	0	1
Participant 11	Control	26	25	23	25	6	5	22	25	26	26	6	2	9	9	0	1
Participant 12	Experimental	25	26	23	25	7	9	20	23	25	24	0	25	9	8	0	3
Participant 13	Control	25	25	16	24	6	6	25	25	26	26	3	0	9	9	0	3
Participant 14	Control	26	25	20	24	4	8	19	24	26	26	23	0	9	9	0	1
Participant 15	Control	25	26	26	19	9	7	19	22	24	26	25	15	9	9	0	3
Participant 16	Experimental	26	26	24	24	7	9	23	26	25	26	4	5	9	9	0	3
Participant 17	Experimental	26	26	25	25	6	8	24	26	26	26	0	25	9	9	3	3
Participant 18	Experimental	24	26	24	26	8	9	26	26	26	26	0	26	9	9	0	3
Participant 19	Control	21	24	20	19	7	5	17	18	24	22	0	8	9	9	0	3
Participant 20	Control	20	4	21	22	6	7	23	21	26	26	10	12	9	9	0	3
Participant 21	Experimental	23	26	0	24	9	9	0	24	21	24	0	24	7	9	0	3
Participant 22	Experimental	22	25	0	22	8	9	25	24	26	26	0	25	6	9	0	3
Participant 23	Control	24	26	17	24	9	6	24	23	26	24	12	8	9	9	0	3
Participant 24	Experimental	26	26	11	20	9	8	19	25	26	26	11	20	9	9	0	3
Participant 25	Control	26	26	0	23	7	7	0	16	26	24	0	0	9	9	0	1
Participant 26	Experimental	22	26	18	23	7	9	23	23	26	26	15	23	9	9	3	3
Participant 27	Control	25	26	14	11	9	9	25	26	26	26	2	1	7	9	0	3
Participant 28	Experimental	25	24	24	25	8	9	26	24	26	26	0	24	9	9	0	3
Participant 29	Control	25	26	23	26	9	9	26	26	26	26	0	6	9	9	3	3
Participant 30	Experimental	25	26	17	24	8	8	23	25	26	26	15	24	9	9	0	3
Participant 31	Experimental	26	26	26	23	4	8	25	26	24	24	19	20	9	9	0	3
Participant 32	Control	24	25	20	20	4	7	24	24	24	22	11	0	9	9	0	0
Participant 33	Experimental	7	26	23	25	5	8	6	25	26	26	2	25	9	9	0	3
Participant 34	Control	24	26	23	10	7	7	20	22	24	24	0	0	9	9	0	1
Participant 35	Experimental	26	26	14	25	7	8	3	26	26	26	0	25	9	9	0	3
Participant 36	Control	26	25	9	9	6	9	18	24	26	26	0	0	9	9	0	1
	Total Marks	867	896	660	798	253	283	679	848	890	903	221	508	311	323	15	91
	Total Control Percentage	94.0%	92.3%	72.9%	78.2%	74.7%	80.2%	73.1%	86.1%	94.7%	95.5%	27.1%	23.7%	97.5%	100.0%	11.1%	68.5%
	Change in Control Performance	-1.7%		5.3%		5.6%		13.0%		0.9%		-3.4%		2.5%		57.4%	
	Total Experimental Percentage	91.2%	99.1%	68.2%	92.3%	81.5%	94.4%	72.0%	95.1%	95.5%	97.4%	20.1%	84.8%	94.4%	99.4%	16.7%	100.0%
	Change in Experimental Performance	7.9%		24.1%		13.0%		23.1%		1.9%		64.7%		4.9%		83.3%	
	Overall Percentage	92.6%	95.7%	70.5%	85.3%	78.1%	87.3%	72.5%	90.6%	95.1%	96.5%	23.6%	54.3%	96.0%	99.7%	13.9%	84.3%
	Overall Change in Performance	3.1%		14.7%		9.3%		18.1%		1.4%		30.7%		3.7%		70.4%	

S No.	Groups	Pre-Test Result	Post-Test Result	Pre-Test Result		Post-Test Result		Pre-Test Result		Post-Test Result		Pre-Test Result		Post-Test Result	
	Marks	9		61		61		99		99		160		160	
		UND 6	UND 6	REM	REM	REM	REM	UND	UND	UND	UND	Both REM & UND	Both REM & UND	Both REM & UND	Both REM & UND
	Groups	Marks	Marks	Total Marks	Percentage	Total Marks	Percentage	Total Marks	Percentage	Total Marks	Percentage	Total Marks	Percentage	Total Marks	Percentage
Participant 1	Control	8	9	54	89%	56	92%	88	89%	71	72%	142	89%	127	79%
Participant 2	Control	9	9	54	89%	47	77%	84	85%	80	81%	138	86%	127	79%
Participant 3	Experimental	9	9	59	97%	60	98%	87	88%	98	99%	146	91%	158	99%
Participant 4	Experimental	9	9	61	100%	61	100%	70	71%	99	100%	131	82%	160	100%
Participant 5	Experimental	9	9	33	54%	60	98%	60	61%	81	82%	93	58%	141	88%
Participant 6	Experimental	9	9	52	85%	53	87%	50	51%	82	83%	102	64%	135	84%
Participant 7	Experimental	9	9	48	79%	58	95%	62	63%	97	98%	110	69%	155	97%
Participant 8	Control	7	9	52	85%	55	90%	45	45%	91	92%	97	61%	146	91%
Participant 9	Control	9	9	58	95%	58	95%	66	67%	93	94%	124	78%	151	94%
Participant 10	Control	9	9	46	75%	55	90%	33	33%	55	56%	79	49%	110	69%
Participant 11	Control	9	8	55	90%	55	90%	72	73%	71	72%	127	79%	126	79%
Participant 12	Experimental	7	9	55	90%	60	98%	61	62%	92	93%	116	73%	152	95%
Participant 13	Control	9	9	47	77%	55	90%	72	73%	72	73%	119	74%	127	79%
Participant 14	Control	7	7	50	82%	57	93%	84	85%	67	68%	134	84%	124	78%
Participant 15	Control	9	9	60	98%	52	85%	86	87%	84	85%	146	91%	136	85%
Participant 16	Experimental	9	9	57	93%	59	97%	70	71%	78	79%	127	79%	137	86%
Participant 17	Experimental	9	9	57	93%	59	97%	71	72%	98	99%	128	80%	157	98%
Participant 18	Experimental	9	9	56	92%	61	100%	70	71%	99	100%	126	79%	160	100%
Participant 19	Control	8	8	48	79%	48	79%	58	59%	68	69%	106	66%	116	73%
Participant 20	Control	9	9	47	77%	33	54%	77	78%	80	81%	124	78%	113	71%
Participant 21	Experimental	9	9	32	52%	59	97%	37	37%	93	94%	69	43%	152	95%
Participant 22	Experimental	9	9	30	49%	56	92%	66	67%	96	97%	96	60%	152	95%
Participant 23	Control	8	8	50	82%	56	92%	79	80%	75	76%	129	81%	131	82%
Participant 24	Experimental	9	9	46	75%	54	89%	74	75%	92	93%	120	75%	146	91%
Participant 25	Control	6	8	33	54%	56	92%	41	41%	58	59%	74	46%	114	71%
Participant 26	Experimental	9	9	47	77%	58	95%	85	86%	93	94%	132	83%	151	94%
Participant 27	Control	9	9	48	79%	46	75%	69	70%	74	75%	117	73%	120	75%
Participant 28	Experimental	9	9	57	93%	58	95%	70	71%	95	96%	127	79%	153	96%
Participant 29	Control	9	9	57	93%	61	100%	73	74%	79	80%	130	81%	140	88%
Participant 30	Experimental	9	9	50	82%	58	95%	82	83%	96	97%	132	83%	154	96%
Participant 31	Experimental	9	9	56	92%	57	93%	86	87%	91	92%	142	89%	148	93%
Participant 32	Control	4	8	48	79%	52	85%	72	73%	63	64%	120	75%	115	72%
Participant 33	Experimental	9	8	35	57%	59	97%	52	53%	96	97%	87	54%	155	97%
Participant 34	Control	8	9	54	89%	43	70%	61	62%	65	66%	115	72%	108	68%
Participant 35	Experimental	9	9	47	77%	59	97%	47	47%	98	99%	94	59%	157	98%
Participant 36	Control	8	8	41	67%	43	70%	61	62%	68	69%	102	64%	111	69%
	Total Marks	305	315	1780	81%	1977	90%	2421	68%	2988	84%	4201	73%	4965	86%
	Total Control Percentage	89.5%	95.1%												
	Change in Control Performance	5.6%													
	Total Experimental Percentage	98.8%	99.4%												
	Change in Experimental Performance	0.6%													
	Overall Percentage	94.1%	97.2%												
	Overall Change in Performance	3.1%													

Appendix D

Publication and Achievement

PUBLICATION

a) Javed, S., Muniandy, M., Lee, C.K. and Husni, H., 2023. Enhancing teaching and learning for pupils with dyslexia: A comprehensive review of technological and non-technological interventions. *Education and Information Technologies*, pp.1-37.
b) Uncovering the current state of Dyslexia Education and Technology Integration in Malaysia (Under review) (Journal of Cultural Cognitive Science) (Submitted on 11 Jan 2024)

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