A TANGIBLE USER INTERFACE DESIGN GUIDELINE TO SUPPORT LEARNING FOR CHILDREN WITH DYSLEXIA

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Abstrak

Interaksi Nyata (TI) kian popular sebagai cara menyokong pembelajaran menggunakan objek fizikal dengan interaksi ruang digital. Pendekatan ini menawarkan pengalaman multisensori kepada kanak-kanak disleksia untuk sesi pembelajaran yang lebih bermakna. Oleh itu, TI berpotensi untuk memenuhi ciri-ciri multisensori ketika menggunakan komputer dan dengan itu, Antara Muka Pengguna Nyata (TUIs) telah muncul. Kerangka TUIs sedia ada menyediakan garis panduan atau alat reka bentuk yang sangat terhad khususnya untuk memenuhi keperluan kanak-kanak disleksia. Kajian terdahulu juga menunjukkan bahawa kerangka kerja ini hanya tertumpu kepada pandangan berpusatkan data yang hanya menggabungkan perwakilan fizikal dan digital sahaja. Walau bagaimanapun, kerangka kerja ini tidak mengambil kira keperluan dan kebolehan kanak-kanak disleksia, seperti kesukaran mereka membaca, menulis dan memproses maklumat visual. Oleh itu, kajian ini mencadangkan garis panduan reka bentuk TUIs yang berkesan untuk kanak-kanak disleksia to menyokong mereka belajar membaca. Kajian ini telah dilaksanakan dalam empat fasa: 1) kajian teori; 2) pengenalpastian komponen reka bentuk TUIs; 3) pembangunan kerangka kerja dan garis panduan reka bentuk; 4) pembangunan prototaip; dan 5) pengesahan garis panduan reka bentuk TUIs. Prototaip telah dibangunkan untuk menilai keberkesanan garis panduan reka bentuk TUIs ketika aktiviti pembelajaran bersama kanak-kanak disleksia. Tujuh oranng pakar telah mengesahkan kerangka dan garis panduan reka bentuk TUIs. Kajian ini menyumbang kepada penambahbaikan garis panduan reka bentuk yang sedia ada. Maklum balas positif dan peningkatan dalam hasil pembelajaran daripada kanak-kanak disleksia mengesahkan keberkesanan garis panduan reka bentuk TUIs ini. Hasil kajian ini menyumbang secara teori dan praktikal kepada bidang TUIs dan HCI. Hasil kajian ini diharapkan dapat membantu para penyelidik dan pembangun perisian dalam membina sistem yang memenuhi keperluan kanak-kanak disleksia. Pembangun sistem akan dapat memahami keperluan kanak-kanak ini dengan adanya garis panduan reka bentuk yang jelas untuk menghasilkan pembelajaran dan pengalaman pendidikan yang lebih baik.

Kata Kunci: Antara muka pengguna nyata, Interaksi nyata, Garis panduan reka bentuk, Disleksia, Kaedah multisensori

Abstract

Tangible Interaction (TI) is gaining popularity as a means of supporting learning using physical tangible objects with the interaction of digital space. This approach provides a multisensory experience to children with dyslexia, making the learning session more meaningful. Therefore, TI has the potential to provide multisensory features when using a computer, and as a result, Tangible User Interfaces (TUIs) have emerged. Current TUIs frameworks offer very few design guidelines or tools specifically tailored to meet the needs of children with dyslexia. Previous studies have highlighted that the framework provides data-centred views that only focus on combining physical and digital representations. However, these frameworks do not consider the unique needs and abilities of children with dyslexia, such as their difficulties with reading, writing, and processing visual information. Thus, this study proposes effective TUI design guidelines for children with dyslexia to support learning to read. The study was conducted in five phases: 1) theoretical study; 2) identification of TUIs design components; 3) framework and design guideline development; 4) prototype development; and 5) the validation of TUIs design guideline. A prototype was developed to evaluate the effectiveness of TUIs design guideline during learning activities with children with dyslexia. Seven experts verified the TUIs framework and its design guideline. This study contributed to improving the present design guideline of TUIs. The positive feedback and improvement in learning outcomes from the children with dyslexia validated the effectiveness of the TUIs design guideline. The findings of this study contribute theoretically and practically to the field of TUIs and HCI. They are expected to assist researchers and developers in developing tangible systems that meet the requirements of children with dyslexia. The system developers would be able to understand the needs of children with dyslexia with a clear design guideline for better learning outcomes and improved educational experiences.

Keywords: Tangible user interfaces, Tangible interaction, Design guideline, Dyslexia, Multisensory method

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List of Abbreviations

DCT	Dual Coding Theory
GUI	Graphical User Interface
HCI	Human Computer Interaction
IxD	Interaction Design
MoE	Ministry of Education
O-G	Orton Gillingham
TI	Tangible Interaction
TUIs	Tangible User Interfaces
UD	Universal Design

List of Publication

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CHAPTER ONE
INTRODUCTION

1.0 Background Study

Tangible interaction (TI) has been gaining its prominence as an alternative approach to support learning by using tangible objects while interacting with a digital space, allowing the user to physically grasp the object with their hands (Jamali, Admodisastro, Abd Ghani, et al., 2018a; Lozano et al., 2018). Many research has shown that TI improves children's learning (Fan, 2017; Lozano, Penichet, Leporini & Fernando, 2018; Shaer & Hornecker, 2010). TI refers to interactions that involve the use of tangibility and embodiment (Bozgeyikli & Bozgeyikli, 2021). In TI, physical artifacts recognised as Tangible User Interfaces or TUIs are the core of the interaction (Bozgeyikli & Bozgeyikli, 2021; Ishii, 2008).

Tangible user interfaces (TUIs) introduced by Ishii and Ullmer in 1997 are referred to as interactive applications that incorporate full-body interaction, tangible manipulation, integration with physical space, and the group of physical and digital illustration. (Ullmer & Ishii, 2000; Hornecker & Buur, 2006; Horn & Jacob, 2007; Manches, O'Malley, & Benford, 2009; Garzotto & Gonella, 2011). TUIs, which are a part of TI, have the potential to be an effective method for supporting children in learning to read (Fan, 2017) and nurturing their overall development to achieve their maximum capabilities (Teh, Ng, & Parhizkar, 2015). Additionally, TUIs offer several advantages similar to those of traditional computers, including cost-effectiveness (Fan, Antle & Cramer, 2016a; Nicolson, Fawcett & Nicolson, 2000), digital feedback (Jamali et al., 2019), playful multimedia learning incorporating text, images, sounds, and physical objects (Fan et al., 2018), as well as motivating game mechanisms

(Mioduser et al., 2000). Several frameworks have been developed to provide a conceptualisation of TUIs (e.g., Ullmer and Ishii, 2000; Fishkin, 2004). Ullmer and Ishii (2000) developed a framework focusing primarily on the design of physical representation and digital representation (TUIs). Similarly, another study by Fishkin (2004) developed a TUIs framework to describe or compare the different systems from the systems perspective without providing any explanations for the relationships between the frameworks. In general, the majority of the frameworks emphasized on the systems taxonomies or as a basis for analysis (Price, 2008), however, the unique affordances of TUIs and their impact on the learning processes are disregarded. According to Antle and Wise (2013), efforts to create a framework of the primary focus of TUI-based learning experiences lies in the design of the physical representation of TUIs, emphasizing the crucial and interdependent design features of the learning activity. to be used for children have been overlooked.

Previous studies have shown that TI and TUIs have the potential to meet the needs of children with dyslexiain learning sessions (Fan et al., 2016a; Fan et al., 2018; Jamali et al., 2019; Marshall, 2007; Rodić & Granić, 2022). According to the Malaysia Ministry of Education in 2022, it is reported that 1491 primary school children are enrolled in special education schools (Ministry of Education, 2022). In addition, there are 657 primary school children enrolled in the class for learning disabilities (CLFD) (Special Education Division, Ministry of Education, 2022). Dyslexia is one of a greater prevalence among the group of learning disabilities which refers to severe difficulty in learning to read (Antle et al., 2015) and affects 20 percent of the worldwide population (Shaywitz, Shaywitz and Shaywitz, 2021). According to British Dyslexia Association (2012), dyslexia is known as a complex neurological condition in origin that affects the most important areas of learning and function. In other words, it refers to a reading disorder whereby an individual has difficulties in reading, spelling, and written language. According to Shaywitz (2003), dyslexia is a common and persistent condition in children that stems from phonological deficits which is characterised by unexpected difficulties in reading despite having the intelligence to perform better in reading skills. The primary characteristics of dyslexia include impairments in phonological awareness, verbal memory, and verbal processing speed (Orton Dyslexia Society, 1994; Ondiek, 2022). These characteristics are often associated with one of three deficits: auditory deficit, visual deficit, or visual-auditory deficit. These deficits contribute to phonological difficulties, making it challenging for children with dyslexiato associate graphemes with their corresponding phonemes (Aziz et al., 2013).

Moreover, children with dyslexia experienced difficulties in comprehending and applying the alphabetic principle, leading to challenges in decoding words during the reading process (Phillips & Kelly, 2016). In common, children with dyslexia have difficulties to learn, especially in reading due to visual and auditory deficits (Aziz et al., 2013). Children with dyslexia encounter difficulties in word recognition, struggles with identifying mirror letters, distinguishing between letter sounds, and constructing syllables within sentences (Jamali et al., 2019). These challenges often result in feelings of discouragement and contributed to emotional and behavioural difficulties that persist throughout their school journey. (Kazakou, Soulis, Morfidi, & Mikropoulos, 2011; Ahmad, Ludin, Ekhsan, Rosmani, & Ismail, 2012). Nonetheless, by detecting dyslexia early on and implementing effective teaching approaches (Cramer et al., 2016), children with dyslexia can make significant improvements in overcoming these difficulties and enhancing their abilities. (Rahim et al., 2018).

Nevertheless, there are very few studies have been done on TI to improve reading for children with dyslexia and thereby overcome their difficulties that were not just affecting their self-esteem but their ability to learn independently without relying on others. (Fan, Antle, Hoskyn, & Neustaedter, 2018; Hamid et al., 2017). A study by Jamali et al., (2018) showed that improving the design learning through TI offers a multisensory environment for children with dyslexia(Jamali et al., 2018). TI is one of the most widely used approaches for children with dyslexia as they learn best with a multisensory method that adopts more than one sense in an effective and meaningful session (Fan et al., 2017). For example, the relationships between the letter (visual) and sound (auditory) used during their reading practices.

In line with this, TI provides multisensory interventions as supported by Orton-Gillingham (O-G) that children can hold or touch letters physically while listening to the sounds (Gattegno, 2010; Fan et al., 2017). Multisensory interventions have shown the advantages of using all available senses simultaneously to facilitate reading for children with dyslexia (Fan et al., 2016). Recent studies showed that this is insufficiently accurate to use traditional multisensory teaching materials because of the features are less appealing, lack of sense, fail to obtain feedbacks like sound (Jamali et al., 2018) and only rely heavily on the teacher's support to guide the students (Hamid et al., 2017). Hence, TI is an approach that can produce a good multisensory when using a computer. The use of tactile or kinesthetic modalities can improve children's attention and memory in learning, while tracing of letters can help children quickly remember shapes of letter and sounds using motor memory. TUIs incorporated various modalities, such as visual, auditory, tactile, and kinesthetic, to facilitate the utilization of multiple senses during the process of acquiring reading skills (Antle, 2013).

Numerous studies have explored the use of TUIs and their interventions for children with dyslexia (Fan et al., 2018; Jamali et al., 2018; Teh et al., 2015). These studies have consistently shown that TUIs possessed the potential to enhance the understanding, communication, self-expression, interaction with others, and independent work abilities of children with dyslexia (Falcão & Price, 2010; Antle et al., 2015; Polat et al., 2019). Previous research primarily focused on computerised interactive multisensory programs for supporting children with dyslexia in reading, with limited attention given to the design features of TUIs that could enhance learning experiences and reading acquisition for children with dyslexia (Fan et al., 2016a). Thus, this research aims to bridge this gap by extending the design features of TUIs.

Design features are considered crucial aspects associated with products and designs, significantly influencing their functionality, performance, and quality (Han et al., 2017). Although a few studies have explored specific design features of TUIs that can support learning outcomes (Fan & Antle, 2015), greater improvement is needed in this area. Several studies attempted to investigate the effects of design features such as 3D tangible letters, dynamic colour cues, texture cues (Fan & Antle, 2015) and font type (Jamali et al., 2019). Nevertheless, there is little explored in the literature on the TUIs design features to be used, and in what way these features can help children with dyslexia in reading (Fan et al., 2016a; Fan et al., 2018). The TUIs design guideline includes the TUI design features to improve the reading of children with dyslexia.

It is important for the development of a tangible system to use a design guideline and suitable design features to enhance user satisfaction, efficiency, and productivity. Design guideline is a statement proposing helping suggestions and considerations to inform the design of a particular feature or component of the interaction in a certain context (Hartson & Pyla, 2012). To date, only few studies focusing on the design guidelines for TUIs aimed at supporting the learning needs of children with dyslexia. (Fan et al., 2016a). Although TUIs have been developed in various capabilities and purposes; however, they are solely developed to support learning other languages such as English, Mandarin, and Dutch (Jamali et al., 2018b). In contrast to other languages, the Malay language possessed shallow alphabetic orthography (i.e., spelling-sound mappings are predictable and transparent), basic syllabic structures, and transparent affixation. For instance, the Malay language employs affixation to create new words from root words by using prefixes (*e.g., belajar*), suffixes (*e.g., ajaran*), circumfixes (*e.g., pengajaran*), and infixes (*e.g., kemelut from kelut*). In contrast, the English language emphasizes prefixes and suffixes (Jamali et al., 2018b). In addition, the previous existing design guidelines only apply one or two design features of TUI while designing tangible prototypes or systems for children with dyslexia (Fan et al., 2016a). In order to better comprehend the tangible system for children with dyslexia, the potential of TUI design features for reading is certainly needed.

Hence, the TUIs design guideline aims to integrate the multisensory method with different types of sensory such as visual, auditory, tactile, and kinesthetics in assisting children with dyslexia. In this regard, TUIs incorporate multiple modalities, including visual, auditory, tactile, or kinesthetic modalities, that may be beneficial in promoting the use of multiple senses in reading acquisition.

This study shed light on the TUIs framework to develop the TUIs design guideline to improve learning to read in Malay among children with dyslexia. In addition, TUIs design based on universal design (UD) principles and interaction design (IxD) dimensions are adapted in this study within TUIs design concept to fulfil users' requirements. Regarding reading difficulties, the relationship between UD and IxD in the guideline is to produce a good design of TUIs for children with dyslexia. UD works best for everyone without separating people into groups or individuals. This will in turn give benefit to children with dyslexia and other children as well. As such, a suitable design based on IxD elements allows children with dyslexia to experience the user interface, for instance, tangible letters are designed to support learning to read. Thus, an evaluation of TUIs is carried out to observe its effectiveness on the learning for children with dyslexia. This needs to be done to enable interaction between children with dyslexia and tangible objects while interacting with digital user interfaces (e.g., computer). This study takes into consideration the needs or requirements of children with dyslexia as well as what the UD principles and IxD dimensions support as the foundation for TUIs framework and guideline for children with dyslexia as denoted in Figure 1.1

In Figure 1.1, children with dyslexia require multisensory stimulation to learn to read. UD is taken into consideration so we can have one design that can meet the needs of children with dyslexia and serve others as well. Understanding that, they require different senses to learn to read, such as audio, visual, tactile and kinesthetic which can stimulate their brain, and having textures on the tangible representations can attract children's attention. In addition, a suitable design based on IxD dimensions is considered for TUIs guideline to materialise dyslexia-friendly TUIs because it facilitates children with dyslexia in learning to read.

In the context of this study, design components consist of appropriate TUI design features, learning contents and styles will be adapted by synthesizing the concepts of IxD dimensions, and UD principles. Therefore, the TUIs design guideline is proposed based on the analysed TUIs framework components, i.e., tangible representations, intangible representations, and digital information, thereby ensuring that the design guideline is suitable for supporting children with dyslexia learning to read in Malay.

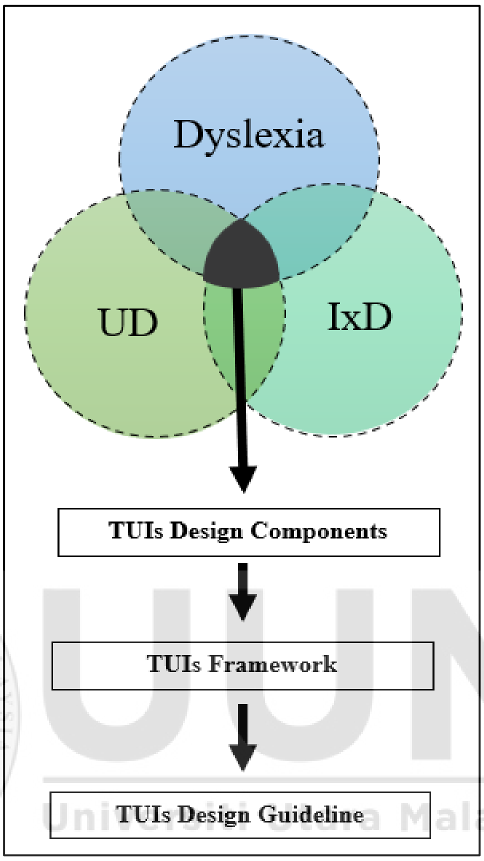

Figure 1.1 The intersection of dyslexia characteristics, UD and IxD that inform TUIs design components, framework and guideline.

1.1 Problem Statement

A number of frameworks and taxonomies which conceptualised TUIs are emerging (Price et al., 2008; Cheung & Antle, 2020). Many researchers have developed frameworks and taxonomies in assisting the developers of TUIs. At present, the researchers made an analysis and comparison on the TUI examples and applied the lessons learned from the development of previous TUI examples for future improvement (Shaer & Hornecker, 2010; Cheung & Antle, 2020). According to Rodić and Granić (2022), the majority of existing frameworks (Ullmer and Ishii, 2000;

Fishkin, 2004) only concentrate on the conceptual design of tangible systems and offer little in the way of actual guidelines or tools for developing TUIs. There are a few main issues highlighted in this study: 1) current TUIs frameworks provide very limited design guidelines or tools in developing a new TUI system for specific needs such as children with dyslexia; 2) TUIs framework did not accommodate any functionality of different design features of TUIs to effectively facilitate learning interactions; 3) only few design guidelines available to support children with dyslexia; and 4) the design features of TUIs need further improvement.

Firstly, previous studies highlighted that the current framework only covers in terms of data-centered views, which are the connection of physical representations with digital representations (e.g., graphics and audio) (Ullmer & Ishii, 2000). For children with dyslexia, it is argued that different features of TUIs, learning theories, and design of the learning activity are also important and therefore must be considered for TUIs to be effective as a tool to facilitate reading (Antle & Wise, 2013; Rodić & Granić, 2022). With a growing number of new technologies that integrated multisensory interaction to support children with learning, the dearth of TUIs frameworks and TUIs design features gave difficulties in designing suitable guidelines of tangible interaction learning to read in Malay. Hence, a few main issues related to the current TUIs framework are highlighted in this study mainly the lack of design guidelines or tools in developing new TUI systems and a lack of design features of TUIs in developing the TUI prototypes.

Secondly, the study also found that the theoretical bases of TUIs framework did not accommodate any functionality of different design features of TUIs to effectively facilitate learning interactions and hence affect learning outcomes (Antle & Wise, 2013). Presently, there is a few guidelines formulated by TUI developers on the design choices and proper ways to make informed design decisions that have significant impacts on the learning outcomes (Fan et al., 2016a). Nevertheless, the ability of TUI to interlace between the physical and digital world has great potential to offer exciting possibilities as a learning platform (Raffaele & Buhagiar, 2017). Therefore, it is evident that there is a growing necessity to investigate TUI learning design to enhance multisensory learning systems tailored specifically for children with dyslexia. For this purpose, the study aims to develop a new design guideline in learning to read in Malay based on Ulmer and Ishii's framework. In addition, this study adds on further improvements to the present design guidelines which have been done in the previous studies.

Thirdly, given the rising prevalence of TUIs systems, only a few design guidelines available to assist children with dyslexia (Falcão & Price, 2010; Fan et al., 2016a; Jamali et al., 2018). However, not every aspect of the TUIs design is found in the previous guidelines to guide the design and study of TUIs (Antle & Wise, 2013). To date, there is only a handful of literature that studied the guidelines on TUIs to support learning for children with dyslexia (Fan et al., 2016a) especially in learning to read in Malay (Jamali et al., 2018) and previous research typically only developed the TUIs in other languages such as English, Mandarin, and Dutch.

In addition, the TUIs design features are necessary to be supported by theories and other related works in the dyslexia domain (Jamali et al., 2019). Present tangible reading systems for children with dyslexia failed to show how TUIs design features can help them (Fan et al., 2018: Cramer et al., 2016: Fan & Antle, 2015) such as 3D tangible letters, dynamic colour cues, and texture cues. This is because limited studies adapted the design features of TUIs in developing tangible prototypes or systems for children with dyslexia (Fan et al., 2016a). Thus, there is a promising potential for the TUIs design features to be applied in designing a tangible system for children with dyslexia.

Finally, the design components in the context of this study comprise TUIs design features, IxD dimensions, and UD principles that will support children with dyslexia reading. Current TUIs are limited in applying any theory or principle to guide an accurate design that meets the needs of children with dyslexia such as Universal Design's low physical effort (principle 6) and size and space for approach use (principle 7) while taking IxD theory as a base in the design of TUIs to ensure meaningful interaction that facilitates memory retention and reduces cognitive load for children with dyslexia. This is essentially important to be included in the design especially with dyslexia in mind. The intersection UD and IxD considered in the guideline is crucial in developing a good design for children with dyslexia (Aziz et al., 2013). This study provides a theoretical base for the design of TUIs that highlights an improved framework and guideline for children with dyslexia to facilitate learning to read in Malay, raising significant questions to be answered in the following section.

1.2 Research Questions

Based on the statement of problem as discussed, the research questions are formed as follows:

1. Which TUIs design components are mainly suitable for children with dyslexia learning to read in Malay?
2. What would be the TUIs design guideline for children with dyslexia?

3. How effective is the design guideline of TUIs to assist children with dyslexia in learning to read in Malay?

1.3 Research Objectives

To answer the research questions, this study proposes a TUIs design guideline that is designed for children with dyslexia learning to read in Malay. Specifically, the study sought to achieve the following objectives:

1. To analyse the TUIs design components specifically for children with dyslexia learning to read in Malay.
2. To construct a TUIs design guideline for children with dyslexia.
3. To evaluate the effectiveness of the constructed TUIs design guideline.

1.4 Research Scope

The study is performed to develop a TUIs design guideline for children with dyslexia to facilitate learning to read in Malay. Hence, the targeted participants are children with dyslexia in the Malaysian context. The children that participate in this study are from primary school between 7 to 12 years old and have similar reading levels as identified and suggested by their special education teachers based on the preliminary study (Ministry of Education, 2019). Most TUIs reading systems use reading for children ranging from as early as 5 years old to 12 years old (Pandey & Srivastava, 2011a; Horn, Crouser, & Bers, 2012; Fan & Antle, 2015; Antle et al., 2015; Teh et al., 2015; Fan et al., 2019). Sixteen children with dyslexia were involved in this study. According to various research, having ten children with dyslexia participation is considered representative (Russell et., al 1996; Ubaidullah, 2007).

This study focuses on development of TUIs design guideline for children with dyslexia in reading based on previous dyslexia research. TUIs prototype was developed based on the proposed design guideline that incorporates design features of TUIs, learning contents and learning styles to evaluate the guidelines in supporting children learning to read. This can help children with dyslexia to grasp reading skills using a TUIs prototype that offers multisensory learning.

This study comprises learning content focusing on Malay language according to reading levels of children with dyslexia. This study includes two levels of learning content. The first content focuses on letter recognition. According to Jamali et al. (2019), letter recognition adopts O-G and dual coding learning theories by which children with dyslexia recognise the letters and associate themselves with the image while reading (Refer to section 2.2.1 for more information on these theories). The second content focuses on spelling which teaches children with dyslexia the spelling of consonant vowels (CV), vowel and consonant vowels (V+CV), and consonant vowels in two syllables (CV+CV). Children with dyslexia adopt the theories of O-G in which the syllables must be identified based on the sound of the letters at this level. In addition, the learning content allows children with dyslexia to arrange and use different senses to manipulate the tangible letter that applied kinesthetic theories.

1.5 Research Taxonomy

The research taxonomy of this study is according to the ACM Computing Classification System (2012) as follows:

Knowledge area: Human-centred computing

Field: Interaction design

Majoring: Interaction design process and methods

Sub-major: User interface design

Focus domain: Children with dyslexia

The focus domain is dyslexia and children with dyslexia. This is because children with dyslexia often struggle when reading. The symptoms of error in reading are primarily caused by the phonological deficit that causes difficulty with the reading (e.g., letter-sound decoding deficits, phonological awareness) (Snowling, 2014; Vellutino et al., 2004). Among the letters that are often mixed up by children with dyslexia are 'b-d', 'u-n', 'm-w', 'g-q', 'p-q', and 'b-p' (Mohammad, 2012). Phonological awareness deficits are referred to as difficulty in noticing and manipulating speech sounds, evaluated by meta-phonological tasks which include the deletion of phoneme ('say the word ''sport'' without the /s/ sound') (Castles & Friedmann, 2014, p.275).

The guideline is significant as it highlights the core design features of the TUIs, learning styles, learning content, IxD, and UD principles that are adapted to the guideline. The guideline emphasises the use of multisensory methods such as audio, visual, and kinesthetic. Fan et al. (2016a) elucidated those children with dyslexia require a multisensory approach to enhance brain stimulation and the learning process through textures. The sub-major is user interface design which refers to TUIs. TUIs have a prospect for learning better in reading among children with dyslexia (Cramer et al., 2016). For instance, the 3D tangible letters with embedded texture cues or colour cues are able to make the children pay attention at the moment once the sounds of letters change appear compared to the static letter colours.

1.6 Research Significance

This study contributes to theoretical and practical knowledge in the field of IxD, particularly in TUIs specifically in the IxD process and methods in user interface design for dyslexic children. First, this study is expected to offer theoretical contributions to the knowledge, of tangible interfaces literature stream. The study examines the potential of tangible interaction in the context of dyslexic experience in enhancing their learning process (as mentioned in the taxonomy).

Practically, this study is of immense significance to the multiple stakeholders including the special education teachers, children with dyslexia, researchers, developers, and the Ministry of Education (MoE).

i. Special Education Teachers and Children with Dyslexia

Specifically, special education teachers can benefit from the TUIs prototype based on TUI design guideline to improve their teaching with children with dyslexia. On the other hand, children with dyslexia will experience more enjoyable learning the Malay language. The TUIs prototype can be further explored to teach children with dyslexia in reading. It could be used to devise a specific way to approach Malay language reading to improve their reading efficiency and enhance their interest in academics.

ii. Researchers and developers

The researchers and developers can benefit from framework and design guideline in developing tangible systems to meet user requirements and evaluate the effectiveness of the TUIs. Apart from that, the present study has proven to be able to provide TUIs design guideline for assisting children with dyslexia in reading in Malay. This is a result of the high preference from dyslexic children, that tend to explore this type of tangible technology because it allows them to engage their sense of touch, which can help them better understand and retain information.

With the framework and design guideline, developers would be able to understand the needs of children with dyslexia in facilitating their learning sessions. In addition, the developers would be able to recognise which design features that is not suitable to be applied in the development of the tangible system. Hence, a deliberate effort in studying the present impact of the design features of TUIs on children with dyslexia is crucial for realising the best possible outcomes.

iii. Ministry of Education (MoE)

This study sheds light on the significance of TUIs prototypes in aiding children with dyslexia Malay reading ability. This is especially important considering that Malay is the primary language in Malaysia and is learned from an early age. Furthermore, all public and private schools registered under the Ministry of Education (MoE) are required to use Malay as the medium of instruction, with over 80 percent of the curriculum dedicated to Malay (Ali, 2022). This policy is in line with the Malaysia Education Blueprint's objective of "Upholding Malay Language and Strengthening the English Language", which mandates Malay as the medium of instruction in National schools, including for Science and Mathematics. However, children with dyslexia, particularly those at the beginner level, may face difficulties in recognizing alphabets and new words, which can impede their reading progress.

This study provides an empirical finding on the effect of TUIs design components on children with dyslexia learning to read in Malay. Future studies may consider getting children with dyslexia to participate from the early start of the design process until the evaluation of the prototype and finally realising the outcome of TUIs on children’s learning sessions. Finally, according to the findings, this research has successfully validated that TUIs design guideline tailored for children with dyslexia are effective in providing multisensory learning experiences to children with dyslexia.

1.7 Thesis Organization

The thesis is structured into seven chapters: Introduction, Review of Literature, Methodology, Tangible User Interfaces Design Components, TUIs Framework and TUIs Design Guideline, The Prototype Development and Validation, and Discussion and Conclusion and Future Recommendations.

Chapter 2 discusses the literature review of the study. This describes a critical review and discussion of previous studies that are important to the research. This includes the tangible interaction and tangible user interfaces, TUI framework, universal design principles, interaction design theory, background of dyslexia, learning theories for dyslexia, design features of TUIs, design guideline of TUIs, and the evaluation methods for this study.

Chapter 3 discusses the methodology for conducting this research. It explains detailed descriptions of the research methodology phases including theoretical study, TUIs design components, framework and design guideline development, prototype development and the validation of design guideline. The following sections are experimental procedures and instruction procedures using the prototype.

Chapter 4 discusses the qualitative findings of the focus group analysis with special education teachers. The findings of the focus group discussion provide detailed insight into children with dyslexia and TUIs. The eight themes that were derived from the findings are classified into eight categories, including characteristics features of children with dyslexia, challenges of children with dyslexia in learning, subjects, and personal interests of children with dyslexia, learning content, learning styles, design features of TUIs, IxD and UD principles.

Chapter 5 discusses the constructed framework and design guideline of TUIs based on an improved version of Ullmer and Ishii's TUIs framework. The framework and guideline are then verified by experts with backgrounds in HCI and arts and design (product design). The improved version of the TUIs framework and design guideline were explained based on the verification results.

Chapter 6 discusses the TUIs prototype that was developed based on constructed TUIs design guideline. The prototype design is explained based on the hardware and software of the TUIs prototype. The process of design guideline validation is described, followed by the results and conclusion.

Chapter 7 concludes the research findings according to the research objectives. Following that, the contributions and limitations of the study are discussed, followed by recommendations for further research.

Also, tangible letters accelerate the children in positioning the letters and concentrating on hearing associated sound changes.

CHAPTER 2
LITERATURE REVIEW

2.0 Introduction

With advancements in TUIs technology, it is increasingly embraced as a valuable tool for supporting learning activities (Fan, Antle, & Cramer, 2016b; Teh et al., 2015), particularly in providing appropriate learning materials through tangible objects and offering concrete examples using physical objects. Furthermore, TUIs actively promote experiential learning by encouraging hands-on engagement (Jamali et al., 2019). Moreover, it plays an important role in supporting children with dyslexia and helps to structure exploratory learning (Falcão & Price, 2010).

As children with dyslexia are viewed as having difficulty learning how to read, they typically experience visual, auditory, and kinesthetic deficits that cause an inability to process information in their brains despite no visual, hearing, or motor impairments. Thus, TUIs are seen to facilitate the learning session as it gives the multisensory experience to stimulate their senses. TUIs, which are part of TI, are recognised as an interactive approach for supporting children with dyslexia in learning to read as it enables interaction between the children and tangible objects. Several TUIs have garnered notable success in enhancing the learning process (Marshall, 2007; Falcão & Price, 2010).

This chapter discusses the literature review of the research on TUIs and dyslexia. It also reviews related literature on the background of dyslexia and TUIs' concept towards reading development of children with dyslexia. Finally, the chapter gives an overview of the learning support for dyslexia through the theoretical framework, design features of TUIs, learning theories, UD principles, IxD theory, design guideline, and method of evaluation.

2.1 Dyslexia

Reading ability is one of a learner's main skills. However, few children were experiencing difficulties in reading or learning disability (LD) so-called dyslexia, irrespective of their social status, intelligence level, or education. This LD is innate and permanent throughout life, thereby requiring early and specialized intervention. Lyon, Shaywitz, and Shaywitz (2003) referred dyslexia as a severe impairment in reading and spelling which inconsistent with the child's intelligence quotient (IQ) or other potential academic abilities (Yuzaidey, Din, Ahmad, et al., 2018). Children with dyslexia can be characterised by different sensory systems including visual dyslexia, auditory dyslexia, and visual-auditory dyslexia (Jamali et al., 2018b, p.169). Table 2.1 summarised the three categories of dyslexia as aforementioned. These impairments were not only affecting the children with dyslexia self-esteem but also made them feel less accomplished and less intelligent than they are supposed to be.

Table 2.1
Categories of dyslexia adapted from Jamali et al., (2018b)

No.	Categories of dyslexia	Description
1.	Visual dyslexia	Individuals who can see well, but are unable to comprehend or recall things that have been seen and have trouble saying a word with many syllables
2.	Auditory dyslexia	It makes it difficult for individuals to comprehend the similarities and differences between sounds heard, recognise each sound in words, blend sounds to come out with the words, diverge a word into syllables. Children will concentrate on hearing words, as whenever the sound is processed by the brain, some information is lost, and sounds can be reversed, fused, and jumbled. Auditory dyslexia are present in most children with dyslexia.

3.	Visual-auditory dyslexia	Individuals who have trouble using both sensory: vision and hearing. The effect then affected the visual and auditory process of obtaining information

Children with dyslexia were found to have learning difficulties, definitely in the language (Jamali et al., 2019). Dyslexia is characterised by difficulties in reading skills, recognising words accurately, differentiating the sound of letters, recognising mirror letters, and forming syllables in sentences (Alias & Dahlan, 2015). Besides, children with dyslexia also have low confidence, are easily distracted, and rely heavily on teachers or parents during their learning processes (Ahmad et al., 2012). The eight major characteristics of dyslexia were presented in Table 2.2 (Bolhasan, 2009; Bakar, ChePa & Sie-Yi 2023).

Table 2.2 *Major Characteristics of Dyslexia adopted from Bolhasan (2009); Bakar, ChePa & Sie-Yi (2023)*

No.	**Major Characteristics of Dyslexia**
1.	Instabilities of writing and speaking vocabulary
2.	Late in oral action
3.	Weak in arranging the content
4.	Short-term memory
5.	Incapable to spell properly
6.	Limitation of understanding; only remember things in the class but will be forgotten during the test
7.	Inaccurate in reading
8.	Not well-planned

Thus, multisensory methods work best for children with dyslexia because they cannot rely on the traditional way of teaching and learning due to their phonological deficits and different and rather unique way of processing phonology and orthography. The multisensory method, "known as visual-auditory-kinesthetic-tactile or VAKT indicates that learners are better taught when knowledge is provided in various modalities" as cited by Sanfilippo, Blazauskas, Salvietti, Ramos, Vert, Radianti, &

Oliveira (2022). According to Sarudin, Hashim and Yunus (2019), multisensory methods involve the use of human senses to improve learning, which involves visual (what we can see), auditory (what we hear), and tactile (what we do or feel). Firstly, a majority of educational research suggests that the use of kinesthetic/tactile senses might help to learn by boosting attention, memory, and understanding. Secondly, the tactile feature of tangible letters can aid trace letters which can help children readily memorize letter forms and sounds with motor memory. Third, physical manipulation of tangible letters can also aid in acquiring abstract ideas like word decoding by downloading complicated mental processing into external instruments (e.g., by physically moving two syllables apart) (Fan, 2017; Antle, 2007). For example, TUIs allow individuals to physically hold or touch and perform any related activities with the letters and spells while also visually stimulating them from the digital space that is the computer.

By invoking additional senses to compensate for their disabilities, children with dyslexia can gradually but steadily develop their reading and spelling abilities. In short, TI, including TUIs, holds promising potential as an alternative approach by leveraging technology to actively engage children in their learning sessions. TUIs offer a captivating, interactive, and enjoyable learning experience by incorporating various senses, making the learning process more stimulating and fun. Fan et al. (2016b) mentioned that multisensory approaches recommend the potential of using colour cues and tactile cues to facilitate learning of letter-sound correspondences.

To facilitate the learning process for children with dyslexia, TI and TUIs had the potential to address this group's needs to easily perform their learning undertaking that they are unfamiliar with hence, created independence in learning. Additionally, it will boost the children's confidence and ability to learn independently without relying on others (Hamid et al., 2017). The following section described the learning theory for dyslexia.

2.1.1 Learning Theory for Dyslexia

Learning theory describes how knowledge during learning is learned, processed, and maintained (Jamali et al., 2018). The following section discusses the adaptation of specific learning theories that was implemented in this study in teaching children with dyslexia, and how TUIs design guideline is designed based on these theories.

2.1.1.1 Theory of Orton-Gillingham

The O-G is a multisensory method of teaching language related skills that emphases on the use of sounds, syllables, words, sentences, and written discourse (Joshi et al., 2002, p.231). It has proven very effective in improving the reading and spelling of children with problems of literacy (McIntyre & Pickering, 1995). O-G theory focused on the visual, auditory, and kinesthetic modalities (Fan, 2017). Based on O-G theory, children heard a letter pronunciation while seeing the letters and can learn to use their fingers to trace letters by encouraging them to connect letters shapes with distinct motor movements.

Teachers may also employ additional indications such as using images and colours (for example, *pat*, *rat*, *bat*) to entice child focus and improve their memory of letter-sound correspondences during activities (Fan et al., 2017). This finding is further supported by Antle et al. (2015), which found that the use of texture cues inherent in 3D tangible letters accelerates reading performance better, particularly for children with dyslexia. Furthermore, the tactile modality can be utilised in the design of tangible systems by incorporating activities like letter tracing and manipulation. This approach offered physical affordances that facilitate the children's learning process and enable them to easily navigate and interact with the system (Sharlin et al., 2004). Thus, this study is adopted based on the O-G theory, which enables children to hold and feel 3D tangible letters. Supported by the theory, this study aims to propose texture cues implanted in 3D tangible letter design features for better improvement of the reading results.

2.1.1.2 Theory of Dual Coding

Dual coding theory (DCT) is an established theory that enlightens on the individual behaviour and experience in the context of dynamic associative processes to have a better function on a rich network of modality-specific verbal and nonverbal (or imagery) representations (Clark & Paivio, 1991, p.149). According to the dual code theory (Clark & Paivio, 1991), children with dyslexia necessitate verbal and non-verbal representations together with visual information such as diagrams, animations, and photographs to facilitate their learning process.

According to Jamali et al. (2018) using a clear picture which colourful enables to entices greater attention of children with dyslexia, accelerates their comprehension, and makes learning a language more fun and engaging. For example, the visual modality comprises printed words and pictures. Words and sound events will be spoken in the auditory modality. A tiger can be represented as a tiger picture and the word tiger or both events in different systems.

Based on DCT, it is easier to learn knowledge both verbally and non-verbally (Clark & Paivio, 1991; Fan, 2017). Therefore, with the associations between letters, sounds, pictures, or other non-verbal cues such as colours, children can learn easily grapheme-phoneme correspondences or vocabulary knowledge (Fan, 2017). Following the prior studies, this study is supported with the DCT which allows the children with dyslexia to see the picture while hearing the associated sound play.

2.1.1.3 Theory of Kinesthetics

When the material is shown visually, children with dyslexia learn more effectively. However, they will be even more successful if they can interact kinesthetically with materials (Reid et al., 2013). Kinesthetic theory empowers the children to accomplish their activities such as manipulating, organising, and interpreting the knowledge after learning through tactile (touch) or kinesthetic (body movement) (Jamali et. al., 2019; Kinesthetic Learning Strategies, 2017). Children with dyslexia learn best through a hands-on approach and when they can move their bodies and provide different senses of touch.

It can be concluded that these three learning theories; 1) theory of O-G; 2) theory of dual coding; and 3) theory of kinesthetic are relevant for children with dyslexia. The theory of O-G and dual coding is important for spelling and reading but they will need to be helped or stimulated by kinesthetics to be more effective. For example, in the visual modality, there are printed words and pictures. There will be spoken words and sound occurrences in the auditory modality. Tiger can be kept as an image of a tiger and the word tiger, or both events in separate systems. Verbal and nonverbal communication will function independently as stated in dual coding theory. In addition, children with dyslexia benefit from kinesthetic learning because they frequently forget to write letters or remember the shape of letters. To assist children with dyslexia, for instance, allow them to play with sand and ask them to write letters on the sand. As a result, there is touch and kinesthetic (hand movements at the time of writing). This will assist children in remembering the letters as they learn. Hence, this study adopted this theory to enable the most efficient learning to take place among children with dyslexia. The subsequent section discussed design features of TUIs.

2.2 Tangible Interaction and Tangible User Interfaces

TI and TUIs have been steadily gaining in popularity and are well-developed in the Human-Computer Interaction (HCI) field (Hornecker & Buur, 2006: Jamali et. al., 2018b; Lozano et al., 2018). The notion of TI is described as an umbrella that consists of TUIs (Jamali et al., 2018b). The following sub-section describes TI and TUIs.

2.2.1 Tangible Interaction

TI is becoming increasingly more popular as an alternative approach to support learning by using physical tangible objects while interacting with a digital space (Shaer & Hornecker, 2010). TI assists children with dyslexia with physical and sensory materials, practical and concrete examples to exemplify explanations, and systematising cooperative learning groups (Falcão & Price, 2010). Also, TI offers a natural and immediate form of interaction to be more accessible to children with dyslexia (O'Malley & Fraser, 2004; Marshall, 2007).

This correlates with the multisensory approach in teaching children with dyslexia as discussed previously where invoking multiple sensories at one time helps increase the learning abilities of a children with dyslexia. According to Indrarathne (2022), multisensory approach that combines the use of visual, auditory, and kinesthetic sensories can enhance memory and promote learning initiatives.

2.2.2 Tangible User Interfaces

Ullmer and Ishii (2000) introduced TUIs as a novel interface type that merges the digital and physical worlds. In 1997, Ullmer and Ishii explored the physical instantiation of interface elements from the graphical user interface (GUI) paradigm, giving physical form to windows, icons, handles, menus, and controls. At large, the adopted GUI is navigated by working on a desktop computer, using a mouse and a keyboard to interact with windows, icons, menus, and pointers (WIMP). Alternatively, the TUI is considered the current GUI paradigm, providing an option to include Mark Weiser's idea of Ubiquitous Computing integrating digital technology into the physical environment (Weiser, 1991). Figure 2.1 demonstrates this TUI instantiations of GUI elements.

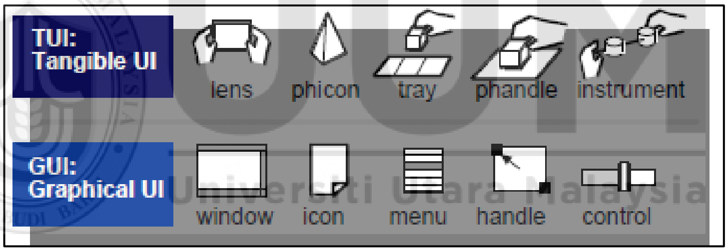

Figure 2.1 TUI instantiations of GUI elements

The GUI “window” device substance as a physical “lens” which may be hand-held, arm-mounted or placed upon another surface. Ullmer and Ishii (1997) physically instantiate GUI "icons" with different levels of representational abstraction as TUI "phicons" (physical icons). GUI "menus" and "handles" are instantiated as TUI "trays" and "phandles" (physical handles). TUIs have a great learning potential, which offers a direct manipulation of physical objects and provides an additional interaction, unlike conventional desktop computers with a GUI focused on a restricted set of physical objects and human capabilities.

In 1997, Ishii and Ullmer introduced the idea of TUIs from a data-centric perspective, which examines possible forms of linkage between material and virtual representations. In 2000, Ishii created a model of TUI interaction that relates to the role played by physical and digital representation, physical control, and digital models. There were two key components: input and output, or control and representation in the interface between people and digital information. Controls allow users to manipulate data when human senses are interpreted through representations.

Ullmer and Ishii (2000) transferred the concept of Model View Controllers (MVC) from the GUIs to the TUIs known as Model Controller Representation (physical and digital) (MCRpd) by Burbeck (1987). MVC was developed together with the Smalltalk-80** programming language as a technical model for GUI software design (Burbeck, 1987). The MCRpd provides TUI designers with means to compare and address important aspects of TI, both tangible and intangible data representation features. Users can directly control the underlying digital representation by presenting information in both tangible and intangible forms. TUI allows for the direct manipulation of digital information through our hands and the perception of it physically in our peripheral senses. The TUI interaction model is shown in Figure 2.2.

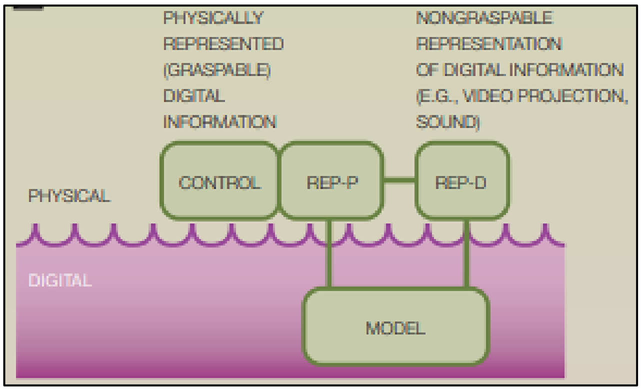

Figure 2.2. TUI interaction model adapted from Ishii (2000)

This model identifies the main features (characteristics) of TUIs: 1) physical representations (*rep-p*) are intertwined with the underlying digital information (*model*); 2) physical representations, interactive control mechanisms; 3) physical representations are perceptively linked to digital representation actively mediated (rep-d); and 4) tangible physical state embody key elements of the digital system state. In addition, this study aims to derive systems from the past, rather than to provide guidelines for the creation of new systems. Figure 2.3 shows the features (characteristics) of TUIs.

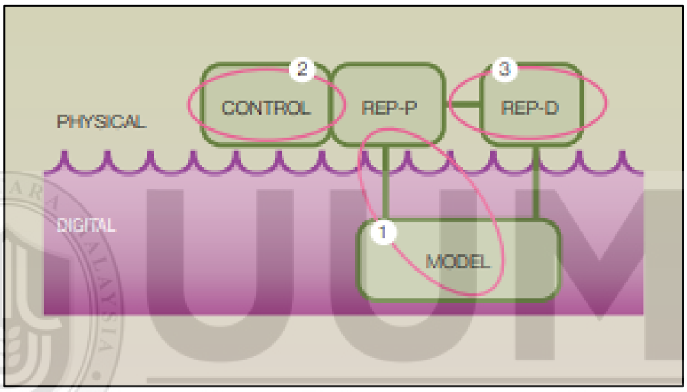

Figure 2.3. Characteristics of TUIs, adapted from Ullmer and Ishii (2000)

Besides, TUIs have opportunities to support children's learning, especially for children with dyslexia (Fan et al., 2016b; Hengeveld et al., 2013). Ullmer and Ishii (2000) also said the main TUI group was closely connected with the field of education. These statements are based on the specific characteristics of TUIs, which are the nature of spatial (Sharlin et al., 2004) and the use of various representational modalities (Antle, 2013), which benefitted both in early reading, mostly among children with dyslexia.

2.3 TUIs Framework

The existing framework of TUIs is limited in terms of detail, description, and perspectives (Antle, 2007; Price, 2008; Cheung & Antle, 2020). Previous studies highlighted that the current framework emphasized on data-centred views, which primarily focus on the linkage between physical and digital representations (Ullmer & Ishii, 2000). In addition, Koleva et al. (2003) develops a framework to classify the tangible interfaces to describe or compare the different systems. However, it is argued that different features of TUIs learning theories and the design of the learning activities (Antle and Wise, 2013) need also to be emphasized for TUI to be effective as a tool to facilitate reading and spelling for dyslexia (Shaer & Hornecker, 2010).

Figure 2.4 illustrates TUI's main concept of making the tangible (physical and graspable) external representation to digital information (Ishii, 2008). There are physical and digital layers in the framework. Users can directly control the underlying digital representations by utilising their hands to receive information in both tangible and intangible representations. The control of the underlying digital information and computational models is computationally linked to the tangible representation. For instance, in Urp (Ullmer & Ishii, 2000) the building models (tangible representation) are always accompanied by a "digital shadow" (intangible representation) without noticeable temporal or spatial gaps. This convinces users of the illusion that the shadows are cast from the building models (rather than the video projector).

The research framework proposed in this study based on Ulmer and Ishii's framework is discussed in Section 5.1. Other theories that have been selected to guide the study are the universal design principles (Connell et al., 1997) and interaction design theory (Sharp, Rogers & Preece, 2015). Universal design principles are discussed in Section 2.3 and interaction design is in Section 2.4.

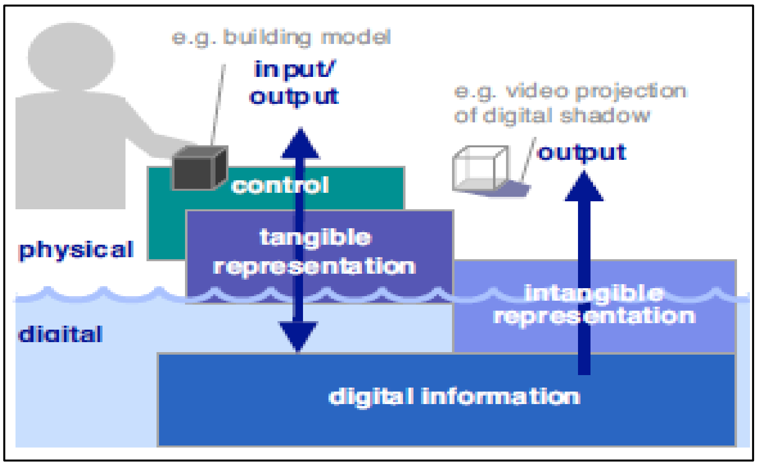

Figure 2.4 TUIs framework (Ishii, 2000)

2.4 Universal Design Principles

A product or environment can be designed for a wide range of consumers, including children, the elderly, disabled people, individuals of atypical size or shape, persons who are sick or injured, and persons inconvenienced by circumstance (Story, Mueller & Mace, 1998). This approach is referred to as universal design (UD). UD has been used extensively as an approach to education and learning (Ostroff, 2011). UD describes the design of products and the environments to be universally used among individuals of all ages and abilities (Story et al., 1998). The UD Centre of the State University of North Carolina described a UD as "the design of products and environments to be utilised as much as possible without the need for adaptation or specialised design for all individuals" (Story, 2001).

According to the Centre for UD (1997), in the fields of design, product creation, and education, the UD principles and related guidelines can be applied. Table 2.3 summarises the following guidelines and principles.

Table 2.3

The Principles of Universal Design adopted from Connell et al. (1997)

Principle	Definition	Guidelines
Principle 1: Equitable Use	The design is useful and marketable to people with diverse abilities.	1a. Provide the same means of use for all users: identical whenever possible; equivalent when not. 1b. Avoid segregating or stigmatizing any users. 1c. Make provisions for privacy, security, and safety equally available to all users. 1d. Make the design appealing to all users
Principle 2: Flexibility in Use	The design accommodates a wide range of individual preferences and abilities.	2a. Provide choice in methods of use. 2b. Accommodate right- or left-handed access and use. 2c. Facilitate the user's accuracy and precision. 2d. Provide adaptability to the user's pace.
Principle 3: Simple and Intuitive Use	Use of the design is easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration level.	3a. Eliminate unnecessary complexity. 3b. Be consistent with user expectations and intuition. 3c. Accommodate a wide range of literacy and language skills. 3d. Arrange information consistent with its importance. 3e. Provide effective prompting and feedback during and after task completion.
Principle 4: Perceptible Information	The design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities	4a. Use different modes (pictorial, verbal, tactile) for redundant presentation of essential information. 4b. Maximize "legibility" of essential information. 4c. Differentiate elements in ways that can be described (i.e., make it easy to give instructions or directions). 4d. Provide compatibility with a variety of techniques or devices used by people with sensory limitations.
Principle 5: Tolerance for Error	The design minimizes hazards and the adverse consequences of accidental or unintended actions.	5a. Arrange elements to minimize hazards and errors: most used elements, most accessible; hazardous elements eliminated, isolated, or shielded. 5b. Provide warnings of hazards and errors. 5c. Provide fail-safe features. 5d. Discourage unconscious action in tasks that require vigilance.
Principle 6: Low Physical Effort	The design can be used efficiently and comfortably and with a minimum of fatigue.	6a. Allow user to maintain a neutral body position. 6b. Use reasonable operating forces. 6c. Minimize repetitive actions. 6d. Minimize sustained physical effort.

Principle 7: Size and Space for Approach and Use	Appropriate size and space is provided for approach, reach, manipulation, and use regardless of user's body size, posture, or mobility.	7a. Provide a clear line of sight to important elements for any seated or standing user. 7b. Make reach to all components comfortable for any seated or standing user. 7c. Accommodate variations in hand and grip size. 7d. Provide adequate space for the use of assistive devices or personal assistance.

Table 2.4 describes each principle in the TUIs design context to demonstrate how TUIs for major tasks can be designed to be accessible to a larger proportion of the population (Dubuc & Edge, 2006, p.5).

Table 2.4

Universal Design of TUIs adapted from Dubuc and Edge (2006)

Principle	TUIs Design
1. Equitable Use	Hand-sized objects that have a high degree of contrast to their environment are likely to be used by a large proportion of the population than very small objects (except for users who are motion impaired) that fade into their environments (except for visually impaired users), whilst at the same time appealing to the sense of playing of all users.
2. Flexibility in Use	TUIs typically use bi-manual skills, but in a natural way, i.e., both left and right-handed users can use this equally well. They can also be customised to meet the level of user expertise: beginner users are presented with the minimum number of physical objects necessary to complete their task, and expert users have the option of creating abstractions and have greater freedom to choose physical-digital mappings.
3. Simple and Intuitive Use	One of the major benefits of the physical component of TUIs is that they use the skills that we have developed over a lifetime of real experience. This is complemented by the TUI virtual component which can recommend possible actions and provide interactive feedback on the effects of user actions.
4. Perceptible Information	The enduring existence of physical objects ensures that tangible information is always evident under normal environmental conditions and even darkness and some visual impairments can be resolved by means of using appropriate lighting on the tangible itself. TUIs can interact with tactile interaction (using static features, such as object weight and texture) and haptic interaction (using time varying features such as skin pressure and muscle tension). Multiple modes of expression can be used for redundant presentation of essential information.
5. Tolerance for Error	The fact that TUIs mainly use space as their medium in contrast to conventional GUIs where interaction is mostly time consuming, provides them with a clear advantage in terms of error tolerance. Although physical objects can easily be reorganized in space, GUI events cannot be rearranged in good time without the additional complexity of temporal abstractions.
6. Low Physical Effort	In terms of error tolerance, a TUI's physical objects cannot be sufficiently light for the accidental movement. This condition must be balanced with the

	requirement that extended use of the TUI does not cause in fatigue-the weights of the tangibles should be chosen to reflect this balance.
7. Size and Space for Approach and Use	The physical objects itself have to be large enough to be easily manipulated in respect of low physical effort. The choice of object size should also take into consideration the space required by all physical objects – any standing or sitting users must be able to access the entire interaction space.

Based on Dubuc and Edge (2006), Table 2.5 proposed the suitable design in TUIs based on previous studies.

Table 2.5

Suitable design based on UD principles adapted from Dubuc and Edge (2006)

Principle	TUIs Design Description	Suitable Design
1. Equitable Use	Hand-sized objects that have a high degree of contrast to their environment are more likely to be used by a large proportion of the population than tiny objects (except for users who are motion impaired) that fade into their environments (except for visually impaired users), whilst at the same time appealing to the sense of playing of all users.	– Use a suitable design that works for everyone relatively than separating people into categories or personas, "blind," "children with dyslexia," "ideal user," "male," or "able-bodied," and should view them as users. – Using the 3D tangible letter will allow hands-on interaction with the letters (Jamali et al., 2018b).
2. Flexibility in Use	TUIs typically use bi-manual skills, but in a natural way, i.e., both left and right-handed users can use this equally well. They can also be customised to meet the level of user expertise: beginner users are presented with the minimum number of physical objects necessary to complete their task, and expert users have the option of creating abstractions and have greater freedom to choose physical-digital mappings.	– A user interface that offers a variety of options for positioning specific content is well-designed for children with dyslexia users. (Scott, McGuire & Shaw 2003; p. 375). – Jamali et al. (2018) mentioned that a flexible learning style helps children with dyslexia practice learning based on the needs of the individual learners.
3. Simple and Intuitive Use	One of the major benefits of the physical component of TUIs is that they use the skills that we have developed over a lifetime of real experience. This is complemented by the TUI virtual component which can recommend possible actions and provide interactive feedback on the effects of user actions.	– Create an interface that easy to learn. For instance, create a clear information hierarchy based on convention. – Use clearly labelled layouts (Zusman, 2015). – Information should not be in text form (Zusman, 2015). – Use audio feedback to read instructions (Jamali et al., 2019)
4. Perceptible Information	The enduring existence of physical objects ensures that tangible information is always evident under normal environmental conditions and even darkness and some visual impairments can be resolved by	– Use different multisensory modalities such as visual, verbal, and tactile for the redundant presentation of essential information (Almeida & Baranauskas, 2010). For example, different modalities

	using appropriate lighting on the tangible itself. TUIs can interact with tactile interaction (using static features, such as object weight and texture) and haptic interaction (using time-varying features such as skin pressure and muscle tension). Multiple modes of expression can be used for the redundant presentation of essential information.	for children with dyslexia in learning to read can stimulate their brains, thus improving learning by having textures to attract children's attention (Jamali et al., 2018b). – Demonstrate to users precisely the information without any distractions they need. – Use children with dyslexia -friendly font. For instance, users who have dyslexia and have the font already will see a children with dyslexia-friendly font, while those without the font will view the website normally (Zusman, 2015).
5. Tolerance for Error	The fact that TUIs mainly use space as their medium in contrast to conventional GUIs where interaction is the most time-consuming, provides them with a clear advantage in terms of error tolerance. Although physical objects can easily be reorganized in space, GUI events cannot be rearranged in good time without the additional complexity of temporal abstractions.	– Allowing errors to be reversed or minimized, for example, the audio feedback message (Zusman, 2015).
6. Low Physical Effort	In terms of error tolerance, a TUI's physical objects cannot be sufficiently light for accidental movement. This condition must be balanced with the requirement that extended use of the TUI does not cause fatigue - the weights of the tangibles should be chosen to reflect this balance.	– The instruction is designed to minimise the non-essential physical effort to maximize learning (Scott et al., 2003). – Design features of 3D tangible letters should be (Fan et al., 2018): (1) hand-sized and made of light and safe material so that children can pick up and hold them easily; (2) Letters must be able to stand up on their own so that the children can easily organize them in space (3) There should be ample space on the table to place all the letters
7. Size and Space for Approach and Use	The physical objects itself have to be large enough to be easily manipulated in respect of low physical effort. The choice of object size should also take into consideration the space required by all physical objects – any standing or sitting users must be able to access the entire interaction space.	– The size of 3D letters should also be pleasant to touch, and easy to move, organize and handle. Providing a small subset of letters for each learning activity and encouraging both teachers and children (e.g., placement in slots) helps focus attention on letters (Fan et al., 2018). – Instruction is designed with consideration for appropriate size and space for approach, reach, manipulations, and views regardless of a children's body size, posture, mobility, and communication needs (Scott et al., 2003; p. 375).

Therefore, UD principles are adapted in this study within the TUIs design concept as suggested by Dubuc and Edge (2006). The reason is that UD works for everyone instead of separating people into personas or groups, as mentioned in Principle 1 (Equitable Use). In other words, every chance to learn in a style that best suits a child with different abilities should be provided (Reid et al., 2013). TUIs are potential alternatives when involving technology to be more engaged in their learning sessions. UD is considered for TUIs for children with dyslexia because using different modalities such as audio, visual, and tactile in learning to read can stimulate their brain, thus improving learning by having textures to attract children's attention as mentioned in Principle 4 (Perceptible Information). This study proposed the TUIs design guideline based on a universal design principle that can meet the user's requirements and evaluate the effectiveness of TUIs to help children with dyslexia learn to read in Malay. This aligns with the UD principles that provide multiple means of representation, engagement, and expression.

2.5 Interaction Design Theory

Interaction design (IxD) is a discipline for the design of interactive products to aid people in their daily lives (Hussain, Abdullah, Husni, et al., 2016). IxD is an area based on user experience (UX) design which enhances and increases the way people work, communicate, and interact (Sharp, Rogers & Preece, 2002; Aziz et al., 2013). The five dimensions of IxD are; words, visual representations, physical objects or space, time, and behaviour, as depicted in Figure 2.5.

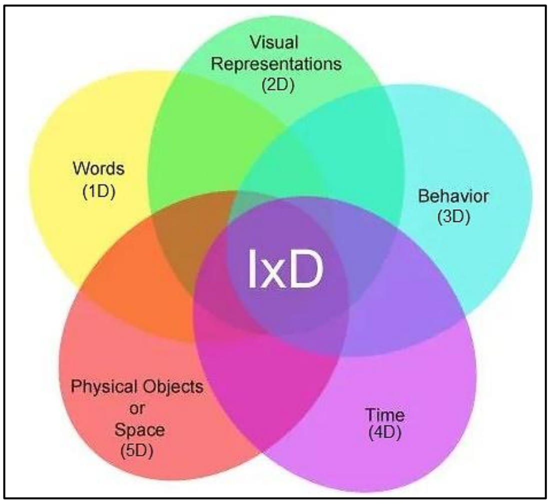

Figure 2.5. IxD Dimensions

The five dimensions of interaction design are beneficial for explaining the concept of interaction design (Interaction Design, 2020). Words define the interaction, for example, button labels. Visual represents what is presented to the user which includes typography, diagrams, icons, and graphics. Physical objects or space are the physical hardware with which users interact while visiting an app or website, like a mouse, a keyboard or a mobile device. Time refers to the content that changes over time, for example, sound, video or animation (Silver, 2007). The behaviour is related to user experience as well as actions or feelings after interacting with the system (Aziz et al., 2013). In this study, the IxD dimensions are adapted to the TUI design concept. The proposed TUIs design based on IxD dimensions is presented in Table 2.6 in the required design based on IxD dimensions.

Table 2.6

IxD for Children with dyslexia

Dimension	TUIs Design	Suitable Design
Words	1. Text	-Avoid using animated words to get their attention and make reading the words easier for them (Aziz et al., 2013). -Avoid using uppercase letters that could make reading more difficult (Fan et al., 2016a; Mcphillips et al., 2015). -Should have a list of structured word (Aziz et al., 2013).

Visual representations	1. Font type	-Use using plain sans serif fonts such as Comic Sans MS for font type (Aziz et al., 2013). -The font size must be 12-14 points. - Children with dyslexia readers need a larger font. -Use selected font type with no mirror effects (Jamali et al., 2019).
	2. Dynamic Colour Cues	-The usage of dynamic colour cues embedded in 3D tangible letters to seek the children's attention for a moment once the letters' sounds changed (Fan et al., 2017).
	3. Colour	-Use the background colour code suggested by Irlen (2005) for dyslexia (Aziz et al., 2013). -Use warm background colours such as, peach, cream and orange can stimulate brain of children with dyslexia reader (Jamali et al., 2019). -Avoid using green & red colour since they lead to distraction (especially to the blind colour people) (Aziz & Husni, 2012)
Physical objects or space	1. 3D tangible letters	-The usage of hand-sized and crafted with light and safe material helps the children to easily pick up and grasp them in their hands (Fan et al., 2018) - The letters used need to be able to stand up on their own for the children to easily organize them in space (Fan et al., 2018).
	2. Texture Cues	-Use tangible letters that are embedded with texture cues to invoke touch sensory of the children (Fan & Antle, 2015)
Time	1. Audio	-The audio elements should fit the pictures. It must also be easy to use in a suitable number (Hussain et al., 2016). -Provide audio output, for example, narrator voice (Aziz et al., 2013). -Use a clear voice to recognize various letter sounds
Behaviour	1. Help	-Voice-based help menu (audio help) (Aziz et al., 2013). -An option could be provided to record the progress of users (Aziz et al., 2013).

Therefore, IxD dimensions are adapted in this study within TUIs design concept. Good design also gives users positive feelings (Aziz et al., 2013). Thus, a good design will help children with dyslexia learn to read by offering an interactive user interface with tangible letters that are designed to make up for their difficulties to make the learning process easier. In order to materialise children with dyslexia -friendly TUIs, certain elements of IxD should also be taken into consideration. In terms of visual representations dimensions based on TUIs design include font type, dynamic colour cues and colour. According to Jamali et al. (2019), selected font type without mirror effects is required for children with dyslexia because it is easy for them to read. Invoking multiple sensories at one time helps increase the learning skills of children with dyslexia (Jamali et al., 2019; Jamali et al., 2018b). Thus, using tangible letters with texture cues can invoke the touch sensory and allow children with dyslexia to better retain in memory the letters as mentioned in physical objects or space dimensions (Fan & Antle, 2015). A suitable design based on IxD dimensions is considered for TUIs design guidelines because it facilitates children with dyslexia in learning to read. Hence, the TUIs design guideline is proposed based on IxD dimensions that can fulfil the user requirements and evaluate the effectiveness of the TUIs to assist children with dyslexia reading in Malay.

2.6 Design Features of Tangible User Interfaces

There has been a lot of research conducted in TI, particularly in the relationships between TI for children with dyslexia through TUIs systems. The design features of TUIs explained what the information means, and content henceforth are presented in the tangible system for children with dyslexia. Cramer et al. (2016) emphasized the significant potential of TI in representing letters as tangible objects that can be interacted easily, as opposed to traditional printed letters. This approach allowed for tracing and organizing letters into groups or linear word sequences, enhancing the learning experience (Fan et al., 2017). Additionally, Price et al. (2003) proposed the use of TI to foster engagement and enjoyment among children with learning disabilities within a fun learning environment. Moreover, TI is readily accessible to children, and they tend to experience naturally and familiar (Zuckerman et al., 2005). The core design features of TUIs that assist the reading process found are 3D tangible letters, dynamic colour cues and other design features discussed in the next subsection.

2.6.1 3D Tangible Letters vs. 2D Tangible Letters

Jamali et al. (2018) conducted a preliminary study of TI supported with the theories and previous studies for children with dyslexia. This study proposed a TI model for children with dyslexia in primary school and found that the model supports learning theories among children with dyslexia which are O-G theory, dual coding theory, and kinesthetic theory. The model plans to use TI in different ways to help children with dyslexia with multiple forms of sensory difficulties including visual, auditory, and kinaesthetic. The proposed model entailed children with dyslexia engaging with physical 3D letters, manipulating them, and connecting their senses with visual representations in the digital realm. A tangible system was developed based on the TI model to assist children with dyslexia in learning to read, spell, and improve their phonological skills.

Meanwhile, SpellBound, a tangible system developed by Pandey and Srivastava (2011a), serves as one of the tools that help children with dyslexia between the ages of 8 and 12 to better understand the connections between letters and sounds. (Pandey & Srivastava, 2011a). It facilitates the children to construct 2D letters by using a set of wooden shapes. In respect with the letter sound and picture of the words, each of the 2D letters can be placed on a platform. Their study employed a cohesive approach to facilitate the learning of English spellings, which supporting by the "Multiple Intelligence" theory. This approach focused on teaching letters and subsequently linking them together to form words that carry associated meanings.

Based on the studies above, the major difference between these TUIs is the standardised or letter-shaped physical representations and either 2D or 3D. For children with dyslexia, letter forms are important as they can facilitate letter shape learning by tracing activities. Fan et al. (2016a) found out that 2D letters had several constraints: (1) they can restrict certain manipulating actions of letters while practicing with them in space; (2) digital 2D letters lack distinct physical constraints that result in children being unable to facilitate simple letters tracing; (2D or cubes) (Fan et al., 2019).

The findings from Fan et al. (2019) indicated that 2D letters are not as suitable as 3D letters. This is because the features of 3D letter cards or tangible letters enable children to establish a precise letter orientation and employed effective strategies for organizing letters during spelling tasks. Aziz et al. (2013) proposed the use of selected letters without mirror effects, and this suggestion supported by Antle et al. (2015) which emphasized the design of 3D tangible letters assisted children with dyslexia. Their study stated that children with dyslexia initially focusing on individual letters rather than whole words, as they often struggle with recognizing letter-sound correspondences and mirror-letter confusion. Besides that, the 3D letters incorporate interactive features like texture, colour and position in delivering information for greater knowledge on the alphabetic principle decoding rules (Antle et al., 2015, p. 535). A study done by Jamali et al. (2018b) was not fully executed because the system was at an early stage.

2.6.2 Dynamic Colour Cues vs. Colour Cues

Pandey and Srivastava (2011b) have developed Tiblo blocks to be tangible educational support, particularly for children with dyslexia aged 8 to 12 years old by linking and physically fitting blocks. According to their interest, children with dyslexia would be able to draw something, nail it up on the block and eventually record a visual-related sound. In addition, Furthermore, Tiblo can ideally be used as a support for different classroom activities such as complex spelling and narrative with an instructor's supervision. Following the completion of the test, the results showed that the children with dyslexia are getting well-engaged in their classroom activities by using Tiblo. Most children with dyslexia preferred coloured blocks compared with neutral ones.

Nevertheless, two participants wanted to paint the neutral blocks because they figured they should colour by themselves. However, Tiblo gave limited assistance in dealing with reading problems in letter-sound correspondences. Letter-sound correspondence or phoneme-grapheme correspondence is an essential component in teaching children with dyslexia to read (Phillips & Kelly, 2022) as it is too being a significant component in reading screening or assessment such as in Woodcock-Johson Tests of Cognitive Ability and Achievement (Schrank & Wending, 2018) and Dynamic Indicators of Basic Early Literacy Skills (DIBELS) (Good, Gruba & Kaminski, 2002).

Another study by Antle et al. (2015) explored a tangible reading system using 3D tangible letters with dynamic colour cues, generating additional knowledge of decoding with a series of word-making activities for children with dyslexia aged 5 to 8 years old. In order to promote the learning of alphabetic principles in English, PhonoBlocks uses 3D tangible letters. The system shifts the colour of 3D tangible letters depending on the sound they produce in a word, which enables the children to use letter shape cues using traceable 3D letters as feedback, and physical restrictions on the 3D letters' platform to help proper orientation of the letters such as p vs. q, b vs. d. However, since this study is still a work in progress at the point of reporting, it is yet to conclude the mappings of colours to the sounds as specific cues. Nevertheless, PhonoBlocks is later extended to augmented reality (Fan et al., 2018). Besides, the participants involved were only teachers specialising in teaching children with dyslexia.

Another study by Cramer et al. (2016) examined how a scheme of dynamic colour coding in a tangible system works for learning to spell. The dynamic colour-coding scheme is designed colour cues to accentuate spelling patterns like semantic and phonological radicals. The dynamic colour coding scheme is applied in developing the dynamic colour codes to elicit the children's attention with a variety of contextual spelling. The study recommended using dynamic colour in TUIs in the study of contextual spelling rules for English.

This study found that three principles can be used in designing dynamic colour codes with a variety of rules for contextual spelling. For the development of colour codes, three design principles are proposed:

a) For example, a rule identified by teachers whose students are struggling to spell consonant-le words should adjust colour codes to spelling rules. Consonant words end in a stable consonant syllable with letters le such as stable and topple.

b) colours should distinguish only facts connected to that rule which only uses colours to highlight the letters concerned.

c) Colours are designed to determine how characteristics change in relation to the context. That means that a system may change the colour of the letter (e.g., u) by a child spelling another part of the word to refocus its attention on the letter which has changed and enhance its appreciation of the relationship between the new sound and its spelling decision.

The integration of dynamic colour has been said to assist children with dyslexia in learning contextual spelling rules, although the effectiveness of colours can also be influenced by individual factors (Fan et al., 2016b). The study identified various factors specific to children that impact the utilisation of colours, emphasizing the need for designers to address these factors to enhance effectiveness. In the context of other systems, adopting dynamic colour coding standards while considering individual factors can enhance the usefulness and impact of colour coding. This finding is supported by Antle et al. (2015), Fan et al. (2016b) and Fan et al. (2017) where the use of dynamic colour cues enables seeking more attention to letter-sound correspondences can improve learning outcomes for children with dyslexia.

One primary limitation of the study conducted by Cramer et al. (2016) is the small sample size, consisting of only nine children with dyslexia. This small sample size posed difficulties in accurately assessing the effectiveness of their color-coding scheme. However, despite this challenge, the study successfully identified three design principles that can be used to create colour coding schemes for different contextual spelling rules. However, only a few principles were applied to derive one coding scheme for one spelling rule. As such, other schemes for other rules need to be derived and evaluated before making any assertions on their design principles. Based on the above studies, the results add to the literature on the design features for designing TUIs prototypes specifically for children with dyslexia.

Consequently, the inclusion of dynamic colour cues within 3D tangible letters served as a design feature in a tangible system that enhanced the learning process and fostered positive learning outcomes. This approach aided children in emphasizing the relationship between changes in letter position, letter sounds, and the physical form of

3D tangible letters. This leads to proper placement of letter and epistemic letter organising techniques to perform spelling tasks easily (Fan et al., 2017). Cramer et al. (2016) found that children can use dynamic colours to diagnose false ones and to find strategies to correct spelling. For some children, combining colours for sound and spelling may be a starting step to directly associate spelling and sound, and then learn the rules (Antle et al., 2015). Aziz et al. (2013) mentioned avoiding using green and red because it may lead to distraction, especially for those children who are colour-blind.

2.6.3 Other Design Features of TUIs

Fan and Antle (2015) developed a tangible tabletop, Tactile Letters, which embraces texture cues for children with dyslexia aged between 5 and 6 years that help to learn letter-sound correspondence in English. The texture cues are designed using a metaphoric approach in the education domain to provide greater contextual information. For instance, a word or a picture is associated with a letter to improve reading for the targeted children. A dual set of tangible letters was designed with or without texture cues whereby each set comprises 24 pieces of letter cards. When placing either 3D tangible letters or letter cards on the interactive tabletop, the children can select an appropriate level to learn the letter sounds. Respectively, each tangible letter (sound) comes together with three letter cards and a pseudo-word. Visual audio feedback is triggered when children make correct or incorrect associations between the 3D tangible letters and letter cards. The study suggested three design objectives based on the outcomes which are: 1) systematic learning approach, starting from fundamental concepts and progressing to more complex ones; 2) incorporating texture cues to identify letters with or without texture; and 3) the design should assist children with dyslexia in distinguishing flipped letters.

On the other hand, Teh et al. (2015) found that an interactive learning tool, TraceIt promotes the learning of children with dyslexia. TraceIt was designed for beginner readers, using multisensory methods that comprise visual, auditory, and kinesthetic. This study employed a technique of interaction in which children with dyslexia using TraceIt could air trace alphabets by engaging with the phonics-based reading system by graspable physical objects of a particular colour. To enable children to visualize and trace alphabets on the screen while hearing corresponding sounds, a colour-based recognition system is implemented to detect hand motion through a tracked coloured object. Upon completing the test, the findings indicated that a majority of the participants expressed interest in participating in the program, as they were able to learn words through the phonics-based reading program.

In a similar vein, Jamali et al. (2019) conducted a study to identify interesting patterns and emerging issues for evaluating study material and types of learning activities being performed in the dyslexia domain. The study recommended TI's guidelines to improve the learning experiences of children with dyslexia. These guidelines encompassed various aspects, including different types of learning, presentation styles, TI system requirements, and learning conditions. Specifically, in terms of presentation style, the study suggested the use of 'Century Gothic' and 'Comic Sans MS' font types for children with dyslexia who were introduced to a primary school in Malaysia (Hamid et al., 2017). Regarding the TI system requirement, essential components for TUIs include audio feedback and physical representations, such as 3D tangible letters, that incorporate textures to enhance the learning experience of children with dyslexia. The study emphasizes the provision of clear and straightforward instructions throughout the learning process to motivate children with dyslexia in task performance, with step-by-step practice activities like letter arrangement and word construction. Finally, three kinds of learning, namely explorative, interactive, and discoverable, can allow children with dyslexia to analyse and explore their learning information and knowledge, as well as collaborate as a group for problem-solving. An initial TI prototype has been developed based on the design guidelines specifically for children with dyslexia. The prototype will serve as an interactive and supportive tool for children with dyslexia to learn Malay language.

In a study conducted by Fan and Antle (2015), the significance of texture cues as design features in learning to read was found to be unclear. This research gap underscored the potential for exploring the design possibilities within the tactile modality, specifically focusing on texture cues, to facilitate the acquisition of literacy skills for children with dyslexia. This is interesting as texture could invoke touch sensory of the children and thus allow them to better retain in memory the letters and the phonological representations of the letters. Therefore, a study on TUIs seizes a window of opportunity to manifest the use of various textures by constantly linking it with two or more different modalities such as associating textures with letter sounds (O'Malley & Fraser, 2004). There is clearly an increasing need to explore the design space of texture cues in TUIs in learning alphabets because the combination of textures embedded in letter shapes and letter sounds can facilitate children with dyslexia to learn better the letter-sound representations. In general, addressing this knowledge gap warrant ongoing research effort to gain an understanding of how to design TUIs learning materials and combine texture cues for enhancing visual or auditory representation modalities of information. Table 2.7 summarises the relevant information extracted from the studies reviewed.

Table 2.7
Comparison of existing related research of TUIs and TI

No	Author	Objectives	Multi-sensory Method	Design Features	Evaluation	Language	Target User
1.	Pandey & Srivastava (2011a)	To support constructing English alphabets, spellings and word meanings	Tactile, Visual	2D tangible letter	User acceptance testing	English	Dyslexic children
2.	Pandey & Srivastava (2011b)	To facilitate learning for English decoding letter-sound pairs	Tactile, Visual, Audio, Kinesthetic	Tangible blocks Colour cues	User acceptance testing	English	Dyslexic children
3.	Antle et al. (2015)	To facilitate decoding problem letter-sound pairs	Tactile, Visual, Audio	Colour cues Tactile cues 3D tangible letter	Experiment	English	Dyslexic children
4.	Fan & Antle (2015)	To support reading in English letter-sound correspondence	Tactile, Visual, Audio	Texture cues and non-texture cues 3D tangible letter	Experiment	English	Dyslexic children
5.	Teh et al. (2015)	To support in reading through multi-sensory.	Visual, Audio, Kinesthetic	Air trace alphabets using toy blocks and balls (physical objects) Colour-based recognition to detect the hand motion	Experiment	English	Dyslexic children

6.	Cramer et al. (2016)	To support learning in English contextual spelling rules.	Visual, Audio, Kinesthetic	Dynamic colour cues, 3D tangible letter	Observation, Experiment	English	Dyslexic children
7.	Jamali et al. (2018)	To support in reading, spelling, and phonology skills.	Visual, Audio, Kinesthetic	3D tangible letter	Observation	Malay	Dyslexic children
8.	Jamali et al. (2019)	To support in reading, spelling, and phonology skills.	Tactile, Visual, Audio, Kinesthetic	3D tangible letter, Font type, Colour cues	Observation	Malay	Dyslexic children

Besides that, Aziz et al. (2013) recommended the use of plain sans serif fonts, specifically recommending Comic Sans MS, for font types. The suggested font size should fall within the range of 12-14 points. It is worth noting that while the recommended font size may be slightly smaller for children, which could potentially impact their reading performance (Wilkins, Cleave, Grayson, & Wilson, 2009) and memory (Halamish, Nachman, & Katzir, 2018), the suggestion is still acknowledged and taken into consideration. However, it is important to mention that some children with dyslexia readers require larger font sizes. It is advisable to avoid using animated text to maintain their focus and make reading more manageable for them. Furthermore, children with dyslexia are generally more familiar with lowercase letters (Jamali et al., 2018a). Husni and Jamaludin (2013) recommended to utilise eight specific background colours, based on Irlen (2005), in reading applications or tools for children with dyslexia. These colours, along with their corresponding RGB codes, are depicted in Figure 2.6.

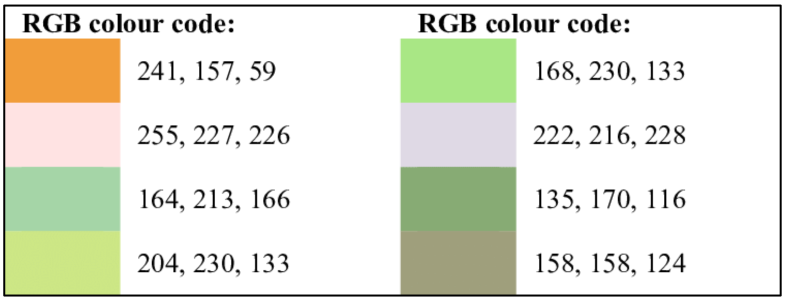

Figure 2.6. The eight colours and the RGB
(Adapted from Husni and Jamaludin, 2013)

In conclusion, the majority of the studies focused on design features such as 2D tangible letters (Pandey & Srivastava, 2011a), 3D tangible letters (Jamali et al., 2018b), dynamic colour cues (Cramer et al., 2016) and texture cues (Fan & Antle, 2015) to support reading comprehension for children with dyslexia. Prior studies used tactile, visual, audio and kinaesthetic approaches either separately or in combinations (Antle et al., 2015; Cramer et al., 2016; Fan & Antle, 2015; Jamali et al., 2019; Jamali, et al., 2018b; Pandey & Srivastava, 2011b, 2011a; Teh et al., 2015). In evaluation, common approaches used in past studies are experimentation (Antle et al., 2015) and user acceptance testing (Pandey & Srivastava, 2011b). In general, five papers presented their prototypes but only two (Pandey & Srivastava, 2011a; Pandey & Srivastava, 2011b) involved users in their evaluations. Nonetheless, SpellBound by Pandey and Srivastava (2011a) was at a preliminary stage and not fully developed at the time of reporting. Meanwhile, Teh et al. (2015) identified various limitations during the experimental sessions including environmental factors, distance factors, fine motor skills, object detection, and tangible object issues. With regards to the studies reviewed, eight design features, found in the current TUIs implemented in the tangible system are presented in Table 2.8. The eight design features are viewed to be fundamental and useful for groundwork towards designing and developing a comprehensive TUIs design specifically and exclusively meant for children with dyslexia learning to read.

Table 2.8

TUIs design features and descriptions

No.	Design Features	Description
1.	2D tangible letter (Pandey & Srivastava, 2011a)	Flat tangible letter that has two dimensions (2D) shape
2.	3D tangible letter (Jamali et al., 2018)	Solid tangible letter that has three dimensions (3D) shape
3.	Tangible blocks (Pandey & Srivastava, 2011b)	Interactive electronic block that can record and play back up to ten seconds of pre-recorded sound
4.	Texture cues and non-texture cues (Fan & Antle, 2015)	Texture cues embedded in the letters to avoid mirrored or flipped letters.
5.	Air trace alphabets using toy blocks and balls (physical objects) (Teh et al., 2015)	Graspable physical objects of a specific colour to interact with the phonics-based reading program.
6.	Colour-based recognition to detect the hand motion (Teh et al., 2015)	To detect the hand motion through the tracked coloured object
7.	Dynamic colour cues (Fan et al., 2016)	Dynamic colour cues that embedded in tangible letter
8.	Font type (Jamali et al., 2019)	Sans serif font type for dyslexic children as the fonts are clear

There are two studies that use built-in dynamic colour cues with flash to seek attention of children with dyslexia (Antle et al., 2015; Cramer et al., 2016). On the other hand, five papers employed 3D tangible letters that support children with dyslexia in reading activities and interaction in their space environment (Antle et al., 2015; Fan & Antle, 2015; Cramer et al., 2016; Fan et al., 2017; Jamali et al., 2019; Jamali et al., 2018b). Furthermore, Teh et al. (2015) explored the use of air trace alphabets with the physical objects of a specific colour for children with dyslexia to interact with the reading programme and colour-based recognition in sensing their hand motion. Another study conducted by Pandey and Srivastava (2011a) used 2D tangible letters in their Spellbound prototype. Similarly, Pandey and Srivastava (2011b) used tangible interactive blocks in their prototype called Tiblo. Texture cues and non-texture cues are also used to promote learning among children with dyslexia (Fan and Antle, 2015). As for font types, sans serif fonts are recommended (Jamali et al., 2019) as the fonts are clearer and do not have decorative strokes which may cause confusion for children with dyslexia. The next section discusses the previous research on design guidelines of TUIs in the dyslexia domain.

2.7 Design Guideline

Design guidelines are a collection of recommendations to provide a positive user experience (Interaction Design, 2002; Leavitt & Shneiderman, 2006; Chilufya, 2014). Designers use guidelines to decide the way principles such as intuitiveness, learnability, efficiency, and consistency can be applied to design persuasive designs and to fulfil and overcome users' needs. Design guidelines are a helpful way to implement design requirements derived from other designers' experiences (Leavitt & Shneiderman, 2006).

2.7.1 Design Guideline in Human Computer Interaction

Human-Computer Interaction (HCI) is a discipline that has investigated the design and evaluation of user interfaces (Delavari, Abdullah, Ibrahim, & Said, 2013). It can be defined as the scientific study of the design and development of interactive systems with a primary focus on how people interact with systems (Guerrero-Garcia et al., 2017). Identification of user characteristics, such as behaviours, interests, abilities, genre, and age are crucial when developing products aimed at specific users since these characteristics may be used to support the design of user interfaces that are focused on the end user (Wong, 2016; Shneiderman, Plaisant, Cohen & Jacobs, 2015). In other words, HCI enables the development of computerised systems that can assist users in carrying out their tasks safely and effectively (Nyabuga & Nyasani, 2018).

Regarding design guidelines in HCI, Abascal and Nicolle (2005) stated that it is a useful method to incorporate design requirements deriving from the successes of other designers and researchers. Although guidelines can have issues such as incoherence and unreliability and can be challenging to manage when they are too numerous, they are a great approach to sharing positive design experiences across large design groups. As a result, it is assumed that the provided design guidelines will serve as an outline for developing the prototype of TUIs. However, for guidelines to be reliable and trustworthy, they must have gone through experimental processes and been validated on targeted users. Methods and tools are also necessary to assist designers in implementing them.

In designing and developing design guidelines, the verification and validation process was carried out based on these recommendations. The design guideline was validated to make sure they could be used by the intended users, which are the designer or researcher. In addition, the verification process was employed to make sure the components suggested in the design guideline are appropriate. Experts in the fields of HCI and product design examined and verified each component in the design guidelines as part of the verification process. The prototype was created after the design guideline was verified. It was then validated by the intended users who tested out the TUIs prototype. The prototype acts as a proof of concept to validate the TUIs design guidelines. The next subsection discussed the design guideline of TI and TUIs.
The next subsection discussed the design guideline of TI and TUIs.

2.7.2 Design Guidelines of Tangible Interaction and Tangible User Interfaces

According to Mazumder and Das (2014), there are many principles and guidelines available for developing user interfaces, but all these rules need to be simpler and followed up on a certain point. Design guidelines fall into different groups, as defined in Interaction Design (2002). These include: (1) style – e.g., brand logos, colours; (2) layout - e.g., list structure; (3) features of the user interface – e.g., menus, buttons; (4) text – e.g., font, sound, labels; (5) accessibility – e.g., Aria marking for handicapped users; and (6) design patterns – e.g., forms.

In the meantime, only a few design guidelines for children, and fewer for children with dyslexia despite the increasing number of TUI reading systems (Fan et al., 2016a). There are several design guidelines on the implementation of learning by MOE (Ministry of Education), however, there are limited guidelines or standard requirements in facilitating learning to read for children with dyslexia, especially in the design of TUIs. Several related works explored TUIs for children with dyslexia focusing on the difficulties of language processing, like reading, phonology, writing or orthography, intended to help particular languages including English (Antle & Wise, 2013; Falcão & Price 2010) and Malay (Jamali et al., 2018b; Jamali et al., 2019). Accordingly, Jamali et al. (2018a) identified the design guidelines of TI in supporting children with dyslexia that are categorised into four themes which are types of learning, presentation styles, TI system requirements, and learning conditions that had the potential to enhance their way of the learning process. Figure 2.7 depicted the design guidelines of TI. In the study, three experts were interviewed. Themes or patterns contained in qualitative data were defined by using the process of thematic analytics.

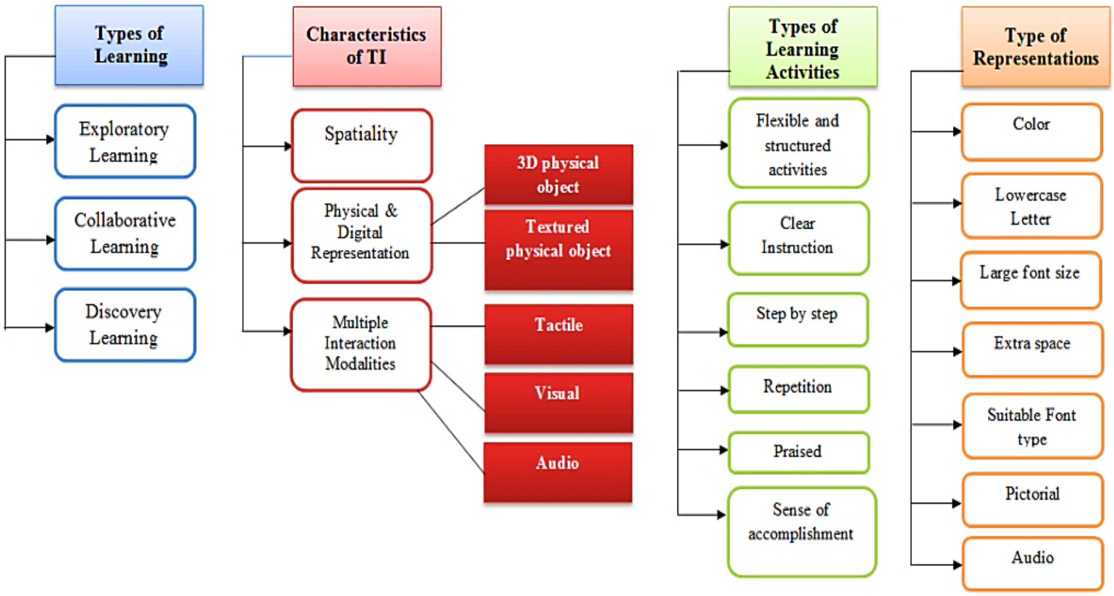

Figure 2.7. Design Guideline of TI adopted by Jamali et al. (2018)

The first guideline is the types of learning that focus on exploratory, collaborative and discovery. Exploratory learning allows children to evaluate and explore their information and knowledge (Yusoh, Devaraju, Zakaria et al., 2008). Collaborative learning encourages children to collaborate as a group to solve their problems and carry out certain tasks (Dillenbourg, 1999b). Discovery learning focuses on the ability of children to take part in problem solving activities by finding solutions based on past experiences (Abdullah, Hisham & Parumo, 2009). The second guideline for design involves TI characteristics, such as spatial, physical, and virtual representations and various modes of interaction.

The third guideline defines the type of learning activities to be incorporated with the TI system. Flexible and structured programs allow children with dyslexia to integrate what they want to learn according to their needs. Next is a clear instruction to allow children with dyslexia (who might be struggling with reading because they have difficulty with memorising) to have clear and easy instructions to follow activities such as letter recognition and listen to the letter sound that match those words with flashcards. In addition, step-by-step action will also help them accomplish such tasks, such as organising letters to construct words. Following that, the repeating activity involves more time and repetitions for children with dyslexia since their time of concentration is reduced. The praise method would increase the motivation forn children with dyslexia to achieve and boost their satisfaction with their accomplishments. The last design is the sense of accomplishment that is what they are proud of.

The fourth guideline is the forms of colour representations. In the learning of children with dyslexia, colours play a significant role. Words must also be displayed in large font size and lowercase letters so that they can easily read the word. Additional spaces between the different font types must also be provided in the words. As for the pictorial, children with dyslexia prefer clear and colourful pictures. Based on these design guidelines, an initial TI prototype is developed to serve as an interactive and supportive platform for children with dyslexia to learn Malay language.

In a similar vein, Jamali et al. (2019) extended their study in the dyslexia domain. This study suggested TI's design guidelines to help children with dyslexia to enhance their learning processes such as types of learning, presentation styles, TI system requirements, and learning conditions as depicted in Figure 2.8. As for the presentation style, they suggested the font type 'Century Gothic' and 'Comic Sans MS' for children with dyslexia that were introduced for a primary school in Malaysia (Hamid et al., 2017). Besides that, ten various types of Irlen colours were recommended for dyslexia as suggested by Rello and Bigham (2017). This is because the use of warm background colours such as peach, orange, and cream has been used to stimulate the brain to read (Irlen, 2005). For the requirement of the TI system, components that are required in a

TUI are audio feedback, and physical representation such as a 3D tangible letter that integrates the use of textures to improve the learning of children with dyslexia.

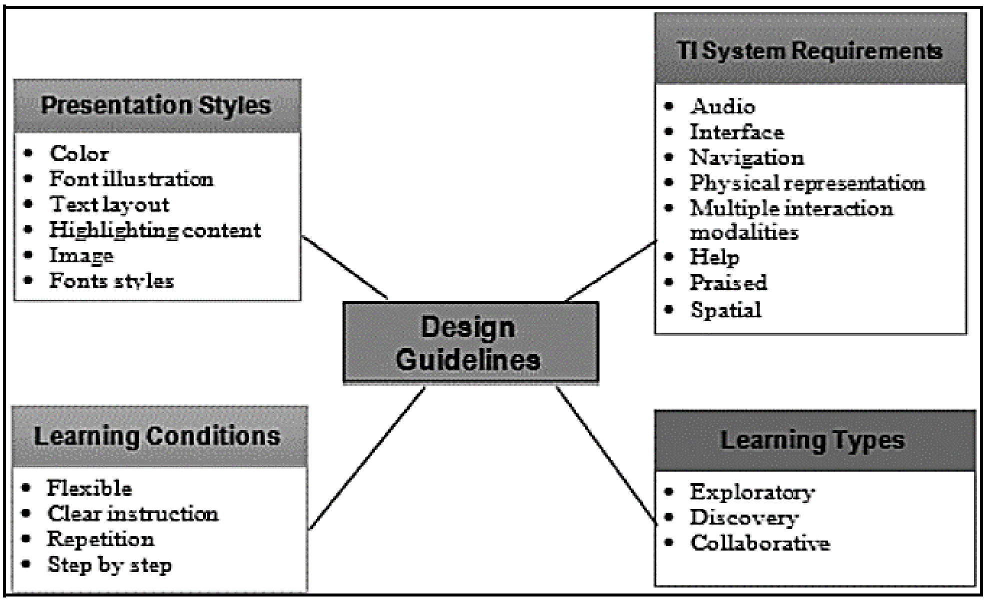

Figure 2.8 Design Guidelines of TI Model for Children with dyslexia adopted by Jamali et al. (2019)

In terms of learning conditions, clear and simple instructions are implemented to inspire children with dyslexia to do a task and a step-by-step practise would encourage children with dyslexia to perform the activity, including constructing words. Finally, three different types of learning, i.e., exploratory, interactive, and discovery, should enable children with dyslexia to examine and explore the knowledge and information obtained through their learning. An initial TI prototype called DisleksiaBelajar 3dT has been developed in compliance with the design guidelines for children with dyslexia. The prototype will serve as an interactive and supportive tool for children with dyslexia to learn Malay.

Meanwhile, Falcão and Price (2010) have discussed how tangible methods and guidelines for special educational needs (SEN) teaching can be implemented. This study focused on implementation guidelines for tangible technology for children with LD. Semi-structured interviews with teachers of SEN are the approaches used in this research. In the classroom, seven hours of unstructured with direct observations were taken. The interviews were conducted through class observations by providing further knowledge and insights from the direct interaction between the interviewer and the children. Qualitative analysis of the interviews and the observations concluded the following: children's needs and concerns, child's positive traits, strategies for addressing of the children’s difficulties, teacher problems and educational tools. The design guidelines developed for the implementation of educational resources and learning activities for LD children have been presented in Table 2.9.

Table 2.9
Design Guidelines of TI adapted by Falcão and Price (2010)

Design Guideline	
Design of Educational Resources	Modes of representation: preferably based on oral interaction, dynamic visualization, and minimal amount of text
	Collaboration: encourage group work
	Kinesthetic approach: offer physical engagement opportunities such as doing, touching, manipulating, and moving.
	Scaffolding: Ensure everyone has a chance to participate
Design of Learning Activities	Clear and shared objectives: should be involved in decisions and be given roles and responsibilities.
	Self-esteem and confidence: children should be encouraged to do things themselves.
	Sense of achievement: challenges should be achieved to allow short - term success and progress
	Structured activities: children need clear and structured activities to avoid distraction and aid concentrating and progressing.

Results from qualitative data show the ability of tangible technology to improve the experiences of these children through different forms of representation, collaboration opportunities, kinesthetic approaches, and scaffolding. As for the design of learning activity guideline, include clear and shared objectives, self-esteem and confidence, a sense of achievement and structured activities. The results show that children with learning problems require more educational tools, including different types of representation and opportunities for physical interaction and collaboration.

The guidelines for the design of 5 interconnected elements of the TUI learning environment have been outlined by Antle and Wise (2013). Figure 2.9 displays the twelve guidelines based on the theoretical and TUI elements. Five interrelated elements of this study-taxonomy include physical objects, digital objects, actions, informational relations and learning activities. Cognition and learning theories have been used to establish guidelines that can help design decisions and work in the TUI learning designs on these elements. Materials like visual attributes (for example, colour), tactile attributes (for example, texture) and auditory attributes (for example, tone) are the physical objects. Digital objects are machine virtual entities with unique features (for example, colour, location and tone). Object actions are a series of input manipulations that learners may take on the physical (and in certain digital situations) objects that the system is sensing. The learning activities are the background, instructions and directions for learners to arrange their interaction with TUI. Figure 2.9 demonstrates the five elements. The guidelines are all focused on cognition and learning theories.

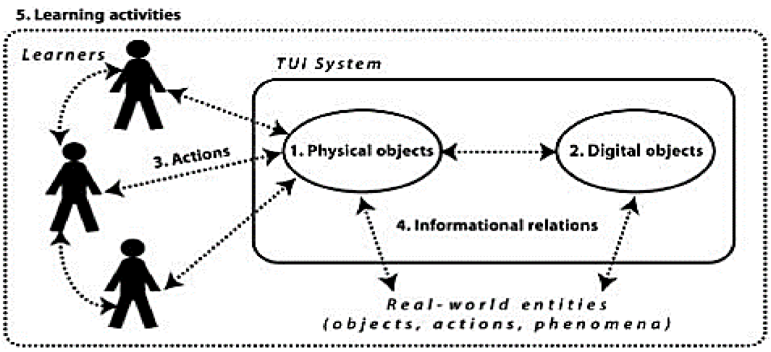

Figure 2.9. Elements of Tangible Learning Design adapted from Antle and Wise (2013)

The first and second guidelines are from information processing perspectives based on theory of cognitive load. Cognitive load theory (Kirschner, 2002; Sweller, 1988; Sweller & Chandler, 1991) is an established theory grounded in the Atkinson and

Shiffrin model of human cognitive architecture (Atkinson & Shiffrin, 1968). In support of the logic of cognitive load theory, TUI designers can use a visual and auditory representational form for distribution of the information processing across the two perception channels to accelerate effective working memory capacity (Pavio, 1991). In particular, the submission of words should be in an audible way for distributing the cognitive load executed by TUI surroundings over the visual-spatial sketch and the articulatory loop (Mayer, 2009). Table 2.10 illustrates the twelve guidelines according to the theoretical perspectives and the TUI elements which are related.

Table 2.10.
TUI Learning Design Guidelines adapted from Antle and Wise (2013)

Perspective	Guidelines	Physical objects	Digital objects	Actions on objects	Informational relations	Learning activities
Info processing	1. Distributing information across modalities can increase effective working memory capacity	X	X			
	2. Making mappings between the form and behaviour of physical and/or digital objects and real-world entities coherent can reduce extraneous cognitive load				X	
Constructivist	3. Creating authentic tasks and using personal objects can support learners in forming individually meaningful goals for interacting with the TUI	X				X
	4. Using spatial, physical, temporal or relational properties can slow down interaction and trigger reflection	X	X	X	X	X

Embodied	5. Distributing parts of mental operations to actions on physical and/or digital objects can simplify and support mental skills			X	X	
	6. Leveraging image schemas in input actions can improve usability and system learnability			X	X	
	7. Using conceptual metaphor(s) based on image schemas to structure interaction mappings may bootstrap learning of abstract concepts					
Distributed	8. Designing objects that allow spatial reconfiguration can enable mutual adaptation of ideas	X	X			
	9. Using concrete representations can support interpretation of symbolic representations of abstract concepts	X	X		X	
Collaborative	10. Creating configurations in which participants can monitor each other's activity and gaze can support the development of shared understandings	X	X			
	11. Distributing roles, information and controls across the TUI learning environment can promote negotiation and collaboration	X				X
	12. Creating constrained or co-dependent access points schemes can			X		

	compel learners to negotiate with each other	

As for Guideline 2, user interfaces also do not contribute to learning of the learner's cognitive needs. The continuous design of TUIs is one way to reduce the excessive load (i.e., the digital system's knowledge connections reflect those in the real world). This mapping allows for a low volume process of cognitive resources in order to free up more cognitive resources for learning. In the literature on ergonomics, consistent mapping between input behaviour and system reactions are called compatibility of stimulus - response (Wickens & Hollands, 2000).

As for guideline 3, if learners' objectives are described as 'finishing a task' or 'victorious a game' or simply 'react with the TUI,' then they will learn different things than if they are guided by the motivated to understand or use the material. The aim is to help learners create expressive content-related objectives to interact with the TUI, the tool should be used in an authentic world-based learning activity in which learners believe their participation is essential. A constructivist view of cognition and learning concepts knowledge derived from experiences actively produced and reproduced by interactions and the environment in this guideline. With regard to guideline 4, TUIs are able to endorse a broad variety of human activities, a constructivist view of learning indicates the need to engage with the environment and focus on facilitating learning. A variety of strategies can use spatial, physical, temporal and TUIs relational characteristics to trigger 'stop out' for reflection. For example, an individual will stop moving to another place to finish activity with the spatial design provided by the TUIs.

In guideline 5, embodiment theories were used to define the role of behavioural activity in the construction of understanding at a detailed level that links behavioural action with cognitive and interaction processes as well. Distributing elements of mental activity to complementary tasks will motivate learners' cognitive performance. This has consequences for the design of information-mapping relations between actions, object and digital representation. For example, mental visualisation (e.g., change of view, zoom, pan, scale, and rotation) tasks can be streamlined by design in order to make the task for learners simpler for physical actions that manipulate digital representation.

Image schemes are mental constructs based on repeated experiential patterns (Johnson 1987), which are applied in guideline 6. Early in life, primary images are evolved and adapted to new situations. Antle, Droumeva, & Corness (2008) indicate that detecting the schematic behaviour of the primary image as controls for an entire body-wide interaction environment has advantages, allowing both children and adults to focus rather than learn how to use the system. With respect to Guideline 7, the metaphorical relationships between the image scheme and the abstract concept can be employed to map the characteristics of physical objects and the significations of digital representations. The physical size of TUI objects, for example, can be associated with the significance of the digital representations.

As for guideline 8, a system that requires students to be able to use objects in order to explore and experiment around the world, with various configurations. As for guideline 9, many representations may be intended to facilitate learning by using one representation to encourage another's interpretation (Ainsworth, 2006). TUIs can do this by presenting a concrete illustration of an abstract concept utilising physical objects, and by means of digital representation one or more symbolic representations of the abstract concept. Both Guidelines 8 and 9 are applicable to distributed cognitive theory, indicating that cognition is interpreted as a process distributed between people and their environments.

The spatial characteristics of tangibles can be used by setting up centralised configurable places to use objects in 3D space to support shared attention as defined in guideline 10. It helps individuals to walk through a TUI in ways which provide visual access to each other and digital objects that allow them to become more aware of what others do, than if they were on a table or a 2D display on the same side.

In guideline 11, theories of computer-supported collaborative learning (CSCL) are open to TUI designers to see how to build for multiple users in the educational context (Dillenbourg, 1999a; Koschmann, 1996; Lipponen 2002; O'Malley, 1995; Stahl, Koschmann & Suthers, 2006). A powerful way of creating a positive interdependency in collaborative learning is to share knowledge, skills, roles or resources amongst learners to work together effectively (Järvelä et al., 2004). With regard to guidance 12, one way to achieve positive interdependence between learners using the TUI system is the possibility of restricted or co-dependent access points. The TUI system has access points enabling users to communicate, take part and participate in group activities (Hornecker, Marshall, & Rogers, 2007). According to the set of guidelines explained, not every aspect of TUI design is covered. This is mainly because to provide a foundation to guide principled design and research of TUIs for learning whilst encouraging other researchers to test and probe these guidelines empirically and bringing other theories to refine and expand the set. Table 2.11 summarises the relevant information extracted from the studies reviewed of TI and TUIs design guidelines.

Table 2.11
Summary of existing related research of TUIs and TI design guidelines

Author	TUI Elements in the Design Guideline	Theory	Evaluation	Target User
Antle & Wise (2013)	1. Physical representation 2. Digital objects 3. Actions on objects 4. Informational relations 5. Learning Activities	• Theory of cognitive load • Theory of complementary actions • Theory of embodiment • Theory of distributed cognition • Theory of computer-supported collaborative learning (CSCL)	Not found any testing or evaluation of the proposed tangible learning design guideline	Children
Falcão & Price (2010)	1. Design of educational resources 2. Design of Learning Activities	No theory was found in this study	Not found any testing or evaluation of the proposed TI design guideline	Children with learning difficulties (LD)
Jamali et al., (2018)	1. Types of learning 2. Characteristics of TI 3. Types of learning activities 4. Type of representations	• Theory of Orton-Gillingham • Theory of Dual-coding • Theory of Kinesthetic	Not found any testing or evaluation of the proposed TI design guideline	Children with dyslexia
Jamali et al., (2019)	1. Types of learning 2. Presentation styles 3. TI system requirements 4. Learning conditions	• Theory of Orton-Gillingham • Theory of Dual-coding • Theory of Kinesthetic	Not found any testing or evaluation of the proposed TI design guideline because the prototype was still at an initial stage.	Children with dyslexia

In conclusion, majority of the studies generate design guidelines for TI (Falcão & Price, 2010; Jamali et al., 2019; Jamali et al., 2018a) while Antle and Wise (2013) focus on TUIs in learning. Two studies (Falco & Price, 2010; Jamali et al., 2018a) employed interview methods to develop their guidelines, whilst Antle and Wise (2013) used the dialectic processes by analysing different theories of cognition and learning to produced guidelines. Whilst, a study was done by Jamali et al. (2018a) analyse the findings using thematic analysis based on Braun and Clarke (2006) which involved six phases including (1) Be familiar with the data; (2) Generate initial code; (3) Search for themes; (4) Review themes; (5) Define themes; (6) Writing up. Meanwhile, Antle and Wise (2013) have elaborated twelve guidelines on the design of five interrelated components of the TUI-Learning Environment.

To date, existing design guidelines of TI and TUI are inadequate particularly on the appropriate design features of TUIs, multisensory approaches, appropriate theories, and learning contents to support learning for children with dyslexia in learning to read in Malay (Jamali et al., 2019). For instance, a study by Antle and Wise (2013) only applies two or three types of modalities (e.g., audio, visual, and tactile) in developing design guidelines for children with dyslexia. In this regard, TUIs are suggested to incorporate multiple modalities including visual, auditory, tactile, and kinesthetic for promoting the use of multiple senses in reading acquisition.

Meanwhile, the design features of TUIs (physical representations) are referred as a set of materials which learners interact with the TUI system (digital representations). Both are material objects that exist concretely with physical properties to be designed, including visual attributes (e.g., colour), tactile attributes (e.g., texture), and sometimes auditory attributes (e.g., tone). A further investigation to understand important features of the physical-digital object mappings led to enhanced performance of learning as mentioned by Antle and Wise (2013).

In certain cases, the concepts and processes have been tested empirically for TUIs or in similar circumstances. All guidelines are supported with the theories of cognition and learning. However, the list of guidelines only includes certain features of TUIs design which provide a foundation to guide principled design and research of TUIs for learning. It is argued that the guidelines need to cover all aspects of the TUI for dyslexia. Following the previous studies, the design guidelines for learning need to incorporate analysed TUIs design features (Fan et al., 2016a), supporting theories (Jamali et al., 2018a), and principles such as universal design and interaction design.

Based on research findings from past studies, the design guidelines designed for children with dyslexia are recommended but require further improvement to facilitate the reading and spelling according to Antle and Wise (2013). In addition, there is no evaluation of the proposed TUI and TI design guidelines were identified in their research. However, Jamali et al. (2018a) develop TI design guidelines for children with dyslexia, but in this study, the design guidelines are within TUIs design concept. Currently, there is no TUIs design guideline specifically for children with dyslexia in learning to read means that the users will have interaction with the computer through the physical environment (tangible letters). In other words, when we have tangible objects for any interaction, but at the same time connected to computers or digital representations, then TUIs come into the picture. TUI design guidelines are developed for this study based on an upgraded version of Ullmer and Ishii's TUI framework. As a result, TUI design guidelines are discussed in Section 3.2 of Chapter 3. Details on the formulation of design guidelines, as well as verification through expert review are covered in Chapter 3.

2.8 Evaluation Methods of Tangible User Interfaces

In terms of evaluation, common methods used were experimentation, user acceptance testing, questionnaire, and observation techniques. In this section, several methods used to evaluate the TUIs prototype were reviewed based on previous studies.

Pandey and Srivastava (2011) developed Tiblo, tangible learning aid for the enhancement of fine motor skills through connecting and fitting the blocks physically for children with dyslexia at the age between 8 to 12 years old. The purpose of this study was to test the usability and effectiveness of Tiblo for children with dyslexia. An evaluation was conducted using the user testing method. The children were given the blocks without guidance on how they should be used based on the user testing process outlined by Pandey and Srivastava (2011). They wanted to test whether sounds and visuals needed to be linked to a block test series. They also decided to see whether teachers would include Tiblo without any guidance from their side as part of the classroom.

The evaluations result concluded that Tiblo blocks worked well as a children's teaching aid, however, are more effective if the blocks were given to the child to keep it at home. Following the completion of the test, the results showed that the children are getting well-engaged in their classroom activities by using Tiblo. In fact, the children have the opportunity to draw something based on their interest, pin it up on the block and finally record a sound in relation to the visual. In addition, Tiblo is more preferred to use as a prop for conducting various activities in class with a teacher's supervision such as explaining different concepts, difficult spellings and stories.

On the other hand, Fan et al. (2017) examined the design and evaluation of a tangible system for at-risk readers in mastering the phonological awareness and alphabetic principle by focusing on tangibility reading effects and spelling acquisition for children with dyslexia. Fan et al. (2017) adopted a mixed-methods approach to examine the effectiveness of PhonoBlocks and evaluate design features of TUIs that affected the learning process of children with dyslexia. The learning activities comprised six rule-based lessons which are consonant-vowel-consonant (CVC), consonant blends, consonant digraphs, magic-e rule, vowel teams, and r-controlled vowels lessons. In two x 20-minute sessions, children learned each of the six rules, for a total of 12 sessions. These rules are selected because they are suitable for children between the ages of 7 to 8 years old. Figure 2.10 depicted the learning activities for children with dyslexia.

Learning Activities: Six Spelling Rules	Examples
1. **Consonant Vowel Consonant (CVC)**: CVC patterns	bet pet jet
2. **Consonant Blends:** two consonants make a blended sound in which you can hear two parts to the sound	f → fl → flag
3. **Consonant Digraphs:** two consonants make one sound	t → th → thin
4. **Magic-e Rule**: vowel sound changes from short to long when an *e* is added at the end of word	gam → game
5. **Vowel Teams**: two vowels make one sound	e → ea → eat
6. **R-Controlled Vowels**: r-controlled vowel sounds in which different vowel-r combinations sound the same	er → stern ur → turn

Figure 2.10. Learning Activities of Six Spelling Rule adapted from Fan et al. (2017)

As for the experimental procedure, the participants were pre-tested for baseline assessment before using the PhonoBlocks. The participants were requested to read the list of 36 words on a computer screen and to spell twelve words on paper during the pre-test. After that, the raw accuracy scores for reading and spelling (e.g., 8/36, 3/12) were then recorded. Meanwhile, the participants were requested to read on a computer screen the same 36 (now trained) and 36 (new) untrained words and spell 12 trained and 12 untrained words on paper throughout the post and maintenance tests. The accuracy scores were then recorded. After all sessions were completed, the children and teachers were given instructions before answering questions. Each child was given a set of closed (Likert scale) and open questions on the system preferences. On the other hand, teachers were interviewed in identifying the challenges of every child's whether they found any progress during the one-month study. The follow-up test was conducted after one month.

The results indicated that the children showed significant signs of progress whereby they were able to read and spell on trained and untrained words in a month, far ahead after learning the system. The qualitative findings of the study suggested that the main design features of TUIs positively affected learning. However, as the sample size was small and only eight children were involved, the analysis of the data was limited. Therefore, the result failed to generalise the effectiveness of the system because of the small sample size. Even though the findings are considerable, the case study was without a control group. In the context of design, the analysis of video and observational findings revealed the main design features facilitated behaviours that the children recognise for them to apply in their learning.

Meanwhile, Teh et al. (2015) evaluated an interactive learning tool for the learning development of children with dyslexia through an experimental method. They developed TraceIt for a beginner-level reader to read using multisensory approaches which include visual, auditory and kinaesthetic. This study employed an interaction technique to examine whether the children with dyslexia using TraceIt would be able to air trace alphabets through graspable physical objects of a specific colour to interact with the phonics-based reading programme. The colour-based recognition system was adopted to sense hand motion through the tracked coloured object, to ensure the children perceive and trace alphabets on the screen and hear the sounds of the alphabet or word.

The evaluation was carried out at the Malaysia Dyslexia Association with nine children with dyslexia of beginner-level classes aged 6-9 years old. The evaluation sessions were held individually for each participant in a room. As for the procedure, students were tested on word family using flashcards. The students were not required to do that specific word class given that the student had prior knowledge of all the words in a word family. However, when the participants fail to know one out of the three words of a word family slightly, they need to practice that word family by using the air tracing reading tool. After that, the participants were verified to identify whether they had learned words from the word family and if they fail to identify the words, they need to repeat the same word family three times.

Following the completion of the test, the results revealed that most of the participants were interested in using the programme because they are able to acquire approximately some words from the phonics-based reading programme. Based on the observations and feedback from the experiments, several changes have been made for improving the effectiveness and usability of the system.

Although there are several evaluation methods for evaluating TUIs similar to those used for other user interfaces, so far limited evaluation methods specific to TUIs have been developed (Vissers & Geerts, 2014). In terms of evaluation, the majority of the studies evaluate their prototype using experimental methods (Fan et al., 2019; Fan & Antle, 2015). In this study, TUIs prototype was developed based on the TUIs design guideline that support the needs of children with dyslexia learning to read in Malay. This study adopts an experimental method to provide more accurate results (Garzotto & Gonella, 2011). The experimental method has a distinct advantage, in terms of accuracy of the results over the other techniques as mentioned in several studies (e.g., Fan et al. (2017) and Lehtonen et al. (2020).

Therefore, the evaluation in this study was conducted using an experimental method. TUIs prototype was tested on children with dyslexia between the ages of 7 to 12 years. Primarily, this study intended to evaluate the TUIs design guideline using the TUIs prototype during the learning activity with children with dyslexia. The processes that took place in the experiment are thoroughly explained. This provides information on the experimental tasks and procedures and the selection of participants discussed in Chapter 3.

2.9 Summary

This chapter provides a detailed analysis of literature covering both TUIs and dyslexia domains. TUIs are able to facilitate reading for children with dyslexia by having the multisensory experience to stimulate their senses. It is clear from the extensive evidence in the literature that appropriate TUIs design features will enhance the learning outcomes of children with dyslexia. A review of the literature on dyslexia outlines the background of this disorder and its effect on learning development among children with dyslexia. This chapter also relates dyslexia and reading to TUIs, whereby TUIs improve the way of learning sessions as it allows children with dyslexia to interact with 3D tangible letters and addresses the evaluation methods and design guidelines. In terms of evaluation, experimentation, user acceptance testing, observation techniques, and experimental studies are the typical methods used for evaluating the prototype. Thus, this chapter reviewed the related literature towards attaining the research objectives as presented in Chapter 1, Section 1.3. The following chapter discusses the research methodology with relevant methods selected in this study.

CHAPTER 3
RESEARCH METHODOLOGY

3.0 Introduction

The previous chapter explains the underlying theories and theoretical framework that directed this study. The research methods used to achieve the research objectives are discussed in this chapter. This chapter also discusses the research design adopted in this study. The four phases of the research framework were extensively outlined and discussed to achieve the research objectives of the study. At the end of this chapter, the summary is presented.

3.1 Research Design

Research design encompasses strategies that a researcher uses to guide the study in a logical and systematic way to address the research problems (Creswell & Clark, 2007). According to Creswell (2009), there are three different research designs that researchers can use when conducting their studies namely quantitative, qualitative, and mixed methods.

This study adopted a mixed-methods approach, which combines both qualitative and quantitative methods of data collection and analysis. Mixed methods help researchers not to rely too much on the statistical data in examining the social phenomenon that is subjective in nature (Jogulu & Pansiri, 2011). The study adopted triangulation to provide reliable findings (Jack & Raturi, 2006) and support this study's research objectives. It employs two or more independent sources of data or data collection methods to support research findings from a study (Bryman, 2006).

In summary, a mixed-methods approach can be a useful and powerful tool for researchers, as it allows them to combine the strengths of both qualitative and quantitative methods to gain a more comprehensive understanding of the research problem and produce more robust and meaningful findings (Creswell & Plano Clark, 2007). Besides, it helps a researcher to identify convergence, corroboration, correspondence of findings from different methods (Schoonenboom & Johnson, 2017; Flick, 2018). Since the mixed method combines qualitative and quantitative data, it aims to provide a strong understanding of the verification and validation results.

This study adopted a combination of survey and focus group methods in a mixed-methods research design to provide a more comprehensive understanding of a research topic. The first phase of data collection involved focus group discussions with special education teachers. Focus group discussions were conducted to gain more insights into children with dyslexia and the design components of TUIs. On the basis of the findings from the literature review and the focus group discussions, the appropriate design features based on IxD and UD principles, children with dyslexia, learning content, and learning styles were identified.

Following the development of the framework and design guideline, the verification and validation process was employed to gather both quantitative and qualitative data. The expert verified the framework and design guideline by answering the questionnaires and providing comments and suggestions. The validation process was performed after modifications had been made based on the verification results. The target user, i.e., children with dyslexia, was involved in the validation process. Children with dyslexia are the ones who utilised the TUIs prototype, which was developed following the design guideline. The thematic analysis was used to analyse the qualitative data from focus group discussions, whereas the Statistical Package for Social Science (SPSS version 20.0) was employed for the quantitative data analysis (survey). This study identified the common themes across the qualitative data that is later complemented by the findings from the quantitative data analysis. The findings are finally interpreted and presented based on qualitative analysis and statistical test results of quantitative data.

Hence, these research designs were employed in this study to evaluate the effectiveness of the constructed TUIs design guideline. To achieve the objectives outlined in Chapter 1, five phases of the activities in this study are specified: 1) theoretical study; 2) identification of TUIs design components 3) framework and design guideline development; 4) prototype development; and 5) the validation TUIs design guideline. Table 3.1 demonstrates the methods and expected deliverables in the research framework based on the designated research designs.

Table 3.1
Research Framework.

Phases	Research Activities	Deliverables	Research Objectives Achieved
Phase 1: Theoretical Study	**Method:** 1) Literature review to identify TUIs design features	**Literature review:** 1) TI and TUIs 2) Related theories for TUIs and dyslexia 3) Design features of TUIs	1) To analyse the TUIs design components specifically for children with dyslexia learning to read in Malay.
Phase 2: Identification of TUIs Design Components	**Method:** 1) Focus group discussion with special education teachers to identify suitable design components of TUIs	**Design Components:** 1) Suitable design features of TUIs 2) Suitable learning contents according to reading level of children with dyslexia. 3) Suitable learning styles. 4) IxD dimensions. 5) UD principles.	
Phase 3: Design Guideline Development	**Method:** 1) Expert review verification for development of design guideline of TUIs.	1) An improved TUIs design guideline for children with dyslexia learning to read in Malay.	2) To construct a TUIs design guideline for children with dyslexia

Phase 4: Prototype development	**Method:** 1) Rapid application development (RAD)	1) TUIs Prototype	3) To evaluate the effectiveness of the constructed TUIs design guideline.
Phase 5: The validation of TUIs Design Guideline	2) Experimental (Evaluation with children with dyslexia)	2) Validated TUIs design guideline	

This chapter is structured according to the phases in Table 3.1. Section 3.1 describes the methods of identification of TUIs design components including learning contents, learning styles and children with dyslexia, which are appropriate for data collection. Section 3.2 outlines the analysis of data which findings lead to the development of the TUIs framework and design guideline. Section 3.3 delineates prototype development, and the validation is clarified in Section 3.4. In Section 3.5, the chapter is finally summarised.

3.1 Phase 1: Theoretical Study

In this phase, the methods used for the theoretical study are literature review. The previous chapter discusses the literature relevant to the research objectives and found the potential design features of TUIs in learning to learn to read for children with dyslexia. Besides, it gives an overview of the learning support for children with dyslexia through the TUIs design features, including 2D and 3D tangible letters, dynamic colour cues, texture cues, and other features that might be suitable for children with dyslexia in learning to read. In addition, in this phase TUI concepts and learning theories of dyslexia were investigated identify the most effective learning among children with dyslexia.

3.2 Phase 2: Identification of TUIs Design Components

Phase 2 involves a collection on the identification of TUIs design components. Data collection is important in the research to generate findings. Focus group sessions with special education teachers was selected as a research instrument in this study. A focus group was conducted to gain more insights about children with dyslexia, learning content, learning styles, and suitable design based on IxD and UD principles.

An important component of the research is data collection and analysis where the TUIs design features are identified and analysed from previous studies. Information on the related study is gathered and analysed through a literature review. A comprehensive literature review is essential to identify the design features of TUIs for children with dyslexia in learning Malay language. The deliverables from this phase are TUIs design features, learning content, learning styles and suitable design based on IxD and UD principles.

Children with dyslexia may find it extremely difficult to learn to read at the appropriate level. Hence, discussions with special education teachers were performed through focus groups to identify children with dyslexia and their reading levels. Moreover, eight design features of TUIs that have been identified from the literature review in Section 2.6 of Chapter 2 were tested with special education teachers to identify which are the most suitable design features for learning to read in Malay. The following subsections discussed the participants, learning content, learning styles, and methods for data collection.

3.1.1 Participants - Children with Dyslexia

Children with dyslexia of the same reading age participated in this study based on the suggestion of special education teachers who are acquainted with their reading levels. The study population primarily consisted of children with dyslexia who met the following criteria through purposive sampling: a) formal diagnosis of dyslexia, b) exposure to the Malay language, c) age between 7 to 12 years old, and d) having difficulties reading in the Malay language. The experimental sessions were carried out at Sekolah Kebangsaan Kayang and Pusat Dyslexia Malaysia (PDM) Sungai Petani with a sample of 16 children with dyslexia aged between 7 to 12 years old.

(a) Children with dyslexia should be formally diagnosed

According to Husni (2009), this can only be performed by qualified phycologists or doctors to diagnose children using an instrument provided by MoE or endorsed by the MoE.

(b) Children with dyslexia who are exposed to Malay language

Children who are not exposed to Malay language most probably are unable to read in Malay. This ensures that the participants in the study have adequate exposure to Malay in their community to understand instructions provided in Malay and are regularly exposed to learning material in Malay (Husni, 2009).

(c) Children with dyslexia aged between 7-12 years old

The study needs to be participated by children from 7 to 12 years of age. According to previous studies, most of the TUIs reading systems use reading for children ranging from as early as 5 years old to 12 years old (Pandey & Srivastava, 2011; Horn, Crouser, & Bers, 2012; Fan & Antle, 2015; Antle et al., 2015; Teh et al., 2015; Fan et al., 2019).

(d) Children with dyslexia based on reading level

Children are chosen depending on their reading level as recommended by special education teachers. Children who can read fluently in sentences and paragraphs are not included since they are able to recognise and pronounce words fluently (Husni, 2009).

3.1.2 Learning Contents

The study includes two types of learning content focusing on Malay language. This study includes two levels of learning content adapted from Buku Panduan Pengajaran dan Pembelajaran Program Pemulihan Khas Bahasa Melayu as reported by Husni (2009). The first content focuses on letter recognition which applied O-G learning theory and dual coding theory by which children with dyslexia recognise the letters and associate themselves with the image while reading. The second content emphasizes spelling, which identifies the syllables based on the sound of letters. The teachers suggest this learning content according to reading levels of children with dyslexia. Children with dyslexia adopt O-G theories in this learning content where they must identify the syllables based on the sound of letters, as suggested by Jamali et al. (2018). The learning content also allows children to arrange and use different senses to manipulate the tangible letter that applied kinesthetic theories. Then, they interact with the tangible letters in their own space and environment, which they connect with the digital representation in the TUIs prototype system. The approach for selecting the learning content is through focus group sessions with special education teachers.

3.1.3 Learning Styles

Learning styles refer to the learner's ability to perceive and process information in learning situations (Ibrahim & Hussein, 2016). The ability to understand the learning styles of children will enhance learning outcomes. For this study, the learning styles that adapted to the TUIs design guideline are structured activities, clear instruction, repetition and step-by-step as suggested in an existing study by Jamali et al. (2018a). To better understand the learning styles of children with dyslexia, as indicated by Jamali et al. (2019) in the previous study, a focus group with special education teachers was conducted. Focus groups are the main methods used in this phase. The details of the methods are elaborated in the next subsections.

3.1.4 Focus Group

In this study, focus group discussion was used to address the research question, which sought to identify TUIs design components that are mainly suitable for children with dyslexia learning to read in Malay. A previous study has been done in TUIs by Fan et al. (2016a) adopted a focus group as their methodology. Following a study by Costa et al. (2019), TUIs have the main feature of prioritising the process of collaborative interaction in a specific physical space. Thus, it is preferable for researcher to adopt a focus group as a research instrument. In addition, the collaboration between fosters group work provides support and an opportunity to observe others while considering individual expression (Jamali et al., 2018a). According to Ionita et al. (2015), a focus group can be supplemented with interviews to generate a collaborative observational quality. Moreover, the focus group structure leads to 'dynamic group interaction quality, which comprises a diverse set of communication processes (Wilkinson, 2004).

Focus group discussions were conducted to obtain the reading level of children with dyslexia who participated in this study, as suggested by Blamire and Omidire (2020). In addition, to identify learning styles and learning content for children with dyslexia, a discussion was performed through focus group sessions with special education teachers. The objective of the focus group sessions is to obtain initial findings on the appropriate Malay words (syllables) to be included in educational materials, in accordance with the suggestions made by Lee & Wheldall (2011) and Razak, Lin, & Aziz (2021).

Four special education teachers were purposefully selected to participate in the sessions based on two specific criteria: 1) their proficiency in teaching children with dyslexia, and 2) their experience in teaching the Malay language. The aim of this study is to develop learning content for children with dyslexia that incorporates syllable spelling. Purposive sampling was used in this study to select the participants who met specific criteria to ensure that the data collected would be relevant to the research question. By selecting special education teachers who have expertise in teaching children with dyslexia and experiences teaching the Malay language, the researchers can be confident that the insights and recommendations gathered during the focus group sessions will be informed by a deep understanding of the needs and challenges facing dyslexic students who are learning Malay.

By using purposive sampling, the researchers can select participants who are likely to have valuable insights and experiences related to the research question. The special education teachers' expertise has a deep understanding of the challenges that children with dyslexia face when learning the Malay language, and their experience teaching Malay means that they are well-positioned to provide insights on which Malay words and syllables are most suitable for children with dyslexia learners.

Overall, using purposive sampling helps to ensure that the data collected in this study is relevant and meaningful to the research question, and helps to increase the validity and rigor of the research findings. They received a set of questions as presented in

Appendix A. The questionnaires were adapted from previous studies and have been validated by experts with HCI and dyslexia backgrounds (Fan, 2017; Dubuc & Edge, 2006; Aziz, Husni, & Jamaludin, 2013; Husni & Jamaludin, 2013)

From the review of the literature in Chapter 2, Section 2.6, eight design features are found in the current TUIs implemented in the tangible systems. In order to identify which design features are most suitable for learning to read in Malay language, special education teachers participate as users in the focus group sessions. During the focus group discussion, the eight design features were tested before including them in the TUIs design guideline.

The focus group consisted of four teachers who participated in a session held at the Program Pendidikan Khas Integrasi (PPKI) class in Sekolah Kebangsaan Kayang (SKK). Due to the Covid-19 movement control order (MCO), which limited movement within the district, SKK was selected as the only school with children with dyslexia at the time. Consequently, only special education teachers from SKK in Perlis who had experience working with children with dyslexia were chosen as participants in the focus group. Previous studies indicate that having four special education teachers participate in these focus group sessions is deemed to be representative (Lee & Lee, 2009; Aziz, 2015). The number of participants in these sessions can vary, ranging from a minimum of three or four individuals to a maximum of six, twelve, or even fourteen individuals, depending on the objectives of the research (Lee & Lee, 2009; Aziz, 2015). In general, smaller groups typically have more potential and are more appropriate when trying to discuss challenging, contentious, sensitive issues, or to encourage detailed stories (Jordan, Lynch, Moutray, O'Hagan, Orr, Peake & Power, 2007; Aziz, Ahmad & Durai, 2012).

An interview protocol was used by the researcher to guide interviews with study participants. During the session, the participants were asked semi-structured questions to allow for flexibility and open-ended responses. The focus group discussion lasted approximately one hour per session.

Thematic analysis was used in this study to address RQ1, which included identifying common and interesting patterns of interaction from audio recordings of focus group sessions and notes. The first objective of this study is to analyse the TUIs design components specifically for children with dyslexia learning to read in Malay. The thematic analysis technique was used to analyse the data generated from the focus group method. Focus group sessions with special education teachers have been conducted to analysed suitable design features for designing TUIs that target learning to read in Malay.

A focus group was first transcribed and analysed for qualitative data analysis using ATLAS.ti (8th version) software, as suggested by Soratto, Pires and Friese (2020). This study follows the process proposed by Braun and Clarke (2006) in carrying out the thematic analysis. There are six phases to be performed in the thematic analysis process:

(a) **Familiarisation with data -** The transcript of the focus group was analysed, and the researcher read and reread the data for a better understanding of the content of the data. Then all data were reviewed and transcribed into written form (notes) to get an early impression of the content.

(b) **Generate initial code -** The data were organised based on the importance of the content at this stage. The relevant data were identified to address the research questions explicitly. Braun and Clarke (2006) mentioned several ways in coding extracts.

The ATLAS.ti project is created in this phase, and the documents (focus group transcripts) are added. Documents can be organised and analysed more efficiently by grouping them into document groups. The first memos on the project's overall aim, including research questions, were then written.

The first step in the coding procedure was to label the topics raised by the focus group participants. During this phase, quotations are created based on the research objectives, and each quotation discovered in the focus group documents saved in the ATLAS.ti tool is assigned with a code. The codes grouped depending on the identification of interesting themes and categories. The purpose of code groups is to help with the sorting and ordering process as well as to act as filters as the data analysis continues. The first coding process produced a list of 29 codes.

(c) **Search for themes -** Themes searched for repeated patterns of meaning that are considered to be relevant. Themes developed based on their importance and visualised in ATLAS.ti network views. The next step was to group the codes into a pattern that was relevant to the research question. Three code groups were created in ATLAS.ti to analyse the data from the focus group. Figure 4.3 in Section 4.9 illustrates the codes that were explored further during the theme development process.

(d) **Review themes -** The initial themes were revised by changing the relevant themes. To associate each theme, colour coding techniques are used. For instance, various colours used to differentiate significant themes.

(e) **Define themes –** This phase aims to establish the final process of theme refining by indicating the connections between them. This study developed a sub-theme to emphasize the TUI's design features, including 3D tangible letters, texture cues, and dynamic colour cues. The network views must be examined at this phase. Other sub-themes include feedback for children with dyslexia during the learning process, such as praises, audio, and 2D images or graphics, as well as design elements and structure of the system that are suitable for children with dyslexia, such as linear navigation, static images, voice-over for each instruction, icon with text label, help icon button with audio, and a colourful interface.

Other important sub-themes were also described, which require a suitable TUIs design based on UD principles, including equitable use, flexibility in use, simple and intuitive use, perceptible information, tolerance for error, low physical effort, and size and space for approach and use.

(f) **Produce the report -** The final analysis of the data extracted is determined at this phase in order to address the research questions. The data relevant to the themes, literature, and research questions are included in this report. The network view depicted in ATLAS.ti can be exported as graphic files and included in the report.

Results from qualitative data in Chapter 4 show the ability of tangible technology to improve the experiences of children with dyslexia through analysed design features of TUIs, IxD, and UD principles.

3.2 Phase 3: Framework and Design Guideline Development

Phase 3 is the creation of a TUIs framework and design guideline that is specifically designed for children with dyslexia. The framework is then verified by seven experts. Descriptive analysis and overall results of verification were employed to analyse the data generated from the expert review. The data collected form as a basis for framework and design guideline of TUIs to be developed for children with dyslexia learning to read in Malay. The framework and design guideline were improved based on the experts' suggestions and comments.

The deliverables of this phase are the TUIs framework and design guideline for children with dyslexia learning to read in Malay. Focus group discussions are performed to identify the suitable design features of the TUIs and suitable designs based on IxD and UD principles for children with dyslexia. Finally, the experts verify the framework and design guideline of TUIs. The suitable IxD dimensions and UD principles to be applied in the TUIs framework and design guideline were explained in the next subsection.

3.2.1 Step 1: Select Suitable Principles to be Adapted in TUIs Framework and Design Guideline

Based on Dubuc and Edge (2006), Table 2.4 of Chapter 2 proposed a suitable design in TUIs based on previous studies. According to Principle 1 in the UD, establishing the design for children with dyslexia must encompass all people without separating them into groups or individuals. Children with dyslexia should be given an opportunity to learn according to their individual learning needs, and at the same time can also benefit other children. In Principle 2, flexible activities (learning style) help children with dyslexia to practice learning based on the needs of individual learners (Jamali et al., 2018).

Accordingly, based on Principle 3, the user interface layout must be simple and clean, while the navigation must be accessible and consistent (Kous & Polančič, 2019). It is vital to use clearly labelled layouts in the user interface, and the content should not be in text form as mentioned in Principle 3 (Simple and Intuitive Use). For children with dyslexia users, seeing or engaging with a product will build their confidence (Zusman, 2015). With the advancement of TUIs technology, the children are highly engaged in their learning session, allowing them to touch the physical letters and spell. At the same time, they can get visualized and stimulated from a digital space like a computer. Children with dyslexia learn effectively with multisensory inputs such as tactile, visual, and audio, as mentioned in Principle 4 (Perceptible Information). Based on Principle 5 (Tolerance for Error), it allows errors to be reversed or minimized, such as the audio feedback message in the user interface (Zusman, 2015).

In terms of suitable design for children with dyslexia based on UD in Principle 6 (Low Physical Effort), the instruction is well-structured to reduce the non-essential physical effort to optimize learning (Scott et al., 2003). Furthermore, Fan et al. (2018) stated that a hand-sized material is lightweight, securing material for the design features of 3D tangible letters, which children with dyslexia can easily take up. Second, letters must stand alone for children with dyslexia to arrange them easily in space. Third, enough space is needed on the table to put all letters to ensure physical restrictions (normally on the bottom) and visual markings (top) are located and organized easily by children in space. In terms of suitable design for Principle 7 (Size and Space for Approach and Use), 3D letters also need to be light, pleasant to touch, and quick to transfer, arrange and manage. For each learning activity, a subset of letters is presented to the teachers, and children's encouragement (e.g., putting in letter slots) helps to concentrate on letters (Fan et al., 2018).

The IxD dimensions adapted to the TUI design concept in this study. Table 2.5 of Chapter 2 presented the required design based on IxD dimensions. According to IxD dimension (words), animated words must be avoided to make it easier for children with dyslexia to read words and they should be given a structured wordlist as suggested by Aziz et al. (2013). In terms of visual representations dimension based on TUIs design include font type, dynamic colour cues and colour. Jamali et al. (2019) suggested that the chosen font type with no mirror effects (e.g.: b & d) could make it easier for them to read. Besides, TUIs design should focus on lowercase letters instead of using uppercase letters, making reading more difficult for children with dyslexia (Fan et al., 2016a; Mcphillips et al., 2015). This finding was supported by the Dyslexia Association of Ireland which advocated the use of lowercase letters so that children with dyslexia can easily read the word. In addition, the background colour code for dyslexia suggested by Husni and Jamaludin (2013) includes the colours based on Irlen (2005).

In terms of suitable design based on IxD dimension (physical objects or space), the use of hand-sized tangible letters and created with light and safe material will help the children with dyslexia to pick up easily and grasp the letters in their hands (Fan et al., 2018). Based on time, the audio aspects should correspond with the images (Hussain et al., 2016). In a similar vein, children with dyslexia need to be provided with audio outputs such as narrator voices, which will help read out instructions (Aziz et al., 2013; Jamali et al., 2019). Finally, the help menu could be in the form of audio that is embedded in the TUIs prototype (Jamali et al., 2019, p.358). TUIs framework and design guideline proposed based on IxD dimensions which can fulfil the user needs and evaluate the effectiveness of the TUIs to support children with dyslexia reading in Malay.

3.2.2 Step 2: Comparison of Existing Design Guideline of TI and TUIs

Based on the review of the literature in Section 2.7.2 of Chapter 2, four selected research papers on design guidelines of TI and TUIs focus on the difficulties they face with language processing, such as reading, phonology, writing, or spelling, and are designed to support particular languages, such as English and Malay. The elements in the design guidelines from previous studies are different based on their requirements for children with dyslexia.

The previous studies (Falco & Price, 2010; Jamali et al., 2019; Jamali et al., 2018a) generate design guidelines for TI, whereas Antle and Wise (2013) focus on TUIs in learning. In terms of Falco and Price (2010) and Jamali et al. (2019) developed their guidelines using interview methods. Meanwhile, Antle and Wise (2013) used dialectic processes to establish guidelines by analysing different theories of cognition and learning, whereas Jamali et al. (2018a) conducted a study to assess the findings using thematic analysis.

Existing TI and TUIs design guidelines are inadequate, particularly in terms of suitable TUI design features, multisensory approaches, appropriate theories, and learning content for supporting children with dyslexia reading in Malay. According to previous studies, design guidelines must include analysed TUI design features (Fan et al., 2016a), supporting theories (Jamali et al., 2018a), and principles such as UD and IxD dimensions. TUIs ought to incorporate various sensory inputs such as auditory, visual, tactile, and kinesthetic to promote the use of multiple senses in reading acquisitions.

According to Antle and Wise (2013), the design guidelines for children with dyslexia are recommended based on the findings from previous studies but require further enhancement to help children with reading. In addition, there is no evaluation of the proposed TUIs and TI design guidelines identified in their research. As a result, TUIs design guidelines were developed for this study based on an improved version of

Ullmer and Ishii's TUIs framework. The details of the guideline development and verification with expert review are covered in Chapter 5.

3.2.3 Step 3: Verification using Expert Review

The framework and design guideline of TUIs were verified by the experts' review as stated in Table 3.1. Seven experts were involved to validate the framework and design guideline of TUIs for children with dyslexia. According to Holzinger (2005), three to five experts are considered sufficient in this process, and not fewer than three are recommended. Based on a study by Fan (2017), using expert reviews led them to select an important part of spelling rules that they need to focus on in the learning activities.

The selected experts have experience in Human-Computer Interaction (HCI) fields and learning product design for children with dyslexia. The expert review session takes approximately two hours. Experts received a set of questions regarding the framework and design guideline verification. The questionnaire consists of five sections; expert demographic, tangible representations, intangible representations, digital information, and framework review of the proposed framework and design guideline.

The questionnaire used in the study was reviewed and validated by five experts with backgrounds in HCI and dyslexia. Their feedback was incorporated to improve the TUIs design guideline. Based on their input, the TUIs framework and design guideline were modified. Once the validation process by the experts was completed, the prototype was developed in accordance with the TUIs design guideline. Phase 3 discussed the development of the TUIs prototype for this study.

3.3 Phase 4: Prototype Development

This section discussed the design and development process of a TUIs prototype. The prototype is developed as a proof of concept. In this phase, the TUIs prototype was developed based on TUI design guideline specifically for children with dyslexia in learning to read. TUIs prototype is used for examining the function of TUIs and evaluating a design concept with users (Shaer & Hornecker, 2010).

The TUIs prototype is a tangible learning system that facilitates children with dyslexia aged 7-12 years to learn how to read in Malay based on two-level learning contents, letter recognition and spelling of vowel and consonant vowels including (V+CV) and (CV+CV). It comprised a four-slot word-making platform and lowercase 3D tangible letters as suggested by Fan et al. (2018). By placing 3D tangible letters on the platform, children learned to recognise letters. The prototype gave feedback to children with dyslexia through audio, the sound of the tangible letters and images when performing the learning contents.

Before using the prototype, children with dyslexia can simulate playing with the letters and rearrange them on the spelling board to make them feel more comfortable and view the learning content provided in the software. In addition, the prototype using dyslexia-friendly fonts for font type. The background colour code includes the eight colours based on Irlen (2005), which are suitable for the reading among children with dyslexia as recommended by Husni and Jamaludin (2013). Children with dyslexia can use a TUIs prototype that utilises the multisensory method, TUI's design features and learning material to grasp reading skills.

3.3.1 TUIs Prototype Development using Rapid Application Development

This study employed the Rapid Application Development (RAD) methodology to develop a prototype for TUIs, specifically designed for children with dyslexia learning to read in Malay. The TUIs design guideline was incorporated into the prototype development process. RAD is a software development methodology that emphasises rapid prototyping over extensive planning (Martin, 1991). The methodology involves the development of functional modules in parallel as prototypes, which are then integrated to create the final product for faster delivery. The RAD methodology consists of four phases, which are requirement planning, user design, construction, and cutover, as illustrated in Figure 3.1.

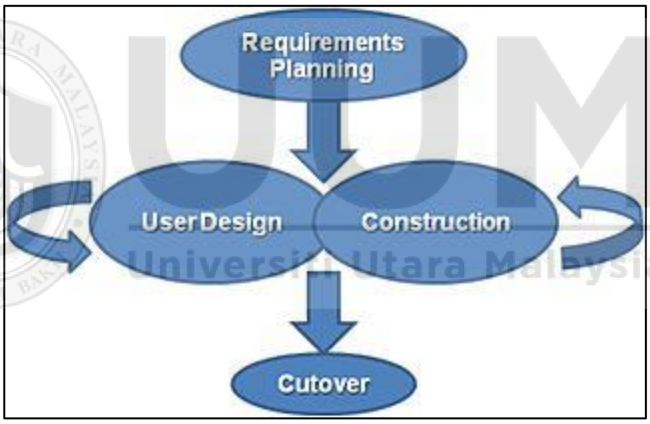

Figure 3.1. Rapid Application Development (RAD)

During the requirement planning phase, the researcher conducted focus group discussions with special education teachers to identify the necessary requirements. Appendix A presents the semi-structured questions that were used during the focus group sessions. The focus groups were conducted to identify TUIs design components that would be suitable for children with dyslexia learning to read in Malay. These design components included relevant TUIs design features, learning content appropriate for children with dyslexia reading level, learning styles, IxD dimensions, and UD principles, based on the suggestions of special education teachers. Additionally, the eight design features of TUIs were tested with special education teachers to obtain further information about suitable design options before incorporating them into the TUIs design guideline.

During the user design phase, the developers walked through a low-fidelity prototype with a researcher to obtain feedback before actual prototype development. This approach was adopted based on previous research by Mohd Zaki, Ishak, and Mohamad (2021) and Christoforakos and Diefenbach (2019). The prototype was collaboratively tested by the researcher and developers, and the user interface was iteratively designed in response to the researcher's suggestions. User design is an interactive process that enables users to fully understand, modify, and agree to a functioning model of the system that meets their requirements. Low-fidelity prototyping is also important for evaluating a range of designs, such as 3D tangible letters, and selecting the best option for further development, as noted by Wiethoff, Schneider, Rohs, Butz, and Greenberg (2012).

Next, the construction phase primarily focused on developing the program and application using the Java language of the Processing IDE. The main objective is to capture the information string received from Arduino and pass it into the PHP script. The TUIs prototype involves both software and hardware components, with the details of the prototype design covered in Sections 6.1.1 and 6.1.2 of Chapter 6. Using SolidWorks software, 26 lowercase 3D tangible letters were designed as part of the hardware component. The prototype includes two types of learning content, namely letter recognition and spelling, to facilitate children with dyslexia in learning to read in Malay.

In the cutover phase, the evaluation process began by scheduling meetings with children with dyslexia who were selected by their special education teachers to participate in the evaluation session. The researcher facilitated the tests, guiding the children to touch and place the 3D tangible letters on the spelling board to ensure they were comfortable using the prototype. One-to-one sessions were conducted with the researcher to provide individual attention. The interaction of the children with dyslexia using the TUIs prototype was recorded using video recording during the evaluation sessions. Phase 5 focused on validating the TUIs design guideline for this study.

3.4 Phase 5: The Validation of TUIs Design Guideline

This phase involved testing the TUIs prototype and validating the design guideline by the target user, children with dyslexia through experimental methods. TUIs prototype was developed based on the proposed design guideline is tested with children with dyslexia using 3D tangible letters. The validation process was crucial to ensure that the prototype functioning efficiently. The study employed purposive sampling to select 16 children with dyslexia between the ages of 7 and 12 years old for an experimental session. These participants were selected based on their abilities to perform learning activities such as letter recognition and syllable construction at their reading level, as recommended by their special education teachers. In this study, the main evaluation was performed using experimental methods following the study by Fan et al. (2018). The experiment was conducted with children with dyslexia together with the researcher as suggested by Fan (2017). The details on the experimental session are discussed further in Section 3.4.1.

3.4.1 Experimental Session and Instruction Procedure using the TUIs Prototype

The experimental sessions involved 16 participants of children with dyslexia and were conducted at Sekolah Kebangsaan Kayang and Persatuan Dyslexia Malaysia, Sungai Petani. The tests were performed with children with dyslexia with assistance of researcher. Children with dyslexia were given a task description for evaluation prior to using the prototype as presented in Appendix D. Researcher assisted the children with dyslexia to touch and try to place the 3D tangible letters on the spelling board. This is to ensure they felt comfortable using the prototype through one-to-one sessions with the researcher. The researcher assisted children with dyslexia answered questions, re-direct them, and supporting them when children were lost during instruction. Three experts with backgrounds in HCI and Computer Science were involved in the validation of the questionnaire.

In this study, the participants were asked to complete the learning content (letter recognition and spelling) based on their reading level in the Malay language. The instruction procedure of using the TUI prototype used for children with dyslexia as suggested by Fan (2017): (1) introducing the name of the lesson and clearly describing the name of the lesson; (2) encouraging the children to learn the lesson.

In addition, every child attempted a set of the questionnaire (5-point scale) on their system preferences with the assistance of researcher, following the post-test. The questionnaire used a 5-point smiley scale i.e., Smileyometer (Read & Fine, 2005) which is suitable for children with dyslexia to express their degree of agreement or disagreement with a statement. The smiley scale used was adopted by Read and Fine (2005) consisted of five emoticons ranging from Awful, Not very good, Good, Very good, and Brilliant. The questionnaires in Appendix C were distributed to the children with dyslexia was adapted from the existing study (Fan, 2017; Husni, 2009).

The questions consisted of user interface experience, effectiveness, and design features of TUIs. The researcher read and wrote the answers due to the children with dyslexia having difficulties to read or write clearly. The questionnaires were then analysed using statistical software namely Statistical Package for Social Science (SPSS version 20.0) to meet the objectives of the study.

3.5 Result Analysis

Focus group conversations, audio and video recordings, photographs, etc. are just a few of the data sources that can be used to obtain information from qualitative data. The focus group data in this research were audio recordings, while the experimental sessions with children with dyslexia used video recording to record the interaction of children with dyslexia using the TUIs prototype. Focus group sessions were transcribed and analysed for qualitative data analysis using ATLAS.ti (8th version) software. Meanwhile, the questionnaire data from the verification and validation process were analysed using the Statistical Package for Social Science (SPSS version 20.0).

3.5 Summary

This chapter provides an overview of the research methodology consisting of four phases: theoretical study, identification of TUIs design components, TUIs framework and design guideline development, prototype development and the validation of TUI design guideline covers all the methods used to attain the objectives as discussed in Chapter 1. Each phase is briefly explained. To achieve the first objective, data collection must be carried out through focus groups with special education teachers.

To achieve the second objective, a TUIs framework and design guideline is proposed as described in phase two and verified by experts' review. To achieve the third objective, a TUI prototype system is developed to evaluate the effectiveness of TUIs design guideline through the validation process as mentioned in phase three. Hence, this chapter outlines and discusses the methods for achieving the objectives as specified.

CHAPTER FOUR
TANGIBLE USER INTERFACES DESIGN COMPONENTS

4.0 Introduction

The findings of the qualitative analysis are presented in this chapter. The first section focuses on the qualitative findings of the focus group, which method is presented in Chapter 3, Section 3.1. The results are divided into eight subsections based on the focus group analysis, including characteristics features of children with dyslexia, challenges of children with dyslexia in learning, subjects and personal interests of children with dyslexia, types of learning contents, types of learning styles, design features of TUIs, interaction design and universal design principles. The following section outlines the qualitative discussions of this study. Finally, a summary concludes this chapter.

4.1 Findings of Focus Group

Four teachers from the Program Pendidikan Khas Integrasi (PPKI) class in Sekolah Kebangsaan Kayang (SKK) were chosen as focus group samples. Due to Covid-19 restrictions, the researcher was only allowed to travel within the state, hence only teachers from SKK in Perlis were chosen as focus group samples. They were named Teachers A, B, C, and D due to their confidential status. The information on the teachers' backgrounds and years of experience teaching children with dyslexia is summarised in Table 4.1.

Table 4.1
Summary of Teacher Background

Teacher	Experience in teaching children with dyslexia Years	Age/ Years of children with dyslexia handled by the teacher	Subject Teaching Specialties
A	5	Year 2	Malay language, Mathematics, and Science
B	4	Year 5	Malay language and Mathematics
C	2	Year 4	Malay language
D	2	Year 6	Malay language and Mathematics

The focus group sessions explore the efforts to develop a TUIs design guideline for children with dyslexia. The views of the respondents provide detailed insight into children with dyslexia and TUIs. Thematic analysis was used to categorise themes or patterns discovered in qualitative data. Based on the themes identified through the thematic analysis, the results are divided into eight categories:

i. Characteristics features of children with dyslexia.
ii. Challenges of children with dyslexia in learning
iii. Subjects and personal interests of children with dyslexia
iv. Types of learning content
v. Types of learning styles
vi. Design features of TUIs
vii. Interaction design
viii. Universal design principles

4.2 Characteristics Features of Children with Dyslexia

This section aims to identify the primary characteristics features of children with dyslexia. The findings indicate a major difference in teaching normal children and children with dyslexia. According to the PPKI teachers, the students tend to make similar mistakes even though they have taught them many times. Besides, children with dyslexia mixed up left and right shoes and had difficulties remembering their birth dates. In addition, children with dyslexia cannot differentiate between the letter “p” and the letter “b” especially when they have been asked to write and recognise words in class.

The statements below were the quotes from the teachers at Sekolah Kebangsaan Kayang (SKK):

Teacher A expresses that the students always write uppercase letters as lowercase letters and vice versa. In addition, among the characteristic of children with dyslexia is aborting and adding words to the sentence.

He mentioned that:

> “When they write a sentence, they will mix lowercase and uppercase letters. If the shape of the letters is more or less the same, they confused. Another characteristic of children with dyslexia is aborting and adding words; however, none of the students got this characteristic in this school.

By way of an example, he adds:

> “…." Ali likes to eat fried rice." However, he would write Ali ate fried rice. The students will remove the word such as "like" in the sentence because he is used to hearing "Ali eat rice", which is also a characteristic of dyslexia. There are also those who like to add words; for example, we told them to write the sentences "Ali likes to eat rice. He will write, "Ali likes to eat nasi lemak." This is also what we call children with dyslexia characteristics. Dropping and adding words are also characteristics of dyslexia.”

In a similar vein, Teacher D mentioned that:

> “When the learning process took more than half an hour, the students signed that the words are moving while reading, which finally leads to lack of concentration among them, and they tend to get out of their position. Due to that, I need to conduct a friendly classroom adjustment by making learning fun with toys to ensure that they behave and not walk around aimlessly”.

Children with dyslexia have difficulties following the standard education curriculum. Teacher C explains that:

> "If they can't read by Year Six, we'll have to teach them how to read all over again, and if they can't recognise letters, we'll have to teach them how to recognise letters all over again." They can fully recognise letters in Year 6 if they are normal children, but if the child has dyslexia, they may still be unable to recognise letters in Year 6. That is the difference between children with dyslexia and normal children."

The findings conclude that the primary characteristics of children with dyslexia are having difficulties recognising an accurate and fluent word and a lack of spelling, decoding, and encoding abilities.

4.3 Challenges of children with dyslexia in learning

There are few challenges faced by children with dyslexia highlighted by the teachers during the focus group sessions. All teachers mentioned that children with dyslexia are unable to write and read appropriately. The problem is compounded by the fact that children with dyslexia need to learn according to the standard curriculum education, just other children. Teacher B expressed himself by mentioning that:

> "The standard syllabus is quite high; to help children with dyslexia, we must go down to the syllabus level".

This makes it difficult for teachers to handle them whereby the teachers need to conduct an extra reading class for those who are unable to read.

In PPKI class, the teachers only teach core subjects such as Malay Language, Mathematics, and Science whereby for other subjects like Islamic Education, children with dyslexia need to attend classes together with normal children. Oftentimes, they feel eager to attend other than PPKI class because they lose motivation to learn and keep giving excuse to absent from the class.

On the other hand, children with dyslexia tend to show slow progress in reading especially in Malay language. The teachers stated that some of the children with dyslexia have good reading abilities according to certain level. For instance, some of children with dyslexia are unable to read until they can spell, and some can proceed with reading straight away. Usually, the students necessitate their teachers to read to them first and they follow along. There are some students that have difficulties to spell syllables and unable to recognise letters. Along the learning process, the teachers have to repeat many times when teaching them.

In a similar vein, Teacher C stated that:

> "Children with dyslexia tend to feel burden with the workload because they tend to get bored easily when they are given with a lot of learning activities".

In relation to current syllabus for Mathematics, the teacher A asserted that the syllabus is not suitable and high level to the children with dyslexia because the value of million numbers difficult to be taught to them. The students were having difficulties in remembering the concept of multiplication, and memorising numbers are quite challenging. For instance, equation of 1000 x 200, they had different expression when they noticed the question and stared at the book. One of the teachers stressed that:

> "Whatever the basics, children with dyslexia must be able to read. The knowledge we want to convey to the students difficult for them to comprehend if they are unable to read."

4.4 Subjects and personal interests of children with dyslexia

In response to the personal interest of children with dyslexia, Teacher A stated that children with dyslexia are more engaged with an electronic media rather than using whiteboards during their learning process. Generally, they are more interested in learning through video. For instance, they prefer to do their learning activities through online Quizizz (internet application). Regardless of the poor score, they keep repeating attempting the online quiz. This shows that they like interactive learning activities compared to traditional learning.

Furthermore, the children with dyslexia love to engage in the physical activities such as badminton and planting. The teachers indicated that the brick ties at the garden at the front of the school were done by the children with dyslexia.

Teacher A stated that:

> “Learning in class for five minutes is sufficient for children with dyslexia. After that, they prefer to go outside for an extended period of time to participate in physical activities. They love to participate in physical activities. Since some of their parents work as contractors or farmers, several children with dyslexia are skilled at mixing cement and planting crops".

Nevertheless, he adds:

> “There are also children with dyslexia who are good in reading are hesitant to enter hot places because they because they dislike the hot weather. When we ask them to pull out the grass, they will first request gloves because they do not want their hands to get dirty.”

4.5 Learning Content

Children with dyslexia mostly fail to recognise letters until syllables because they are unaware of a wide range of syllables. Every child with dyslexia in Sekolah Kebangsaan Kayang has a different level of ability to read. For instance, in this school, only four students from Year 6 can read the storybooks when the teacher requests them. According to the teachers, the school organised an online e-story competition due to the pandemic Covid-19. They found that some children with dyslexia can read fluently from the recording with their teacher’s help.

From the discussion with the teachers, the findings indicate that letter recognition and syllable spelling are two types of learning content in the Malay language that is suitable for children with dyslexia. The teacher A asserted that:

> "In terms of letter recognition, children already know letters. They are just confused with the shapes of the letters. When we show it to them, they know the letters, but when they write, they always reverse the letters."

Meanwhile, the teachers agreed to include all types of Malay language syllables in a word for children with dyslexia. They said that all syllables' patterns mentioned are suitable for children with dyslexia at their school. However, the teacher C adds:

> "I suggest that the first section should focus on letter recognition including vowel and consonant letters, followed by a spelling section that teaches children with dyslexia how to spell vowel and consonant vowels (V+CV)."

The syllable-based spelling part should emphasize the words they always used in their daily speaking, such as places, animals, and transportation. The 24 syllable patterns in Malay language are selected from the *Program Pemulihan Khas: Buku Panduan Pengajaran dan Pembelajaran Bahasa Melayu.* Table 4.2 illustrates the syllable pattern denoted by the consonant, C and vowel, V. Words from textbooks and the *Program Pemulihan Khas: Buku Panduan Pengajaran dan Pembelajaran Bahasa Melayu* that match each group of the syllable patterns in Malay language were chosen at random.

Table 4.2.
Syllable patterns
(Source: Program Pemulihan Khas: Buku Panduan Pengajaran dan Pembelajaran Bahasa Melayu)

	Syllable Pattern		Syllable Pattern
1.	V+CV (vowel + consonant vowel)	13.	V+CVCC (vowel + consonant vowel consonant consonant)
2.	CV+CV (consonant vowel + consonant vowel)	14.	CVC+CVCC (consonant vowel consonant + consonant vowel consonant consonant)
3.	CV+CV+CV (consonant vowel + consonant vowel + consonant vowel)	15.	CVCC+CV (consonant vowel consonant consonant + consonant vowel)
4.	CVC (consonant vowel consonant)	16.	CVCC+CVC (consonant vowel consonant consonant + consonant vowel consonant)
5.	V+CVC (vowel + consonant vowel consonant)	17.	CVCC+CVCC (consonant vowel consonant consonant + consonant vowel consonant consonant)

6.	CV+CVC (consonant vowel + consonant vowel consonant) - cawan	18.	CV+CV+CVCC (consonant vowel + consonant vowel + consonant vowel consonant consonant)
7.	CVC+CV (consonant vowel consonant + consonant vowel)	19.	CV+CVC+CVCC (consonant vowel + consonant vowel consonant + consonant vowel consonant consonant)
8.	CVC+CVC (consonant vowel consonant + consonant vowel consonant)	20.	CVC+CV+CVCC (consonant vowel consonant + consonant vowel + consonant vowel consonant consonant)
9.	CV+CV+CVC (consonant vowel + consonant vowel + consonant vowel consonant)	21.	CVCC+CV+CVC (consonant vowel consonant consonant + consonant vowel + consonant vowel consonant)
10.	CVC+CV+CVC (consonant vowel consonant + consonant vowel + consonant vowel consonant)	22.	CV+CVCC+CVC (consonant vowel + consonant vowel consonant consonant + consonant vowel consonant)
11.	CVCC (consonant vowel consonant consonant)	23.	Word with diphthong dan paired vowel
12.	CV+CVCC (consonant vowel + consonant vowel consonant consonant)	24.	Words with joined consonant letters (digraphs)

4.6 Learning Styles

All teachers stated that the learning styles suitable for children with dyslexia are structured activities, clear instruction, repetition activity, step by step, and flexible. The teacher mentioned that a flexible learning style is good for children with dyslexia. Thus, for those children who did not recognise letters, they can practice learning activities through letter recognition.

Teacher B stated that:

> “There should be a repetition and structured activities for children with dyslexia. This is because children with dyslexia frequently forget what they have learned; sometimes I have to ask them several times to get them to remember what they learned the day before.”

However, the Teacher A adds:

> “A direct and clear instructions should be given to children with dyslexia to promote active participation in learning activities. While doing class activities, a step-by-step instruction may help children with dyslexia to accomplish the task, such as arranging letters to build words”.

4.7 Design Features of Tangible User Interfaces

Based on the design features TUIs presented and demonstrated, all teachers indicated that 3D tangible letters, texture cues, and dynamic colour cues are suitable for children with dyslexia learning to read in Malay.

4.7.1 3D Tangible Letters

According to the teachers, the students love to participate in physical learning activities. They tend to get bored when they learn using a whiteboard during their learning process in the class. Teacher C explains that:

> “The 3D tangible letters are perfect for children with dyslexia because they can hold and feel the letters' shape as well as move them. It is multisensory. The letters should be bigger enough for children with dyslexia to handle comfortably”.

Teacher C further gives an opinion:

> “In terms of letters, can you make the letters that children with dyslexia can recognize which one of the letters' curves at the bottom line such as "g"? Sometimes the curve of the letter "g” they write in a book is above the line. They cannot adjust the letter below the line such as the letter "g". Those are the characteristics of dyslexia as well”.

Following the focus group sessions, all teachers agreed to use the letter shapes (*Papan Sintok*). Figure 4.1 shows the “*Papan Sintok*” from previous research.

Figure 4.1 Papan Sintok ™

4.7.2 Dynamic Colour Cues

One of the teachers asserted that colour would make learning become interesting for children with dyslexia. Thus, dynamic colour cues can enhance their learning outcomes as stated by the teachers in PPKI class. Teacher C expresses that the students are more interested in colours during learning. By way of an example, she adds:

> “I think it's okay if there are colourful because they are more interested in colours during learning. The letters should be bigger. If the letters are too small, they will get distracted during learning.

In similar vein, the teacher A, B and D adds:

> “The colour for vowel letters should be a contra colour with consonant letters. The letters should be contra with the background. If there are a lot of colours or objects in the background, they tend to be distracted to focus. Letters should have an interesting colour, for example, use a soft colour. Please try to avoid bright colours for letters”.

4.7.3 Texture Cues

The teachers mentioned that the letters with texture cues could stimulate children's touch sensory response, thus facilitating learning to read for children with dyslexia. The felt fabric, sandpaper, and sackcloth were among the texture cues presented to the teachers, and they preferred the felt fabric material. Thus, this study aims to propose texture cues on 3D tangible letters as one of the design features for better improvement of the reading.

4.8 Interaction Design

This section identifies the IxD elements to be adapted to the TUI design concept. Table 4.3 summarised the IxD with suitable design in TUIs as proposed by all teachers.

Table 4.3

IxD with suitable design in TUIs

Questions	Interaction Design Elements	Teacher			
		Teacher A	**Teacher B**	**Teacher C**	**Teacher D**
Type of feedback is appropriate from the system to be used for children with dyslexia	Audio (3D)	X	X	X	X
	Praises (3D)	X	X	X	X
Design element and structure of the system suitable for children with dyslexia	Colourful Interface (2D)	X	X	X	X
	Linear Navigation (1D)	X	X	X	X
	Help icon button with audio (2D)	X	X	X	X
	Static images (2D)	X	X	X	X
	Icon with text label (2D)	X	X	X	X
	Voice-over for each instruction (3D)		X		

4.8.1 Feedback for Children with dyslexia during Learning Process

All teachers agreed that feedback such as audio and praise is necessary to be integrated in the system for children with dyslexia. One of the teachers mentioned that when the students answer the question incorrectly, a digital audio *(try again*) can be associated to make them attentive.

The teacher C stated that:

> "If they make a mistake during the learning activities, there is a "try again" audio triggered when the answer given is incorrect, and a different audio when the answer given is correct."

By way of an example, Teacher D adds:

> "For example, an applause sound is integrated when they give the correct answer during the learning activity. When they make a mistake, possibly the system can give a signal sound like "try again" for them to get motivated to do the question again."

4.8.2 Design element and structure of the system suitable for children with dyslexia

In response to the system's design elements and structure, all teachers were in the same opinion that a colourful interface layout, a help icon with audio, an icon with a text label, and a static image to be integrated in the system. Teacher C noticed that a static image is more appropriate than animation when it comes to images. She claims that children with dyslexia distracted during learning when the image is moving like in animation.

On the other hand, Teacher C stated that icon with text label is more suitable for children with dyslexia. She further stated that colourful colours are suitable for interface design because children with dyslexia are more attentive in colours during learning.

Teacher C adds:

If possible, the colour should be in contrast to the background, so that the colour of the letters should be a little brighter".

However, the Teacher B mentioned that:

"Children with dyslexia may require assistance from teachers to read instructions. I think voice-over for each instruction can help them."

The findings conclude that voice-over for each instruction is needed because they often demanded their teachers to read to them first and they follow along. This will make learning easier for children with dyslexia.

4.9 Universal Design Principles

This section aims to discuss the identified universal design (UD) principles within TUI's design concept to fulfil the requirements of children with dyslexia. Owing to the fact that UD works best for everyone without separating people into groups or individuals, this will in turn give benefit to children with dyslexia and others.

4.9.1 Seven Principles of Universal Design

All of the teachers agreed that seven universal design principles are vital to be considered when designing the TUIs for children with dyslexia. These key areas include equitable use, flexibility in use, simple and intuitive use, perceptible information, tolerance for error, low physical effort, and size and space for approach and use. Table 4.4 summarised the seven principles of UD with suitable design in TUIs as proposed by all teachers.

Table 4.4
Seven principles of Universal Design with suitable design in TUIs

Principle	Suitable design	TA	TB	TC	TD
a) Equitable Use	i) Setting up a design (hand-size physical object) for children with dyslexia must perfectly cover all the learning needs of other children without separating them into groups or individuals.	✓	✓	✓	✓
b) Flexibility in Use	i) A flexible activity will help children with dyslexia to practice learning based on the child's individual needs. For example, allowing children with dyslexia to integrate what they want to learn according to their needs/abilities. ii) Provides various options for displaying specific learning content on the user interface. Choice in methods of use.	✓	✓	✓	✓
c) Simple and Intuitive Use	i) Create a user interface layout that is easy to learn. The interface design layout of the system should be simple and clean, and navigation should be easy, consistent, and visible at all times. ii) Use icons clearly for user interface design. iii) Avoid a lot of text on the user interface design	✓	✓	✓	✓
d) Perceptible Information	i) Use different multisensory modalities such as visual, audio, and tactile to deliver important information. For example, using different methods for children with dyslexia to learn to read can stimulate their brains, thus enhancing learning by having textures on the letters to engage the child. ii) Provide and deliver easy and quick information to understand without interruption. iii) Use fonts type that is suitable for children with dyslexia.	✓	✓	✓	✓

e) Tolerance for Error	i) Allows errors to be reversed or minimized; for example, audio feedback message	✓	✓	✓	✓
f) Low Physical Effort	i) Instruction is designed to reduce the constant physical effort to allow maximum attention to learning. For example, reducing repetitive actions. The design can be used efficiently and comfortably and reduces fatigue. ii) The design features of 3D tangible letters must be: – hand-sized and made of a lightweight and safe material. – the letter should be easy to pick up and hold by children with dyslexia. – Letters must stand up on their own so that the children can easily organize them in space. – Have plenty of space on the table to place all the letters	✓	✓	✓	✓
g) Size and Space for Approach and Use	i) The size of 3D tangible letters should be easy for children with dyslexia to manipulate, arrange, and control. ii) The spelling board should have adequate space for the letters to be placed.	✓	✓	✓	✓

Notes
TA: Teacher A
TB: Teacher B
TC: Teacher C
TD: Teacher D

Therefore, this study adapted UD principles within the TUIs design concept. This is because UD works for everyone rather than categorising people into personas or groups hence making the guideline more robust. In other words, an opportunity to learn in a style that best matches a child with different abilities should be provided. Hence, TUIs are potential options when incorporating technology so that children can be more engaged in their learning sessions.

In addition, UD principles will consider all of the different experiences and provide a design that is suitable for everyone. As a result, the seven principles can be adopted as general guideline for TUI design to assist developers and researchers for developing a good experience in learning for children with dyslexia.

4.10 Qualitative Discussion

The section presents a recap of the research findings in line with the objectives of the study. The main objective of this study is to analyse the TUIs design components specifically for children with dyslexia learning to read in Malay. This section discusses the research findings, focusing on the eight key themes identified during focus group sessions. Table 4.5 summarises the eight essential themes aforementioned.

Table 4.5

Eight essential themes from focus group findings

Profile - children with dyslexia	Characteristics features of children with dyslexia
	Challenges of children with dyslexia in learning
	Subjects and personal interests of children with dyslexia
Learning content	Learning contents
Learning styles	Learning styles
Design features of TUIs	3D tangible letters
	Dynamic colour cues
	Texture Cues
IxD Elements & Dimensions	a) Audio (3D) b) Praises (3D) c) Colourful Interface (2D) d) Linear Navigation (1D) e) Help icon button with audio (2D) f) Static images (2D) g) Icon with text label (2D) h) Voice-over for each instruction (3D)
UD principles	a) Equitable Use b) Flexibility in Use c) Simple and Intuitive Use d) Perceptible Information e) Tolerance for Error f) Low Physical Effort g) Size and Space for Approach and Use

4.10.1 Characteristic features of Children with Dyslexia

The study identified four main characteristics of children with dyslexia: having difficulties recognising an accurate and fluent word and a lack of spelling, decoding, and encoding abilities. These findings are further supported by Abd Rauf, Ismail, Balakrishnan, et al. (2018) that the primary characteristic features of children with dyslexia are having difficulties in spelling, reading, writing, doing simple calculations, and differentiating words in reverse, such as on-no. The findings also found that children with dyslexia often tend to forget what they have learned before, as evidenced in studies by Hebert, Kearns, Hayes, et al. (2018). This is because the students can only focus for up to half an hour throughout their learning.

Overall, there seems to be some evidence to indicate that children with dyslexia have difficulty remembering orthographic patterns, and this difficulty is caused by an inability to process the phonological information and link it with the visual components of the orthography (i.e., letter order) (Herbert et al., 2018). Sahari and Johari (2012) revealed that children with dyslexia would forget the word and its meaning in the larger context of the sentence or paragraph. This study also found that children with dyslexia are slow learners compared with normal children. This finding further supports the notion Shaywitz, Skudlarski, Holahan, et al. (2007) described a few characteristics of children with dyslexia including slow progress in reading skills, slow writing, terrible spelling, and having a history of reading, spelling, and foreign language problems in family members.

4.10.2 Challenges of children with dyslexia in learning

Regarding learning challenges for children with dyslexia, the findings showed that the standard education curriculum is relatively high and difficult for children with dyslexia to follow. Another commented on the existing Mathematics curriculum, stating that teaching the value of million numbers to children with dyslexia is challenging. In fact, children with dyslexia tend to show slow progress in reading, especially in the Malay language. These findings align with a previous study that indicated fluency OF children with dyslexia in mastering Malay language reading is influenced by their reading problems Subramaniam, Mallan, & Mat (2013). On the other hand, the study found that children with dyslexia must be able to read to learn all subjects. The findings concluded that such challenges faced by children with dyslexia could be addressed with an interactive learning process to ensure they can learn like normal children. As a result, TUIs have the potential to improve learning processes for children with dyslexia by promoting interactive and engaging learning experiences (Fan et al., 2017).

4.10.3 Subjects and Personal Interests of Children with Dyslexia

In response to the personal interest of children with dyslexia, slow learners tend to participate in outdoor activities, and they are physically active. Even though outdoor activities are excluded from the class schedule, the teachers often permit them to do outdoor activities for about 15 minutes to reduce their stress. Besides that, children with dyslexia love participating in learning activities through online Quizizz (internet application). They are more attracted to learning online videos through YouTube (online video sharing).

4.10.4 Learning Contents

Meanwhile, appropriate learning content is essential to enhance the learning process of children with dyslexia (Jamali et al., 2018). The findings showed that children with dyslexia mostly fail to recognise letters until syllables because they are unaware of a wide range of syllables. The findings indicate that letter recognition and syllable spelling are two types of learning content in the Malay language suitable for children with dyslexia. In addition, the words for learning content comprise all types of Malay language (BM) syllables patterns selected from the *Program Pemulihan Khas: Buku Panduan Pengajaran dan Pembelajaran Bahasa Melayu.*

4.10.4 Learning Styles

In terms of learning style, this study found that structured activities, clear instruction, repetition activity, step by step, and flexible are suitable for children with dyslexia. According to Subramaniam and Nasir (2020), children with dyslexia have short-term memory; therefore, the activities should be repeated from time to time so that they will not forget their lesson. The findings conclude that a flexible learning style allows children with dyslexia to apply learning according to the need of the individual learners. The style emphasizes different levels of achievements, and the learners can participate according to their capability when using the TUI prototype.

4.10.5 Design features of TUIs

For the design features of TUIs, the findings reveal that the design features of TUIs which assist the students in the reading process are 3D tangible letters, dynamic colour cues, and texture cues. Hence, the 3D tangible letter size with a height of 7 centimetres, a width of 6 centimetres, and a depth of 2.5 centimetres are appropriate for children with dyslexia to hold and feel the letters' shape. In addition, two sets of consonant letters with vowels provided for children with dyslexia.

According to Jung and Stolterman (2010), physical objects (3D tangible letters) contain a wealth of visual and tactile information such as size, shape, colour, and texture. For instance, when a child places one or more tangible letters on a tangible tabletop, the related digital information for the letter sound(s) and 3D letter(s) in the same spatial order will appear on the screen straight away. The spatial consistency of physical-digital mappings in TUIs may facilitate clear letter-sound connections, specifically significant for children with dyslexia.

In addition, the study revealed that the students are more attracted to colours during learning, however the letters need to be in soft colour instead of bright. The findings further confirmed that dynamic colour cues help to improve the learning process for children with dyslexia. Accordingly, the 3D tangible letters with embedded dynamic colour cues help the children give more attention when the sounds of letters change appear compared to the static letter colours (Cramer et al., 2016; Fan et al., 2016b). This finding further supports the notion of Sahari and Johari (2012) that employing different colours for different letters or syllables assists children and children with dyslexia in distinguishing between letters and syllables.

On the other hand, the use of textures cues is helpful for children with dyslexia to improve reading performance better. The results suggested that the felt fabric to be applied to the 3D tangible letters. The association between textures (on the letter shapes) and letter sounds may act as affordances to efficiently support children with dyslexia learning letter-sound (Fan & Antle, 2015). Bara, Gentaz, & Colé (2007) suggested that the multiple cues naturally embedded in the physical letters (e.g., colour, shape, and texture) add value in learning letter-sound correspondences.

4.10.6 Interaction Design

The findings showed that the IxD with suitable design in TUIs fitted for children with dyslexia in learning to read, as summarised in Section 4.7 of Chapter 4. In relation to the type of feedback, IxD elements that need to be integrated in the system for children with dyslexia are audio and praises. A digital audio signal (*beep*) attached when the students answer the question incorrectly. In addition, the praise setting when the students provide answer incorrectly helps to boost their motivation to complete tasks and give satisfaction with their accomplishments (Jamali et al., 2019).

In terms of design elements and system structure based on IxD, a colourful interface layout, a help icon with audio, an icon with a text label, and a static image integrated into the system. The following study by Husni and Jamaludin (2013) further highlighted that playing with colours appears to be a potential solution that could help children with dyslexia leverage their reading or make it easier for them to read. Static images used in the learning contents to avoid distraction during their learning process.

Moreover, the TUIs designed using eight colours recommended by Irlen (2005). The design for the TUIs prototype interface applied the colours proposed by Irlen to help children with dyslexia to read. In addition, this study found that soft colours are suitable for the interface design. In a similar vein, the voice-over for each instruction is required to help children with dyslexia during learning activities. This finding is further supported by Aziz et al. (2013), who found that children with dyslexia need to be provided with audio outputs such as narrator voices which will help to read out instructions. Previous studies highlighted those children with dyslexia give good attention during learning sessions with the help of suitable voice instructions (Azmi, Nasrudin, Wan, et al., 2017).

4.10.7 Universal Design Principles

Regarding reading difficulties, the relationship between UD and IxD is to produce a good design for children with dyslexia. In fact, UD has been used extensively as an approach to education and learning. Based on Table 4.4 summarised in Section 4.8.1, there are seven principles of UD with suitable design in TUIs are proposed; (1) equitable use; (2) flexibility in use; (3) simple and intuitive use; (4) perceptible information; (5) tolerance for error; (6) low physical effort; and (7) size and space for approach and use. The suitable design in TUIs is specified based on previous studies by Dubuc and Edge (2006).

According to principle 1 (Equitable Use) in the UD, setting up a design for children with dyslexia must perfectly cover all other children's learning needs without separating them into groups or individuals. For example, children with dyslexia should be allowed to study in the way that best suits them (Reid, Strnadová, & Cumming, 2013). A flexible learning style will help children with dyslexia practice learning based on the child’s individual needs, as mentioned in principle 2 (Flexibility in Use). For instance, allowing children with dyslexia to integrate what they want to learn according to their needs or abilities.

In principle 3 (Simple and Intuitive Use), it is essential to use a simple and clean interface layout (Kous & Polančič, 2019). According to Nielsen & Molich (1990), user interface design should, “minimize the user’s memory load by making objects, actions, and options visible.” Hence, the navigation should be easy, consistent, and visible. For example, necessary information to use the design, such as 'field labels' or 'menu items,' should be visible or easily accessible when required.

Children with dyslexia learns effectively with different multisensory modalities such as visual, audio, and tactile for the delivery of important information as mentioned in principle 4 (Perceptible Information). For example, using different methods for children with dyslexia in learning to read can stimulate their brains, thus enhancing learning by having textures on the letters to engage the child while learning. Besides that, providing and delivering easy and quick information to understand without interruption is necessary for children with dyslexia. The use of appropriate fonts type is required for children with dyslexia to learn very well. According to Zusman (2015), a dyslexia-friendly font can improve readability for children with dyslexia.

Allows errors to be reversed or minimised; for example, an audio feedback message must be integrated into the system, as stated in principle 5 (Tolerance for Error). Based on principle 6 (Low Physical Effort), instruction can be designed to reduce the constant physical effort to allow maximum attention to learning. For example, reducing repetitive actions. The design can be used efficiently and comfortably and reduces fatigue. In addition, Fan et al. (2018) stated that the creation of 3D tangible letters must be hand-sized, made of a lightweight and safe material, easy to pick up and hold by children with dyslexia. Letters must be able to stand up on their own so that the children can easily organize them in space. It is required to have plenty of space on the table to place all the letters to ensure that children with dyslexia can arrange the letter on the spelling board.

Finally, in terms of suitable design for principle 7 (Size and Space for Approach and Use), the size of 3D tangible letters should be easy for children with dyslexia to manipulate, arrange, and control. The spelling board should have adequate space for the letters to be placed. Teachers can help children with dyslexia to focus when inserting 3D letters into the space (e.g., placement in slots) provided. The network diagram based on the qualitative findings of the focus group sessions has been presented in Figure 4.2.

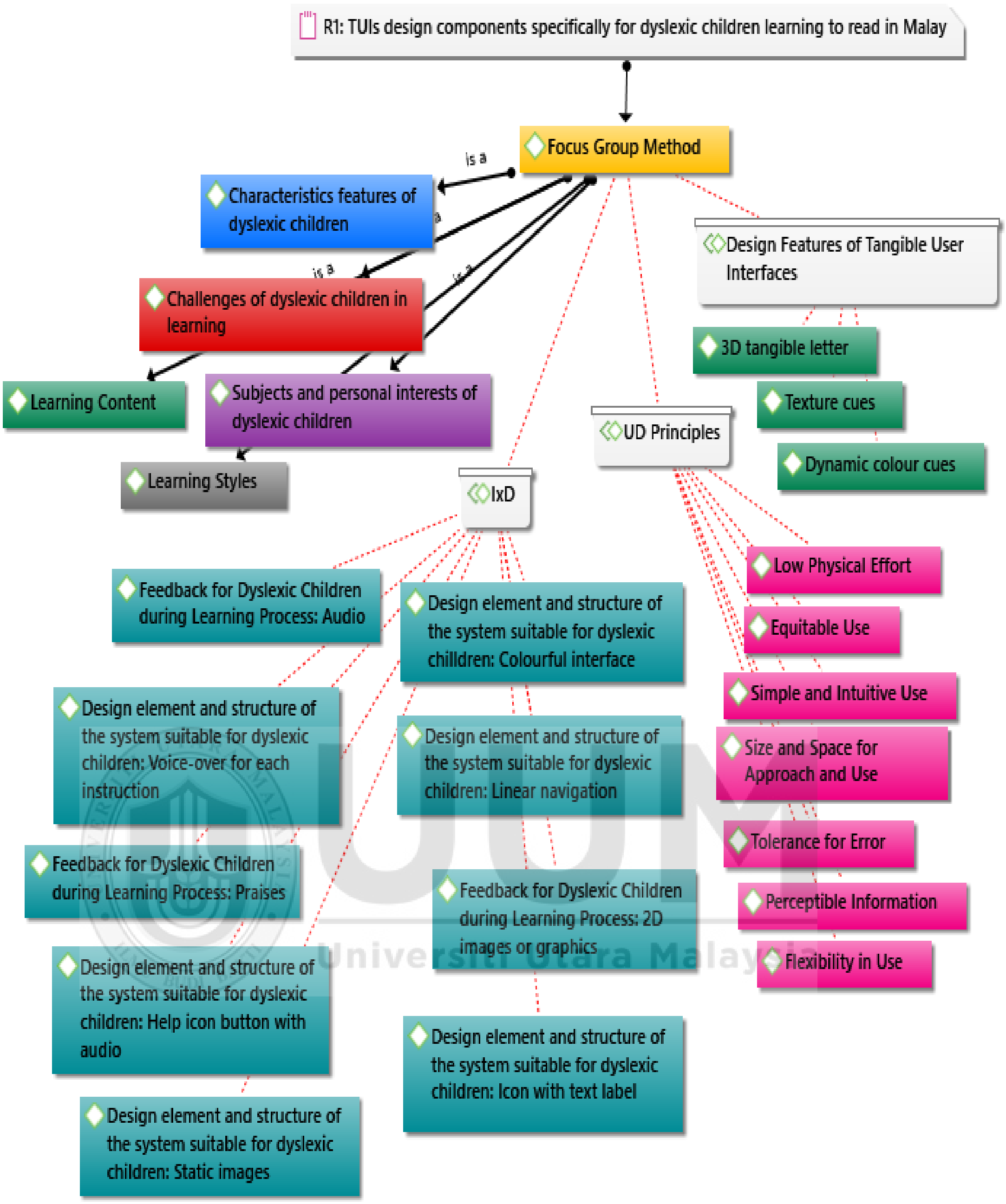

Figure 4.2 Network of Focus Group Findings

4.11 Summary

The qualitative findings of children with dyslexia and the design of TUIs are presented in this chapter. The first section introduced the focus group analysis with special education teachers at Sekolah Kebangsaan Kayang. The respondents provide a wealth of information about children with dyslexia and TUIs. This chapter also reported and analysed the eight themes derived from the focus group. The results are divided into eight categories based on the themes identified through the thematic analysis, including characteristics features of children with dyslexia, challenges of children with dyslexia in learning, subjects and personal interests of children with dyslexia, learning content, learning styles, design features of TUIs, interaction design and universal design principles. Finally, the qualitative discussion of this study addresses the research findings, emphasizing the eight significant themes found during focus groups. The next chapter discussed design guideline creation based on the proposed TUIs framework.

CHAPTER FIVE
TANGIBLE USER INTERFACES FRAMEWORK AND DESIGN GUIDELINE

5.0 Introduction

Following Chapter 4, this chapter presented the constructed TUIs framework and design guideline based on an improved version of Ullmer and Ishii's TUIs framework. The framework and design guideline are discussed in Sections 5.1 and 5.2. The framework and the guideline then undergo a verification process as discussed in Section 5.3. Based on the results of verification (Section 5.4), the revised version of the TUIs framework and design guideline are discussed in Section 5.5.

5.1 The proposed TUIs Framework

This section presents the theoretical framework aligning with the objectives of this study. The TUIs framework is based on Ulmer and Ishii's framework (Ullmer & Ishii, 1997; Ullmer & Ishii, 2008). According to Ishii (2008), using a multisensory method such as kinesthetic gestures and movement is another potential to facilitate learning concepts. Hence, the TUIs framework proposed entails a multisensory interaction with different sensory types such as visual, auditory, and kinesthetics to assist children with dyslexia in their learning.

Figure 5.1 provides an overview of the TUIs framework proposed in this study. The framework comprises both physical and digital layers. By using their hands to receive information in both tangible and intangible representations, children can directly control the underlying digital representations. The tangible representation is computationally connected to the control of underlying digital information.

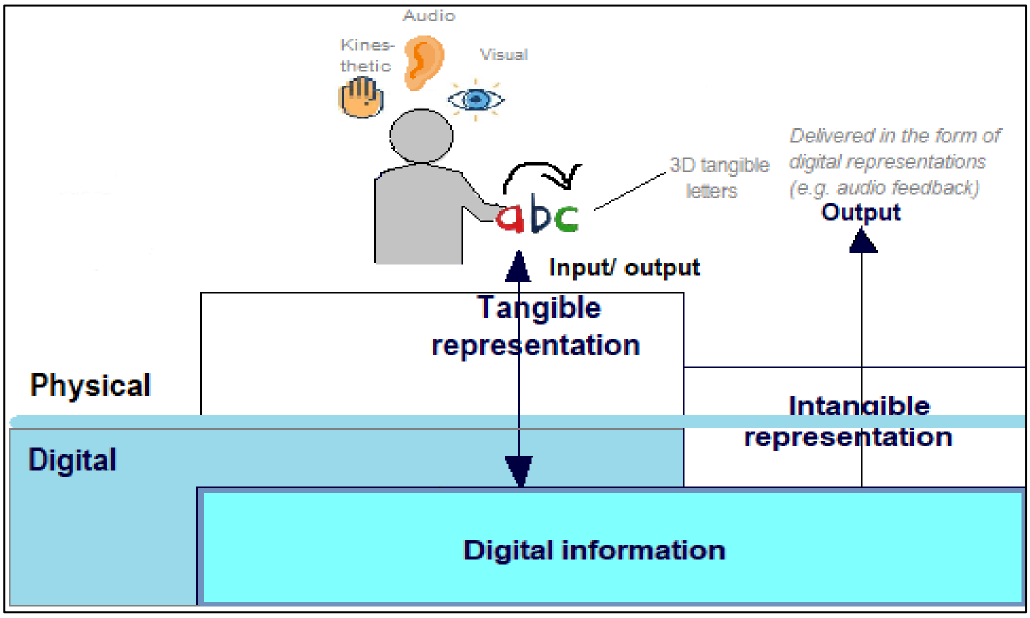

Figure 5.1 The proposed TUIs framework for Children with Dyslexia

Next, tangible representations of TUI, for instance, 3D tangible letters, simultaneously work as an interactive physical control. It can be physically inert, moving solely as manipulated by the hands of a user (Ullmer & Ishii, 2000). The intangible representation of TUI, primarily the visuals and audio, disseminates sufficient dynamic information provided by the underlying computation (see Figure 5.1). According to Antle et al. (2015), a tangible system allows for simultaneous use of visual, audio, kinesthetic, or tactile modalities in both physical (tangible) and digital (intangible) representations.

In this study, the TUIs framework begins with a physical layer involving children with dyslexia interacting with 3D tangible letters through manipulating letters. Following that, different sensory used to connect with intangible representation in a digital layer. The TUIs prototype will recognise the 3D tangible letters as soon as the children place them on the spelling board which holds the letters. Depending on the learning contents (e.g., letter recognition or spelling), the arrangement could be a single letter or a combination of letters to construct a word. This prototype is able to provide children with dyslexia with audio feedback (intangible representation) by playing the letter sound and correctly detecting the word on the screen.

There are three components based on the theoretical framework: tangible representation, intangible representation, and digital information. The suitable design mapping with TUIs framework components is presented in Table 5.1.

Table 5.1.
Suitable design based on framework components.

Framework Component	**Suitable Design of TUI for dyslexia**
Tangible representations (The tangible representations of TUIs function as an interactive physical control)	a) 3D tangible letters b) Dynamic colour cues c) Texture cues d) Font type e) Low physical effort f) Size and space for approach and use g) Equitable use
Intangible representations (Intangible representations are computationally mediated displays that are perceptually observed in the world but are not physically embodied, and thus "intangible" in form.)	a) Audio feedback b) Colour c) Simple and Intuitive Use d) Perceptible Information
Digital information (Digital information is directly manipulatable with our hands and perceptible through our peripheral senses by physically embodying it).	a) Letter recognition b) Syllable spelling c) Linear navigation d) Help icon button with audio e) Static images f) Tolerance for error

TUIs prototype entails learning contents that incorporate letter recognition and spelling activities. TUIs framework implemented based on three supporting learning theories on dyslexia and TUIs. The theories related to learning for dyslexia include the theory of Orton-Gillingham, the theory of dual-coding (Clark & Paivio, 1991), and the theory of kinesthetic. The TUIs framework also considers the suitable learning styles for children with dyslexia as discussed in Section 4.10.4 of Chapter 4. In addition, the universal design principles (Connell et al., 1997) and interaction design theory (Preece, Sharp & Rogers, 2002) have been selected and mapped with the framework components to guide the study.

Finally, the TUIs framework was verified by an expert review. Experts provided comments, which assist in the improvement of TUI's framework. TUIs design guideline created based on the proposed framework to improve learning experiences for children with dyslexia hence facilitating learning to read in the Malay language. The findings of this study used to help construct the design guideline discussed in the following section.

5.2 Design Guideline Creation

This section presents the proposed design guideline development aligning with the second objective. The qualitative data from the focus group were used to address the second research question: "*What would be the TUIs design guideline for children with dyslexia?* "

From the thematic analysis that was conducted, the design guideline was categorised based on the five themes from eight themes identified from the focus group sessions. Three themes have not been selected in the design guideline: characteristics features of children with dyslexia, challenges of children with dyslexia in learning, and subjects and personal interests of children with dyslexia. The three themes have not been chosen in the design guideline because the researcher wants to understand how children with dyslexia learns. The design guideline was constructed based on framework components of TUI, as shown in Figure 5.2.

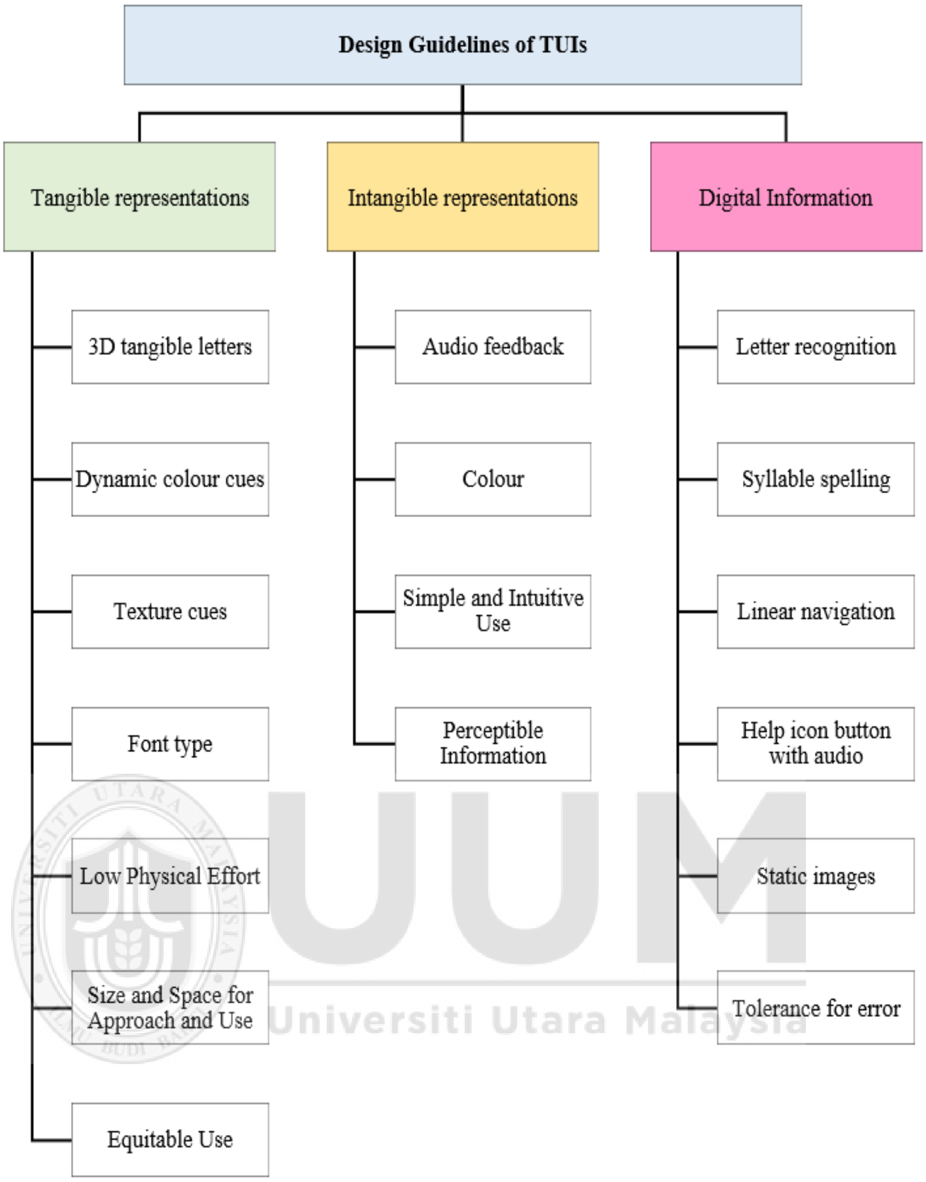

Figure 5.2 The Proposed Design Guideline of TUIs for Children with Dyslexia

The construction of the design guideline of TUIs comprises three main components based on the theoretical framework: (1) tangible representations; (2) intangible representations; and (3) digital information to ensure that the design guideline is suitable for supporting children with dyslexia learning to read in Malay. Table 5.2 describes the framework components and sub-component designs for the proposed design guideline.

Table 5.2
Description of proposed TUIs Design Guideline

Design Guideline of TUIs		
Framework Components	**Sub. components**	**Description**
Tangible representations	1) 3D tangible letters	i) Use letters that can stand up on its own so that the children can easily organize them in space (spelling board).
	2) Texture cues	Use texture cues (felt fabric) on 3D tangible letters to invoke touch sensory response for children with dyslexia
	3) Dynamic colour cues	Use dynamic colour cues embedded in 3D tangible letters to attract children's attention to the moment when letters' sounds change.
	4) Font type	i) Special font type for children with dyslexia using '*papan sintok'* letter shapes. ii) Use lowercase letters to avoid mirrored letters.
	5) Low Physical Effort	i) Instruction is designed to reduce the constant physical effort to allow maximum attention to learning. For example, reducing repetitive actions. The design can be used efficiently and comfortably and reduces fatigue. ii) The design features of 3D tangible letters must be: – hand-sized and made of a lightweight and safe material. – the letter should be easy to pick up and hold by children with dyslexia. – Letters must stand up on their own so that the children can easily organize them in space. – Have plenty of space on the table to place all the letters
	6) Size and Space for Approach and Use	i) The size of 3D tangible letters should be easy for children with dyslexia to manipulate, arrange, and control. ii) The spelling board should have adequate space for the letters to be placed.
	7) Equitable Use	Setting up a design (hand-size physical object) for children with dyslexia must perfectly cover all the learning needs of other children without separating them into groups or individuals.

Intangible representations	**1)** Audio feedback	i) Use audio feedback such as voice-over for each instruction. ii) Use a signal sound like "try again" for them to get motivated to do the question again when they make a mistake. iii) Use applause sounds (praise) to provide satisfaction when they correctly answer the question.
	2) Colour	i) Use colourful interface background colour code. ii) The colour should be in contrast to the background, so that the colour of the letters should be a little brighter.
	3) Simple and Intuitive Use	i) Create a user interface layout that is easy to learn. The interface design layout of the system should be simple and clean, and navigation should be easy, consistent, and visible at all times. ii) Use icons clearly for user interface design. iii) Avoid a lot of text on the user interface design.
	4) Perceptible Information	i) Use different multisensory modalities such as visual, audio, and tactile to deliver important information. For example, using different methods for children with dyslexia to learn to read can stimulate their brains, thus enhancing learning by having textures on the letters to engage the child. ii) Provide and deliver easy and quick information to understand without interruption. iii) Use children with dyslexia specified fonts type.
Digital Information	1) Letter recognition	The first content focuses on letter recognition which applies O-G learning theory and dual coding theory, by which children with dyslexia recognise the letters and associate them with images of the letters while learning.
	2) Syllables spelling	Identify the syllables based on the sound of letters. Children with dyslexia will adopt O-G theories and kinesthetic theories in this learning content. This will allow children with dyslexia to arrange and use different senses to manipulate the tangible letter applied by kinesthetic approaches.
	3) Linear Navigation	Use linear navigation in the TUI prototype.
	4) Help icon button with audio	Provide a help icon button with audio (audio help)

	5) Static images	Use a static image in the learning contents for children with dyslexia.
	6) Tolerance for error	Allows errors to be reversed or minimized; for example, audio feedback message.

In addition, it gives an overview of the learning support for children with dyslexia through the tangible representations, including 3D tangible letters, dynamic colour cues, texture cues, suitable font type, low physical effort (UD principle), size and space for approach and use (UD principle) and equitable use (UD principle). The design guideline also considers the suitable learning theories (Section 2.2) and design theories (IxD and UD principles), as discussed in Chapter 2.

The fundamental advantage of UD is that it promotes everyone's usefulness by addressing the diverse needs of special populations. However, following the UD principles, it can improve the experience of all users by providing ease of use and well-being. Based on UD principles, most technologies and interfaces are the same for all users. Hence, developers should consider what designs can be universalized to serve a large audience without dividing them into groups or individuals (Yang et al., 2013).

Experts verify TUIs design guideline and provide suggestions and comments to help improve the TUIs design guideline. After the expert verification, the prototype is developed in line with TUIs design guideline.

5.2.1 Tangible representations

The tangible representations of TUIs functions as an interactive physical control (Ishii, 2008). Hence, the guideline specifies seven different sorts of tangible representations, including 3D tangible letters, texture cues, dynamic colour cues, font type, equitable use (UD principle), low physical effort (UD principle), and size and space for approach and use (UD principle). The 3D tangible letters are a solid tangible letters with three dimensions (3D) shape and can stand up on its own so that the children with dyslexia can simply organize them on the spelling board. In addition, the letter size and material were chosen to allow a child to easily grasp, hold, and play with a letter with their hands or line them up on a table.

In terms of font type, the special font type (*e.g., Papan sintok)* requested by teachers utilised since it can overcome mirror letters for children with dyslexia. Words should be displayed in large font sizes and lowercase characters to make reading easier for children with dyslexia. For children with dyslexia, lowercase 3D tangible letters are required. This is because they are capable of picking up the letters at the beginning rather than words. After all, they have difficulties tracing letters.

For children with dyslexia, the use of colour will make learning more exciting. According to special education teachers, dynamic colour cues can improve student learning results since children are more interested in colours during learning. The term "dynamic" refers to the fact that the colour of a letter at a specific place might change during activity and that the change is apparent to children (Cramer, 2012). As a result, the colour for vowel letters should be opposite that of consonant letters to help children focus on learning content while avoiding extraneous information.

Meanwhile, the texture cues attached to the 3D tangible letters since special education teachers have stated that including textures cues during the learning process might invoke touch sensory in children with dyslexia. Children with dyslexia need multisensory interaction to stimulate their brains and learn effectively through the use of textures, which will help them improve their reading results.

Additionally, according to Principle 1 (Equitable Use), the design for children with dyslexia must fulfil all of the learning requirements of other children without grouping or individualising them. As a result, special education teachers recommended that the appropriate design of 3D tangible letters be in a hand-size physical object that children with dyslexia can hold while also appealing to all users' sense of play with their hands.

In terms of tangible representation based on UD principles, the instruction should minimise the constant physical effort to allow maximum concentration throughout learning, according to principle 6 (Low Physical Effort). Reducing repetitive actions, for example, will assist children with dyslexia in learning more comfortably and reducing fatigue. Furthermore, the design of 3D tangible letters must be hand-sized and built of a lightweight and safe material that is easy for children with dyslexia to pick up and hold. The 3D tangible letters must be able to stand on their own so that the children can arrange them in space. Children with dyslexia require enough table space to set all letters and place them on the spelling board.

Principle 7 (Size and Space for Approach and Use) necessitates 3D tangible letters to be light, easy to touch, move, arrange, and manipulate by children with dyslexia to help them learn to read. Teachers can assist children with dyslexia in focusing by allowing them to place 3D letters into the space (spelling board) provided. Hence, the size of the letter block is 7 centimetres in height, 6 centimetres wide, and 2.5 centimetres thick produced as suggested by the special education teachers. Moreover, they mentioned that two sets of consonant letters with vowels are needed.

5.2.2 Intangible Representations

Intangible representations are computationally mediated displays that are perceptually observed in the world but are not physically embodied, and thus “intangible” in form

(Ullmer & Ishii, 2008). A balance of tangible and intangible representations is required for tangible interfaces. Although embodied tangible aspects play a major, defining function in the representation and control of a TUI, the TUI's intangible representation plays a supporting role. Much of the dynamic information provided by the underlying computing is often mediated by the TUI's intangible representation (e.g., visuals and audio). As a result, intangible representation can complement tangible representation by synchronising with it.

Hence, the guideline outlines five types of intangible representations: audio feedback, praise, colourful interface, simple and intuitive use (UD principle), and perceptible information (UD principle).

In terms of intangible representation, children with dyslexia are able to obtain audio feedback by correctly recognising the word on the screen and playing the letter sound. In addition, to make learning easier for children with dyslexia, audio output, such as voice-over, is required for each instruction. When children with dyslexia give the correct answer during a learning activity, the applauding sound (praise) integrated into the system. A signal sound like "try again" will encourage them to perform the question again if they make a mistake.

Regarding the use of colour in TUIs design, children with dyslexia love the colourful interface layout. As a result, the suggested colour code by Irlen (2005) used to 'cure' visual problems for children with dyslexia. Furthermore, the colour of the letters should contrast with the background, making the letters appear brighter.

In terms of intangible representations based on UD principle, the user interface design should be simple and intuitive to understand, according to principle 3 (Simple and Intuitive Use). Additionally, navigation should be easy, consistent, and visible. For children with dyslexia to focus during a learning activity, the icons must be clear, and there should be no excessive text on the user interface.

Principle 4 (Perceptible Information) suggests that different multisensory interactions (e.g., visual, audio, and tactile) are required to provide important information to children with dyslexia to master basic reading abilities such as letter recognition and spelling. For example, utilising different methods to teach children with dyslexia to read can stimulate their brains, enhancing learning by incorporating textures on the tangible letters. Furthermore, a font type suitable for children with dyslexia is required to overcome mirrored letters for effective reading outcomes.

5.2.3 Digital Information

TUI enables users to interact with digital information in their physical surroundings. Digital information is directly manipulatable with our hands and perceptible through our peripheral senses by physically embodying it (Ishii, 2008). TUI attempts to embody the digital information in physical form, maximizing the directness of information by coupling manipulation to the underlying computation. Therefore, the guideline comprises two learning content including letter recognition and spelling. The guideline utilises TUIs with multisensory methods such as audio, visual, and kinesthetic to help children with dyslexia with different sensory types difficulties. According to Sarudin et al. (2019), the multisensory method assists children with learning disabilities in one or more areas, including reading, spelling, and writing.

O-G theory, dual coding theory, and kinesthetic theory are three learning theories that support the study on dyslexia and TUIs. According to dual coding theory, multiple modalities can help learners grasp and recall information better. This is due to the fact that the more representations that encode an event, the more ways children have to recall it (Clark & Paivo, 1991; Sadoski & Paivio, 2004).

Hence, the first content focuses on letter recognition which applies O-G learning theory and dual coding theory, by which children with dyslexia recognise the letters and associate them with images of the letters while learning. The second learning content is spelling which identifies the syllables based on the sound of letters. Children with dyslexia adopt O-G theories and kinesthetic theories in this spelling section. This allows children with dyslexia to arrange and use different senses to manipulate the 3D tangible letters applied by kinesthetic theories.

Since all children with dyslexia have different reading levels, all teachers selected 24 syllables patterns in the Malay language listed in the *Program Pemulihan Khas: Buku Panduan Pengajaran dan Pembelajaran Bahasa Melayu.* Words from textbooks and the *Program Pemulihan Khas: Buku Panduan Pengajaran dan Pembelajaran Bahasa Melayu* that match each group of syllable patterns in Malay language chosen at random. Table 5.3 exemplifies the words listed based on syllables patterns.

Table 5.3
Example of words according to syllable patterns of consonant-vowel categories

Syllable Pattern	Word	Syllable Pattern	Word
1. V+CV	*ibu*	13. V+CVCC	*udang*
2. CV+CV	*buku*	14. CVC+CVCC	*bintang*
3. CV+CV+CV	*kereta*	15. CVCC+CV	*bangku*
4. CVC	*beg*	16. CVCC+CVC	*cangkul*
5. V+CVC	*epal*	17. CVCC+CVCC	*longkang*
6. CV+CVC	*ketam*	18. CV+CV+CVCC	*tempurung*
7. CVC+CV	*bendi*	19. CV+CVC+CVCC	*selendang*
8. CVC+CVC	*landak*	20. CVC+CV+CVCC	*pendatang*
9. CV+CV+CVC	*basikal*	21. CVCC+CV+CVC	*bangsawan*
10. CVC+CV+CVC	*cempedak*	22. CV+CVCC+CVC	*belangkas*
11. CVCC	*rung*	23. Word with diphthong dan paired vowel / *Perkataan yang melibatkan diftong dan vokal berganding*	*air*

12. CV+CVCC	*kucing*	24. Words with joined consonant letters (digraphs) / *Perkataan yang melibatkan huruf konsonan bergabung (digraf)*	*bunga*

In terms of digital information based on IxD, children with dyslexia must be provided with essential support in the TUI prototype; a help function has to be in the form of an audio (icon button with audio). To materialise dyslexia-friendly design, linear navigation is vital for children with dyslexia to learn more effectively.

In addition, special education teachers indicated that utilising a static image in the learning content is preferable for children with dyslexia than employing animation, which can cause them to become distracted while learning. In the meantime, a text label needs to be positioned near an icon to convey its meaning in that specific context to make learning easier for children with dyslexia. Icon with text labels should be displayed at all times, even if the user does not interact with them.

Regarding the digital information based on UD principles, the TUIs prototype allows errors to be reversed or minimised in accordance with principle 5 (Tolerance for Error); for example, the audio feedback message is integrated into the prototype. The next section discussed the verification process of the framework and design guideline of TUIs.

5.3 Verification of Framework and Design Guideline using Expert Review

Expert review was conducted to verify the proposed framework and design guideline of TUIs in this study. There are three components of theoretical framework verification consist of tangible representation, intangible representation, and digital information. The construction of the design guideline of TUIs is revised based on the analysed framework components and sub-components to ensure the design guideline is appropriate for assisting children with dyslexia in learning to read in Malay.

Overall, seven experts (six arts and design experts, and one HCI experts) are involved in the verification process of framework and design guideline of TUIs for children with dyslexia. According to Holzinger (2005), three to five experts are considered sufficient in this process, and not fewer than three are recommended. They were named as Expert A, B, C, D, E, F and G due to their confidential status. The information on the experts' backgrounds is summarised in Table 5.4.

Table 5.4.
Summary of Experts Background

Expert	Academic Qualification	Specialization	Years of Experience
A	Master’s degree	Product design (educational for dyslexia)	16
B	Master’s degree	Product design (educational)	13
C	Master’s degree	Automotive and product design	5
D	Master’s degree	Furniture design and product design prototyping	10
E	Master’s degree	Product and furniture design	9
F	Ph.D.	Automotive design and virtual prototyping	15
G	Ph.D.	Human computer interaction (HCI), multimedia and e-learning	5

The questionnaires were self-administered by the researcher to the experts. The researcher provided an explanation to the experts before answering the questionnaire. Throughout this stage, the experts provided their suggestions and comments towards the guideline for further improvement. The findings from verification of framework and design guideline are discussed in the next subsection.

5.4 The Verification Results

This section presents the descriptive analysis of TUIs framework and design guideline. The perception of the experts provides detailed insight on the TUIs for children with dyslexia. There are four components in the framework and guideline were verified by the experts which are tangible representations, intangible representations, digital information verification and framework review. The final section summarised overall verification results for all four components of the guideline. The questionnaire data were analysed using the Statistical Package for Social Science (SPSS version 20.0).

5.4.1 Tangible Representations

Tangible representations are measured by using seven items. Based on Table 5.5, the result reveals that the mean values of the tangible representations namely 3D tangible letters, texture cues, dynamic colour cues, font type, low physical effort, size and space for approach, and equitable use range between 3.71 and 4.42, with standard deviations 0.53 and 0.89 respectively.

Table 5.5
Descriptive Statistics of Tangible Representations

Items	Code	N	Min	Max	Mean	SD
1. 3D tangible letters	TR1	7	3.00	5.00	4.1429	.89974
2. Texture cues	TR2	7	3.00	5.00	3.7143	.75593
3. Dynamic colour cues	TR3	7	3.00	5.00	4.1429	.69007
4. Font type	TR4	7	4.00	5.00	4.4286	.53452
5. Low physical effort	TR5	7	3.00	5.00	3.8571	.69007
6. Size and space for approach	TR6	7	4.00	5.00	4.4286	.53452
7. Equitable Use	TR7	7	4.00	5.00	4.2857	.48795
	Valid N (listwise)	7				

The average mean value and standard deviations of the tangible representations indicate a moderate agreement of the majority of experts. Therefore, the results imply that these tangible representations are appropriate for assisting children with dyslexia in learning to read in Malay. In addition, further improvements on this component are required in light of expert comments.

5.4.2 Intangible Representations

Table 5.6 shows the results of intangible representations. Intangible representations are measured by using eleven items namely a) audio feedback: voice-over for each instruction; b) audio feedback: signal sound; c) audio feedback: applause sound; d) colour: colourful interface layout; e) colour: the colour of the letters should be in contrast to the background; f) simple and intuitive use: user interface layout that is easy to learn; g) simple and intuitive use: use icons clearly; h) simple and intuitive use: avoid a lot of text on the user interface; i) perceptible information: use different multisensory modalities to deliver important information; j) perceptible information: provide and deliver easy and quick information; k) perceptible information: suitable font type.

Table 5.6
Descriptive Statistics of Intangible Representations

Items	Code	N	Min	Max	Mean	SD
1. Audio feedback: voice-over for each instruction.	IR1	7	4.00	5.00	4.5714	.53452
2. Audio feedback: signal sound	IR2	7	3.00	5.00	4.2857	.75593
3. Audio feedback: applause sound	IR3	7	4.00	5.00	4.5714	.53452
4. Colour: use colourful interface layout	IR4	7	2.00	5.00	3.8571	1.06904
5. Colour: the colour of the letters should be in contrast to the background.	IR5	7	3.00	5.00	4.5714	.78680
6. Simple and intuitive use: user interface layout that is easy to learn.	IR6	7	4.00	5.00	4.4286	.53452
7. Simple and intuitive use: use icons clearly	IR7	7	4.00	5.00	4.7143	.48795
8. Simple and intuitive use: avoid a lot of text on the user interface.	IR8	7	4.00	5.00	4.5714	.53452
9. Perceptible information: use different multisensory modalities to deliver important information.	IR9	7	4.00	5.00	4.5714	.53452

10.	Perceptible information: provide and deliver easy and quick information	IR10	7	3.00	5.00	4.2857	.75593
11.	Perceptible information: suitable font type	IR11	7	4.00	5.00	4.7143	.48795
		Valid N (listwise)	7				

As shown in Table 5.6, the mean score for those items ranges from 3.85 to 4.71, which reflects the agreement level toward these items. The results shows that the mean values of each item for intangible representations is agreed upon by a majority of those experts. Items of IR7 and IR11 have the highest mean values at 4.71 while the standard deviations are within range from 0.48 to 1.06 for all items. The results found that majority of the experts agreed with the design of the intangible representation for children with dyslexia.

5.4.3 Digital Information

Letter recognition, spelling, linear navigation, audio help icon button, static images, and error tolerance are all components of digital information. According to Table 5.7, the highest mean value is 4.42 for items DI3 and DI4, and the lowest value is 4.14 for items DI1, DI2, and DI5, with standard deviations of 0.37 and 0.89, implying that the majority of experts agreed with the design of digital information.

Table 5.7.

Descriptive Statistics of Digital Information

	Items	Code	N	Min	Max	Mean	SD
1.	Letter recognition	DI1	7	3.00	5.00	4.1429	.89974
2.	Spelling	DI2	7	3.00	5.00	4.1429	.69007
3.	Linear navigation	DI3	7	3.00	5.00	4.4286	.78680
4.	Audio help icon button	DI4	7	4.00	5.00	4.4286	.53452
5.	Static images	DI5	7	4.00	5.00	4.1429	.37796
6.	Tolerance for error	DI6	7	4.00	5.00	4.2857	.48795
		Valid N (listwise)	7				

Thus, the results indicate that experts agreed that the construction of the design guideline of TUIs based on the analysed digital information is appropriate for supporting children with dyslexia learning to read in Malay.

5.4.4 Framework Review

Framework review are measured by using six items. Table 5.8 shows that the mean values of framework review for each item range between 3.71 to 4.57, while the standard deviation values for each item range between 0.48 and 0.75 respectively. The highest value is 4.57 for item FR5 and the lowest value is 3.71 for item FR1.

Table 5.8

Descriptive Statistics of Framework Review

Items	Code	N	Min	Max	Mean	SD
1. The whole framework is clearly presented.	FR1	7	3.00	4.00	3.7143	.48795
2. The framework components in the TUIs framework are defined clearly.	FR2	7	4.00	5.00	4.4286	.53452
3. All relations of the framework components are clearly presented.	FR3	7	3.00	5.00	4.1429	.69007
4. The design of tangible representations as specified in the framework are suitable for children with dyslexia.	FR4	7	3.00	5.00	4.2857	.75593
5. The design of intangible representations as specified in the framework are suitable for children with dyslexia.	FR5	7	4.00	5.00	4.5714	.53452
6. The design of digital information as specified in the framework are suitable for children with dyslexia.	FR6	7	4.00	5.00	4.4286	.53452
	Valid N (listwise)	7				

The framework review's average mean value and standard deviations indicate a level of agreement among the majority of experts. As a result, this framework is appropriate for assisting children with dyslexia in learning to read in Malay. In addition, a few changes based on expert feedback are required, as explained in Section 5.5 in Table 5.11.

5.4.5 Overall Framework and Design Guideline

Table 5.9 shows the mean, standard deviation, minimum and maximum scores of the overall framework and design guideline verification. The results demonstrate that the mean values of the items, namely tangible representations (Tangiblerep), intangible representations (Intangiblerep), digital information (Digitalinfo), and framework review (Framework), range between 4.14 and 4.46, with standard deviations range between 0.38 and 0.51, respectively.

Table 5.9
Descriptive Statistics of Overall Framework and Design Guideline

Items	N	Minimum	Maximum	Mean	Std. Deviation
1. Tangiblerep	7	3.43	4.57	4.1429	.38686
2. IntangibleRep	7	3.82	5.00	4.4675	.43418
3. Digitalinfo	7	3.50	5.00	4.2619	.51691
4. Framework	7	3.67	4.83	4.2619	.49868

The average mean value and standard deviations of the items in the framework review and sub-components of guideline indicate an agreement of the majority of experts. Experts also shared their views and suggestions for further improvement on the proposed framework and design guideline. Therefore, the results indicate that experts agreed that the construction of the design guideline of TUIs based on the analysed framework components is appropriate for supporting children with dyslexia learning to read in Malay. The following section discuss additional comments by the experts on the framework and design guideline verification in the questionnaire.

5.5 Other Results of Framework and Design Guideline Verification

In addition to the results from questionnaire, experts provided their comments and suggestions regarding the proposed framework and design guideline. The experts' comments and suggestions were summarized in Table 5.10. The comments and suggestions of experts are analysed based on framework components and sub-components.

Table 5.10

Other Verification Results of TUIs Design Guideline

Framework Components	Sub. components	Expert	Comments and Suggestions
Tangible representations	3D tangible letters	A	Make sure the edges of the 3D tangible letters are smooth.
		A	Use children with dyslexia -friendly font.
		D	Add sound to each 3D tangible letter (rattling sound).
	Size and Space for Approach and Use	E	Add pattern on one side of the font only to help children arrange better
Intangible representations	Audio feedback	A	Use audio feedback such as voice-over for each instruction (adult voice over -avoid computerised).
	Simple and intuitive use	A	i) Use icons (universal icon) clearly for user interface design.
			ii) Use simple text for children with dyslexiato recognise.
Digital Information	Syllables spelling	A	Use suitable syllabus for children with dyslexia *(Buku Panduan Pengajaran dan Pembelajaran Program Pemulihan Khas Bahasa Melayu)*

In relation to the tangible representations, Expert A, indicated that the edges of the 3D tangible letters need to be smooth and not sharp, and the children with dyslexia - friendly fonts to be used for children with dyslexia. In a similar vein, for size and space for approach and use, Expert D suggested to add sound to each 3D tangible letter. Therefore, children with dyslexia can hear a rattling sound for each letter when they hold or grab the 3D tangible letters. In light of these comments, modifications are made to the 3D tangible letters.

On the other hand, Expert A suggested adult voice-over for each instruction to be adopted rather than computerized audio feedback. Expert A also mentioned that universal icons are better for user interface design and adoption of simple text for children with dyslexia to recognise simple and intuitive use. Furthermore, Expert A stated that too much text will prevent children with dyslexia from focusing on learning activities.

For syllables spelling (digital information), Expert A recommended suitable syllabus for children with dyslexia is adapted from *Buku Panduan Pengajaran dan Pembelajaran Program Pemulihan Khas Bahasa Melayu.* Hence, necessary improvement on suitable design guideline's subcomponents is needed. Table 5.11 shows expert comments and suggestions on the framework review.

Table 5.11
Other Verification Results of TUIs Framework

Framework Review	Expert	Comments and Suggestions
The whole framework is clearly presented.	E	Visual presentation of the framework is a bit confusing at first look
The design of tangible representations as specified in the framework are suitable for children with dyslexia.	C	Need a design consideration
	F	Need finer adjustment
The design of digital information as specified in the framework are suitable for children with dyslexia.	C	Arrangement of symbol (icon) on user interface

Expert C suggested that the framework requires design consideration in terms of tangible representation. In the meantime, Expert F adds comments regarding the necessity for finer adjustment in the design of tangible representations as specified in the framework. Changes to the sub-component of the framework are required in consideration of these comments.

In addition, Expert C mentioned the arrangement of the icon on the user interface concerning the digital information design. He also indicates that the icon in digital information (user interface) should be clear to be displayed to children with dyslexia while doing learning activities. Based on experts' comments, the TUIs framework and design guideline was appropriately modified and discussed in the next section.

5.5 The Revised version of the TUIs Framework and Design Guideline

Following the suggestions and comments given by the experts, the framework and design guideline were adjusted appropriately. After that, a revised version of the TUIs design guideline and framework was constructed. The updated TUIs framework for children with dyslexia is depicted in Figure 5.3.

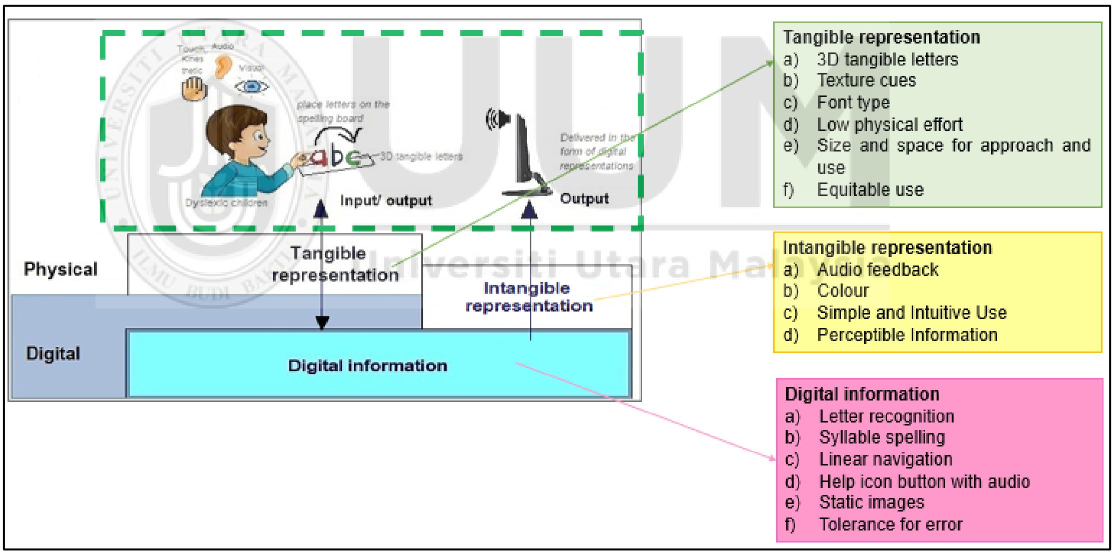

Figure 5.3. The Revised version of the TUIs framework for Children with Dyslexia

In accordance with the comments and suggestions given by experts C, E, and F, the visual representation of the framework has been modified to demonstrate its process flow for a better understanding of how the framework works. Users can identify where to begin and what the next steps are by incorporating a process flow. It shows the process from the physical layer to the digital layer. TUIs framework begins with a physical layer involving children with dyslexia interacting with 3D tangible letters that are computationally connected to the control of underlying digital information.

Another modification to the framework in this study was the design of the tangible representation and digital information. Tangible representation serves as an interactive physical control that is manipulated by the user's hand. The process begins with children with dyslexia holding or grasping the 3D tangible letters with their hands. The 3D tangible letters will then be placed on the provided spelling board. Once the children place the 3D tangible letters on the spelling board, digital information will immediately recognise them. Depending on the learning content (e.g., letter recognition or spelling), the system will then be able to provide audio feedback once the children spell the correct words or place the correct letter.

In a similar vein, it will enable the simultaneous use of several modalities (visual, auditory, kinesthetic, and tactile) in both the physical and digital layers. TUIs enable children with dyslexia to hold, touch or do any other associated action with the letters while at the same time visually stimulating them from the digital world.

Meanwhile, Table 5.12 presents the proposed TUI design guideline, including changes to the framework component's description and TUI sub-components.

Table 5.12.
*Description of proposed TUIs Design Guideline after Expert Verification (*denotes the changes/revision made)*

Design Guideline of TUIs		
Framework Components	**Sub. components**	**Description**
Tangible representations	1) 3D tangible letters	i) Use letters that can stand up on its own so that the children can easily organize them in space (spelling board). *ii) Make sure the edges of the 3D tangible letters are smooth. *****iii) Use children with dyslexia -friendly font.

			*iv) Add sound to each 3D tangible letter (rattling sound).
	2)	Texture cues	Use texture cues (felt fabric) on 3D tangible letters to invoke touch sensory response for children with dyslexia.
	3)	Dynamic colour cues	Use dynamic colour cues embedded in 3D tangible letters to attract children's attention to the moment when letters' sounds change.
	4)	Font type	i) Special font type for children with dyslexia using '*papan sintok'* letter shapes. ii) Use lowercase letters to avoid mirrored letters.
	5)	Low Physical Effort	i) Instruction is designed to reduce the constant physical effort to allow maximum attention to learning. For example, reducing repetitive actions. The design can be used efficiently and comfortably and reduces fatigue. ii) The design features of 3D tangible letters must be: – hand-sized and made of a lightweight and safe material; – the letter should be easy to pick up and hold by children with dyslexia. – Letters must stand up on their own so that the children can easily organize them in space. – Have plenty of space on the table to place all the letters
	6)	Size and Space for Approach and Use	i) The size of 3D tangible letters should be easy for children with dyslexia to manipulate, arrange, and control. ii) The spelling board should have adequate space for the letters to be placed. *iii) Add pattern on one side of the font only to help children arrange better
	7)	Equitable Use	Setting up a design (hand-size physical object) for children with dyslexia must perfectly cover all the learning needs of other children without separating them into groups or individuals.
Intangible representations	1)	Audio feedback	*i) Use audio feedback such as voice-over for each instruction (adult voice over -avoid computerised). ii) Use a signal sound like "try again" for them to get motivated to do the question again when they make a mistake. iii) Use applause sounds (praise) to provide satisfaction when they correctly answer the question.

	2)	Colour	i) Use colourful interface background colour code. ii) The colour should be in contrast to the background, so that the colour of the letters should be a little brighter.
	3)	Simple and Intuitive Use	i) Create a user interface layout that is easy to learn. The interface design layout of the system should be simple and clean, and navigation should be easy, consistent, and visible at all times. *ii) Use icons (universal icon) clearly for user interface design. iii) Avoid a lot of text on the user interface design. *iv) Use simple text for children with dyslexia to recognise.
	4)	Perceptible Information	i) Use different multisensory modalities such as visual, audio, and tactile to deliver important information. For example, using different methods for children with dyslexia to learn to read can stimulate their brains, thus enhancing learning by having textures on the letters to engage the child. ii) Provide and deliver easy and quick information to understand without interruption. iii) Use children with dyslexia specified fonts type.
Digital Information	1)	Letter recognition	Identify vowel and consonant letters which helps children with dyslexia recognise letters and associate them with images of the letters while learning.
	2)	Syllables spelling	i) Identify syllables based on letter sounds. In this learning content, the children with dyslexia are able to arrange and use different senses to manipulate the tangible letters. *ii) Use suitable syllabus for children with dyslexia *(Buku Panduan Pengajaran dan Pembelajaran Program Pemulihan Khas Bahasa Melayu)*
	3)	Linear Navigation	Use linear navigation in the TUI prototype.
	4)	Help icon button with audio	Provide a help icon button with audio (audio help)
	5)	Static images	Use a static image in the learning contents for children with dyslexia.
	6)	Tolerance for error	Allows errors to be reversed or minimized; for example, audio feedback message

Based on Experts A, D, and E's suggestions for 3D tangible letters in Table 5.13, the improvements of sub. components were made. In terms of tangible representation, the edges of each 3D tangible letter need to be smooth and not sharp to be used by children with dyslexia. In addition, the 3D tangible letters use a specified children with dyslexia-friendly font (*papan sintok*) as suggested by Expert A.

Table 5.13.
Additional Modification to Description of proposed TUIs Design Guideline

Sub. components	**Additional Modification to Description**
3D tangible letters	The edges of the 3D tangible letters need to be smooth.
	Use dyslexic-friendly font.
	Add sound to each 3D tangible letter (rattling sound).
Size and Space for Approach and Use	Add pattern on one side of the letter only to help children arrange better
Audio feedback	Use adult voice over audio feedback - avoid computerised).
Simple and intuitive use	i) Use icons (universal icon) clearly for user interface design.
	ii) Use simple text for dyslexic children to recognise.
Syllables spelling	Use suitable syllabus for dyslexic children (Buku Panduan Pengajaran dan Pembelajaran Program Pemulihan Khas Bahasa Melayu)

Previously, the design of 3D tangible letters did not have any sound. However, a new design for the 3D tangible letters produced with a hollow at the base of the letters since experts advise giving each letter a sound (rattling sound). The hollow will then be filled with tiny objects like green beans or rice to produce the sound. In addition, for size and space for approach and use, a pattern added to one side of the 3D tangible letters to help children arrange the letters better.

In addition, the revised version of the design guideline for intangible representations was modified as required. The use of audio feedback, such as voice-over, for each instruction use adult voice-over rather than computerised voice-over. In order to create a user interface that is simple and intuitive, the researcher uses a universal icon.

Another important suggestion is to use simple text to help children with dyslexia focus during learning activities. As a result, the user interface design should be simple and easy to understand. Focusing on the digital information in Table 5.12, the syllables spelling is using a suitable syllabus for children with dyslexia that adapted from *Buku Panduan Pengajaran dan Pembelajaran Program Pemulihan Khas Bahasa Melayu.*

The other findings from the verification indicate that modifications are required for the sub-components of tangible representations, intangible representations, and digital information as depicted in Table 5.13. Enhancements to the framework's process flow are also necessary, including the relationships between framework components, as depicted in Figure 5.3 and Table 5.12.

5.4 Summary

This chapter discussed the process before and after the framework and guideline were verified, including explanations for the designated framework components and sub-component designs for the proposed design guideline. The theoretical framework consists of three components: tangible representation, intangible representation, and digital information. Based on the proposed framework, TUIs design guideline are developed. The design guideline of TUIs comprises three main components based on the theoretical framework to ensure that the design guideline is suitable for assisting children with dyslexia in learning to read in Malay. In this chapter, the quantitative findings related to the framework and design guideline are also discussed. The proposed framework and design guideline for TUIs were verified by a total of seven experts. The findings from the descriptive analysis revealed that the researcher should improve the framework and design guideline in light of the moderate results. According to the other verification results of TUIs design guideline and framework, changes to the sub-components are required. After that, a revised version of the TUIs framework was developed based on expert feedback. The modifications of the revised framework were also discussed in this chapter. Additional changes were made to the sub-components of the design guideline, such as digital information, intangible representations, and tangible representations. The prototype development in this study discussed in the following chapter.

CHAPTER SIX

THE PROTOTYPE DEVELOPMENT AND VALIDATION

6.0 Introduction

This chapter discussed the TUIs prototype that was developed based on the constructed TUIs design guideline as discussed in Chapter 5. The prototype design is discussed in Sections 6.1. The hardware and software parts of the TUIs prototype are discussed in Sections 6.1.1 and 6.1.2. The following section discussed the TUIs prototype, which undergoes validation with children with dyslexia, as well as the results and discussions. Finally, a summary concludes this chapter.

6.1 The Prototype Design

The TUIs prototype aims to provide children with dyslexia with learning basics reading skills with multisensory methods such as audio, visual, and kinesthetic to help children with dyslexia with different sensory types of difficulties. This prototype was developed based on TUIs design guideline specifically for children with dyslexia in learning to read in Malay. Hardware and software details of the prototype design are covered in Sections 6.1.1 and 6.1.2, respectively.

6.1.1 Hardware

26 lowercase 3D tangible letters were designed using SolidWorks software as shown in Figure 6.1. In terms of font type, the special font type (*e.g., similar with Papan Sintok*) was utilised to overcome mirror letters for children with dyslexia. Each letter has its base and can stand up on its own so that the children with dyslexia can easily organize them in space. The dimension of the letter block is 7 centimetres in height, 6 centimetres in width, and 2.5 centimetres in depth are appropriate for children with

dyslexiato hold and feel the letters' shape as depicted in Figure 6.2. In addition, 21 consonant letters with two sets vowels (*a, e, i, o, u*) are provided for children with dyslexia.

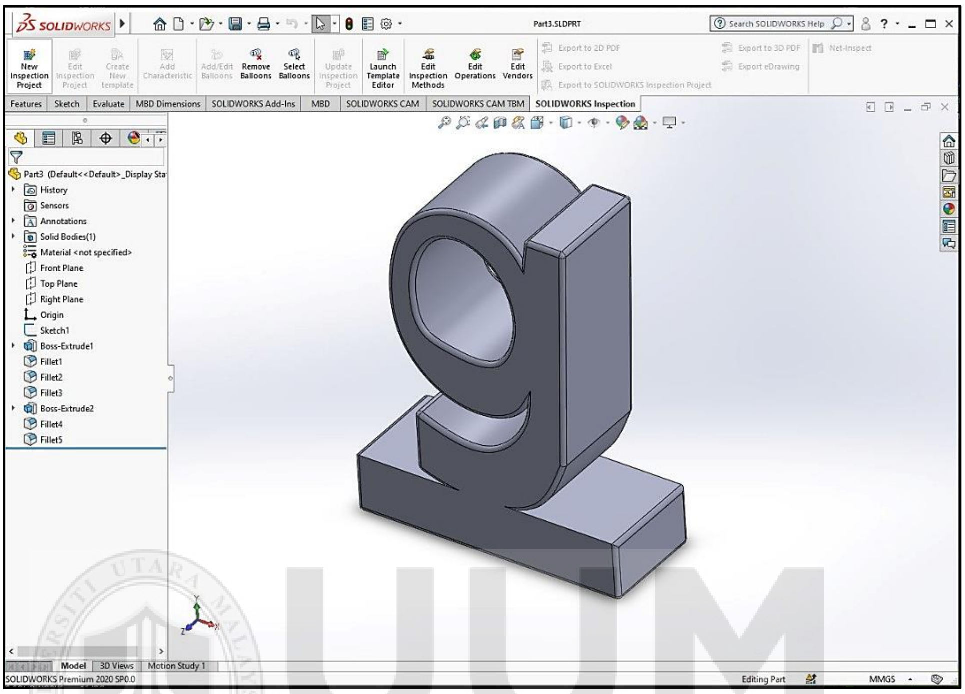

Figure 6.1 Drawing of 3D tangible letter using Solidworks

All of the letter shapes for children with dyslexia were printed using 3D printing. The design of the letters allows children with dyslexia to grasp and feel the letter's shape. Using a computer-generated design, 3D printing is an additive manufacturing (AM) technique for building three-dimensional objects layer by layer from a digital file (Ngo et al., 2018). Layers of material are built up during the 3D printing process to produce 3D tangible letters. The 3D tangible letters were printed using a 3D printer. Polylactide acid (PLA) is the filament material that was utilised to print the 3D tangible letters, and the filament colour used was white. It is made of a lightweight and safe material for children with dyslexia as it does not have any chemical reactions.

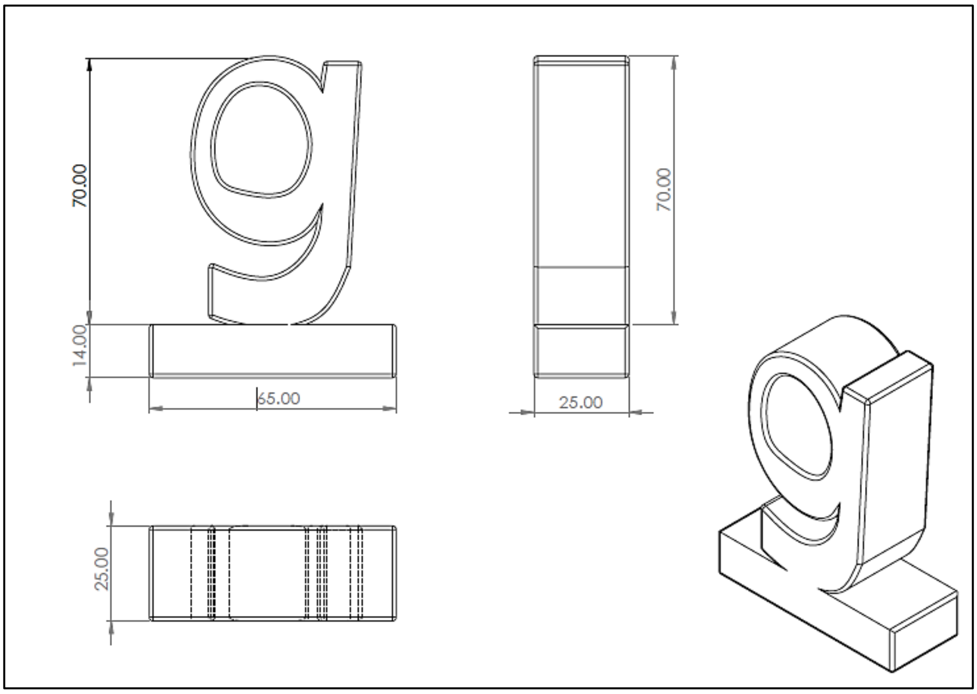

Figure 6.2 Dimension of 3D tangible letter

The implementation of 3D tangible letters has a specific configuration of an electronic magnet underneath the letter base, which is connected with the resistor that serves as its ID, as depicted in Figure 6.3. The resistor is connected to 4 analog input pin that represents 4 letter slots respectively which are: a) Pin A0 for Slot 1; b) Pin A1 for Slot 2 c) Pin A2 for Slot 3; and d) Pin A3 for Slot 4. The spelling board contains an Arduino nano that can identify each letter and pass the letter identity and location (slot number) to a custom web application hosted inside a web host server.

When a 3D letter is inserted into a slot, the Arduino read the analog input value of the resistor inside the 3D letter to determine what letter is inserted and which slot is occupied by the letter. Then, the Arduino generated an information string in the format *of Slot 1 letter, Slot 2 letter, Slot 3 letter, and Slot 4 letter*, and transmit it to the laptop via USB serial CH340 micro type-B cable as represented in Figure 6.4.

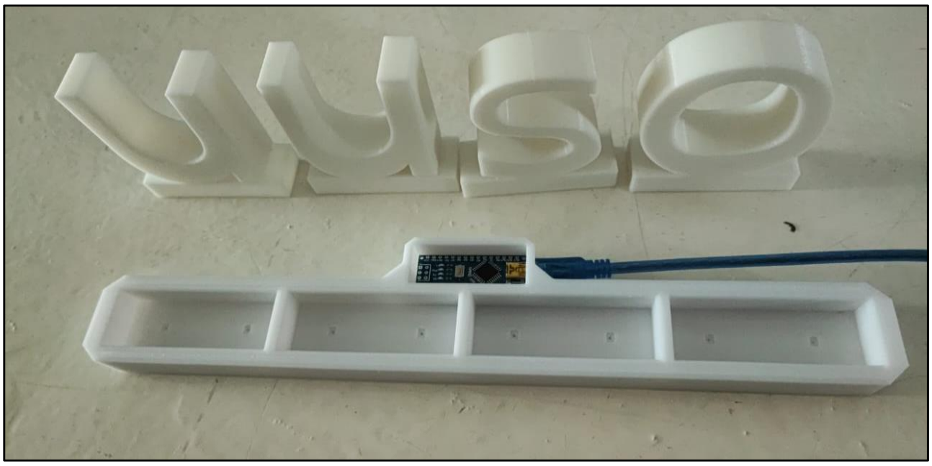

Figure 6.3 Spelling board of TUIs prototype

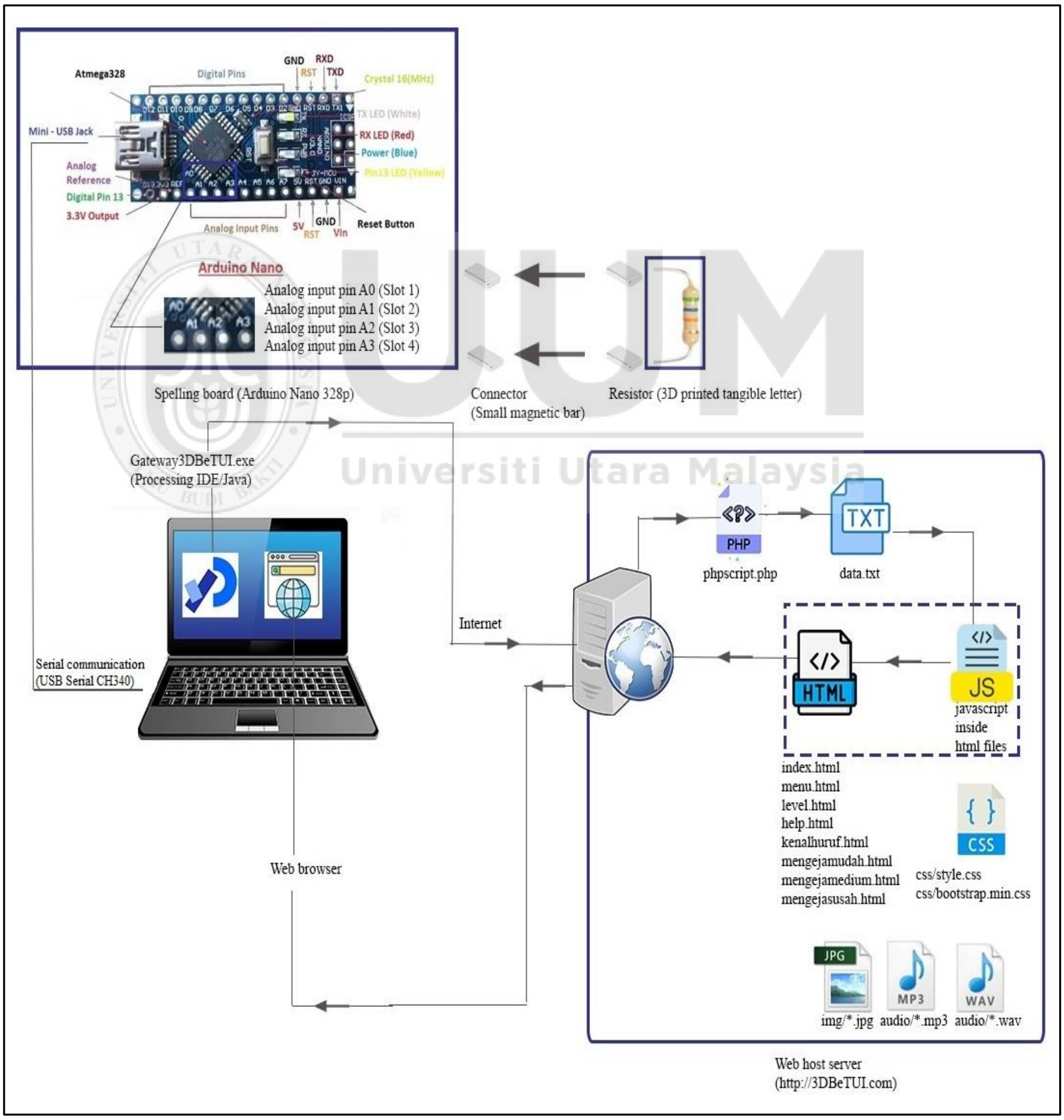

Figure 6.4 TUIs Prototype system data processing flow cycle

6.1.2 Software

The software comprises two types of learning contents which facilitate children with dyslexia in learning to read in Malay as presented in Figure 6.5. The first learning content focuses on letter recognition (*Kenal huruf*), with children with dyslexia attempting to recognise letters and associate them with pictures of letters. Children with dyslexia can learn the 26 letters (a-z) in the learning content provided in the software. Images of the letters are displayed on the screen as static images following the design guideline requirement.

Figure 6.5 Learning contents for children with dyslexia in learning to read in Malay.

The second learning content is spelling (*Mengeja*) which identified the syllables based on the sound of letters and images of the spelling tasks. The spelling task supported the O-G theories and kinesthetic theories which allowed the children with dyslexia to arrange and use different senses to manipulate the 3D tangible letters. The spelling tasks are offered in three levels of difficulty: easy (CV), medium (V+CV), and hard (CV+CV). Children with dyslexia are taught how to spell consonant vowels (CV), vowel plus consonant vowels (V+CV), and consonant vowels in two syllables (CV+CV) in the second content, which focuses on spelling as shown in Figure 6.6.

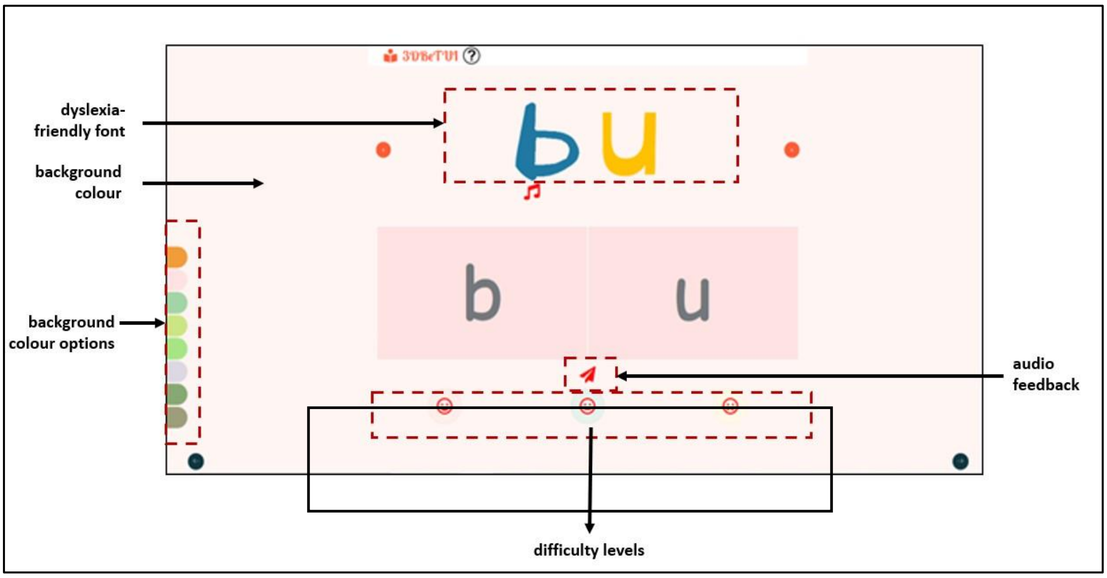

Figure 6.6 Three Difficulty Levels for Spelling Task

The learning contents (letter recognition or spelling) that are suited for reading levels of children with dyslexia might help them learn about letter sounds by arranging 3D tangible letters on the spelling board. Once the child places the 3D tangible letters on the spelling board, and links them to the program correctly or incorrectly, audio feedback is provided. For example, the system interacted with a children with dyslexia child by triggering audio (.mp3 and .wav files format) to a) pronounce the audio of displayed tangible letters pictures, syllables, and objects pictures when the hint button (*music note icon*) is clicked; b) pronounce correct letters and spell the inserted 3D letters when sending button (*paper plane icon*) is clicked if the inserted 3D tangible letters matched the displayed pictures number count values ('bilanganHuruf' variable) and play applause sound together with congratulate audio ("*Hebatnya, anda sudah berjaya*!"); c) request the child with dyslexia to try again if the wrong 3D letters are inserted with try again the audio ("*Sila cuba lagi*").

The custom software developed in the computer used Java language of Processing IDE acted as a gateway to capture information string received from Arduino and passed the information string into the PHP script (*phpscript.php*) located inside the web host server as shown in Figure 6.7. Next, the PHP script processed the information string and write it directly inside the text file (*data.txt*). The data written to the text file was opened and read by JavaScript inside HTML files as an array, split the delimiter (,) and modify HTML codes to display inserted letters on the internet browser. After that, the JavaScript function checked and compared received letters that were saved inside a text file (*data.txt* with displayed letter/letters or picture on the HTML pages which is from "*Letter Recognition Page*", "*Easy Spelling Page*", "*Medium Spelling Page*" and "*Hard Spelling Page*" and then when the inserted tangible letters matched with displayed letter/letters or picture on the web page. Following that, the JavaScript played the audio (*.mp3/.wav files*) mentioned inserted letter and congratulated the children with dyslexia once he or she presses the submit button (paper plane button underneath letterbox) as presented in Figure 6.8 to 6.11. When the children with dyslexia inserted the wrong letter and pressed the submit button, the JavaScript played an audio mentioned the children to "*try again*".

Figure 6.7 Software Gateway

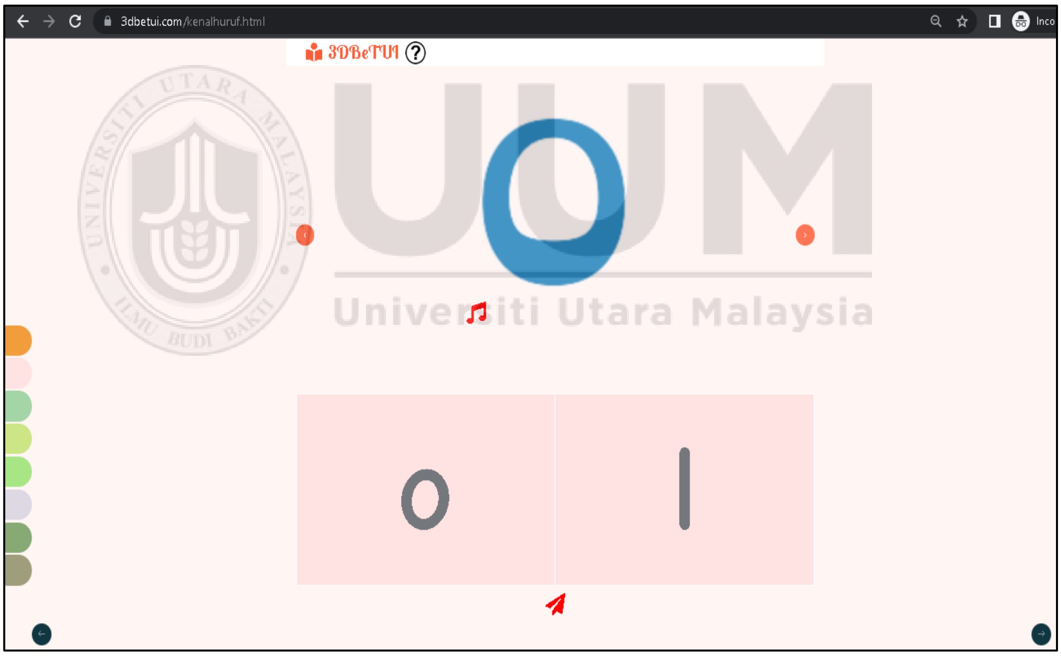

Figure 6.8 Letter Recognition Page

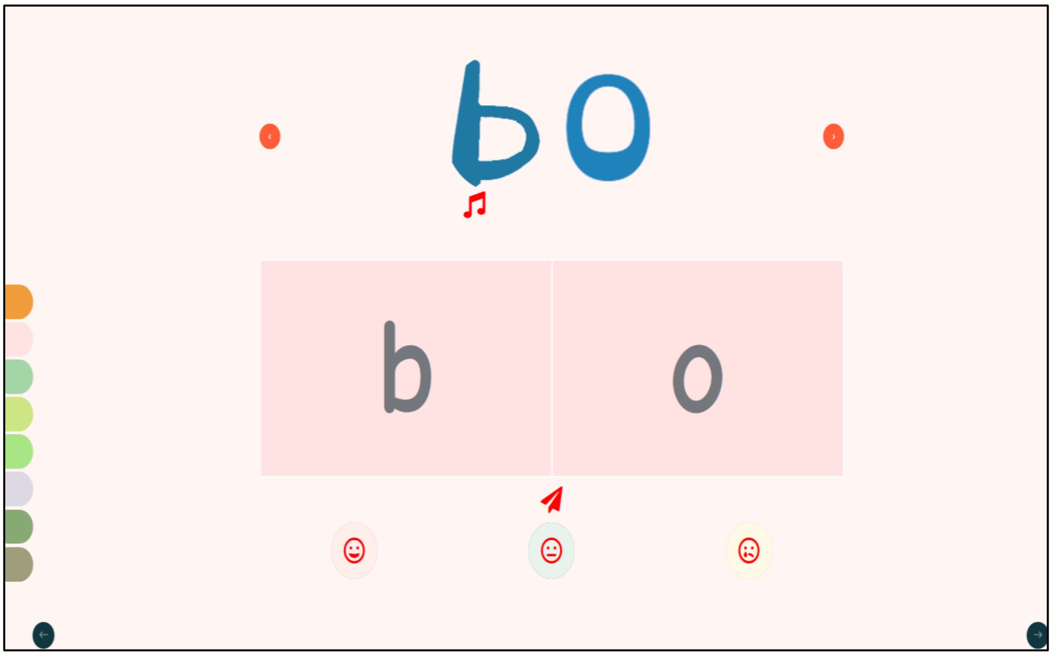

Figure 6.9 Easy Spelling Page

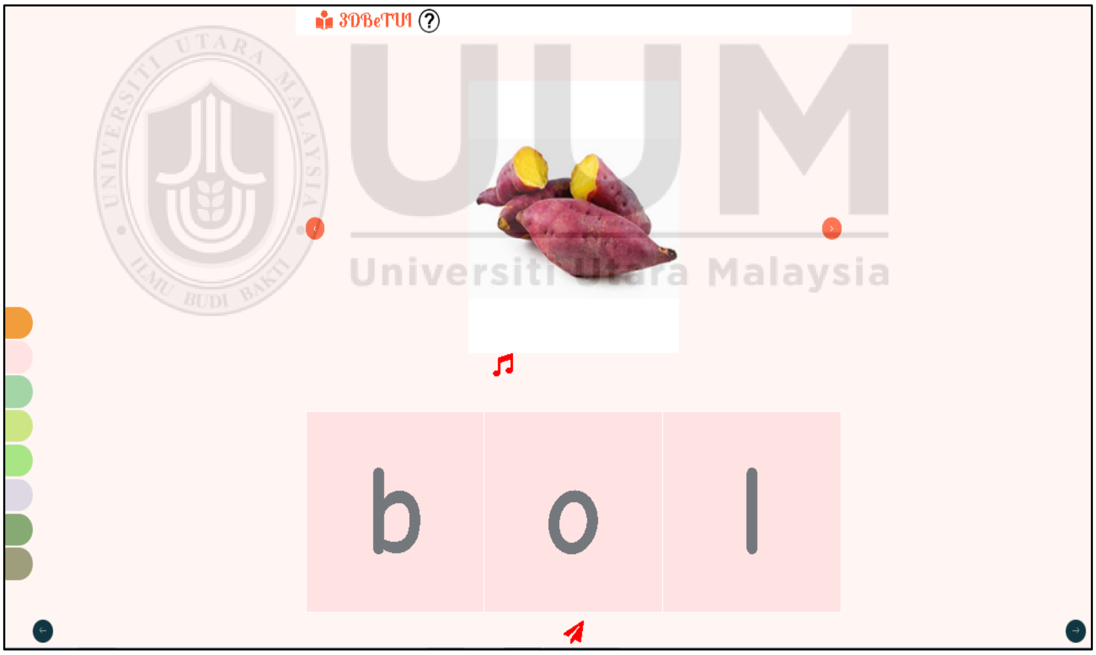

Figure 6.10 Medium Spelling Page

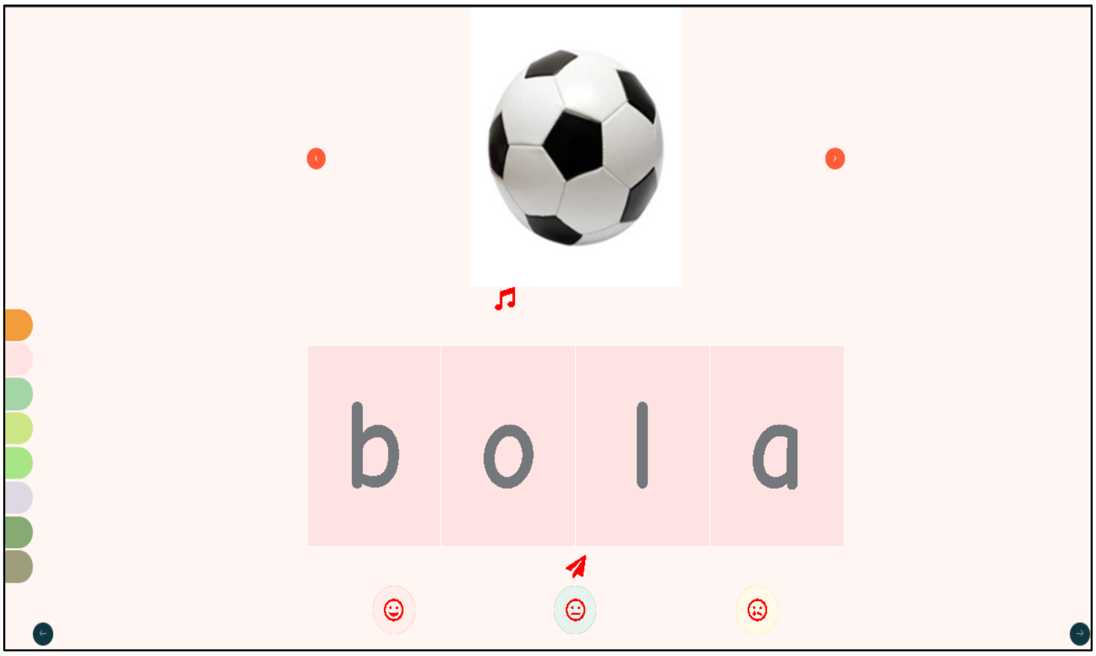

Figure 6.11 Hard Spelling Page

In addition, the colour of the background needs to be contrasted for a little brightness. The colour code suggested by Irlen (2005) for dyslexia is applied in this software. When the coloured button is clicked, the JavaScript codes appended the styles of the HTML document body background and HTML element with Id "kotakHuruf" executed.

The background colour changed from RGB colour code (255, 227, 226) to other dyslexia-friendly colour codes (241, 157, 59). For example, when a button with the colour rgb (241,157,59) is clicked, the JavaScript function "color1()"executed and changed the current background colour to the selected colour for the HTML body and "kotakHuruf" background. Figure 6.12 and Figure 6.13 depicted the change in the background colour.

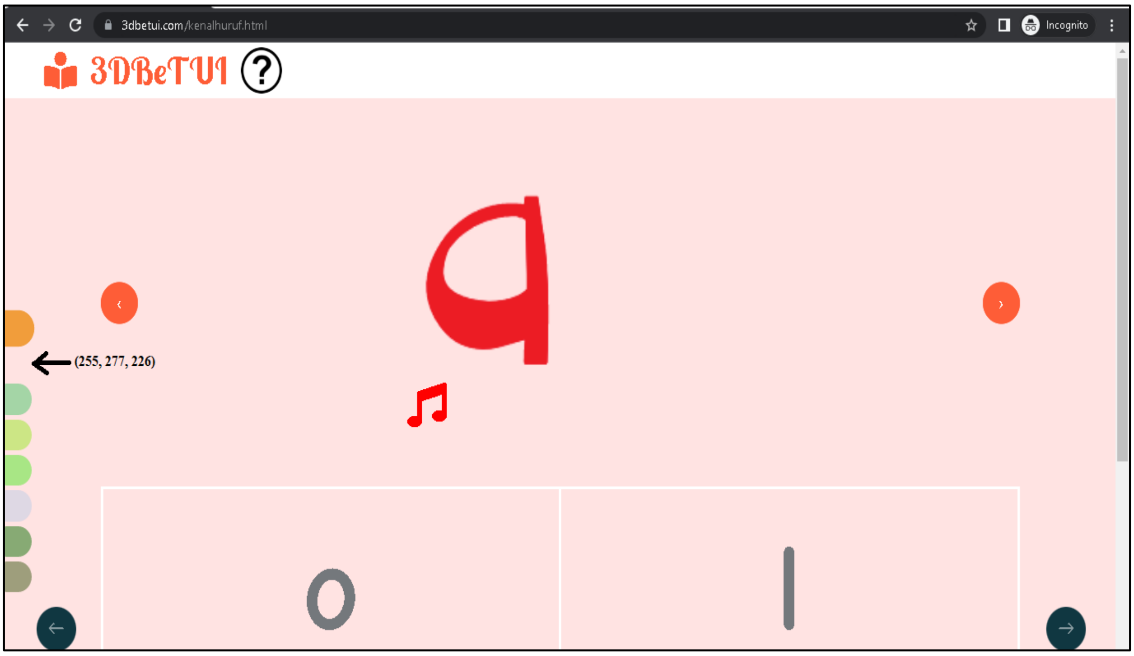

Figure 6.12 RGB Colour Code Background (255, 227, 226)

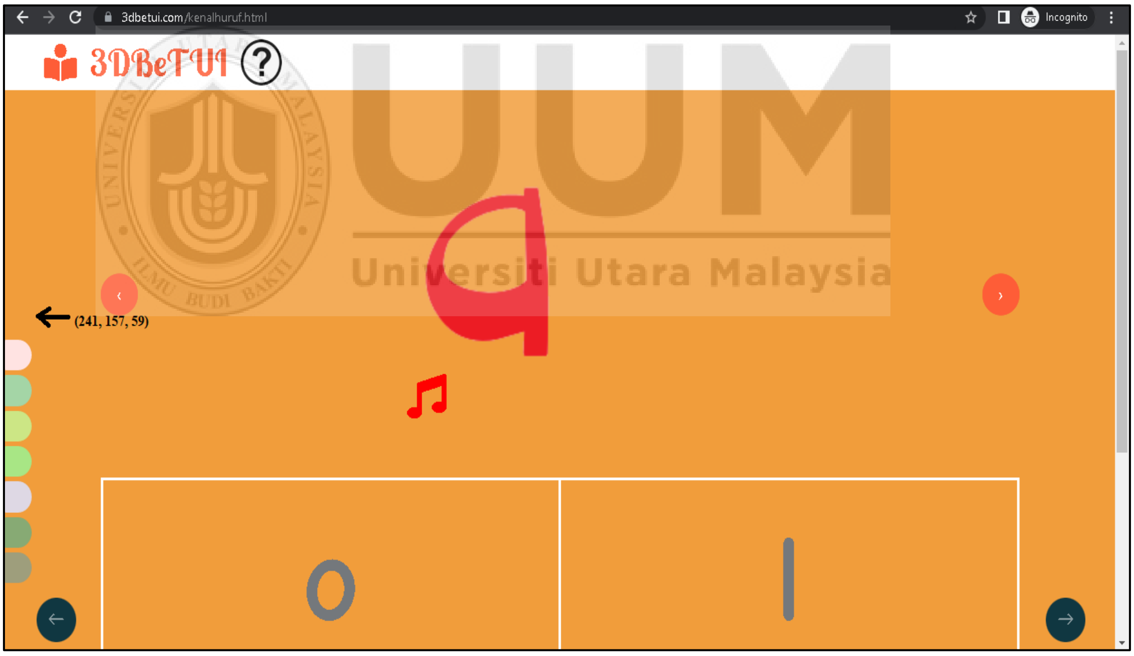

Figure 6.13 RGB Colour Code Background (241, 157, 59)

6.2 The Validation with Children with dyslexia

Following the creation and verification of the proposed design guideline of TUIs, this research goes on to validate the guideline, which employed target users who are children with dyslexia. This study employs an experimental study with 16 participants.

According to previous studies, having sixteen children with dyslexia involved in this experiment is considered representative (Russell et., al 1996; Husni, 2009).

In this study, children with dyslexia were chosen to validate the guideline using the TUIs prototype. Hence, this study aims to evaluate the effectiveness of the constructed TUIs design guideline by employing an experimental study. The TUIs prototype can be used by children with dyslexia to complete a task that they can understand and help in utilising features that are designed specifically for them. The guideline may help researchers and developers create practical solutions that satisfy user requirements and evaluate the effectiveness of TUIs. The next subsection discusses the design guideline validation by children with dyslexia using the TUIs prototype.

6.2.1 Experiment Session with Children with Dyslexia

The experiment was carried out with sixteen children with dyslexia aged from 7 years old to 12 years old at the Sekolah Kebangsaan Kayang and Persatuan Disleksia Malaysia Sungai Petani by using the TUIs prototype. The experiment was scheduled based on the availability of the teachers and children with dyslexia. The experiment took about 15 to 20 minutes for each child.

The researcher prepared the Task Description for Children with dyslexia in Appendix D for them to follow during the experiment. Then, following their reading levels, they must complete the task reading session, and finally, with supervision from the researcher, they must complete the questionnaire. More details on the experiment have been discussed further in the experimental procedures section in Chapter 3.

6.2.2 Material Preparation for Children with Dyslexia

Children with dyslexia required multisensory interaction to stimulate their brains and effectively learn by using textures, for better improvement in their reading results. The contours of textured letters can be traced to aid children with dyslexia in learning mirrored or flipped letter shapes such as b, d, p, and q (Dehaene 2009; Regtvoort & van der Leij (2007). Figure 6.14 depicts texture cues (letters material) on 3D tangible letters that were used for children with dyslexia during the experiment session.

Figure 6.14 Texture cues on 3D tangible letters

A variety of visual and tactile features, including size, shape, colour, and texture, are appeared in tangible objects such as 3D tangible letters (Djajadiningrat et al., 2004). Tangible objects are considered as an effective tool for delivering multisensory information when they are connected to digital information because they allow learners to engage with information using their senses of touch and sight, this is supported by dual-coding theory, which suggests that information transmitted by both verbal and nonverbal channels may be easier to learn thus contributing to better learning outcomes (Clark & Paivio, 1991). Five types of materials used for 3D tangible letters is summarised in Table 6.1.

Table 6.1
Type of Materials used for 3D tangible letters

Letter	Material used
d	fur ball
h	microfibre cloth
u	decoration button
p	sand paper
w	tie rope

The questionnaire in Appendix C was developed in Malay language for children with dyslexia was adapted from prior study conducted by Fan (2017). The questionnaire was validated via a meeting with three experts in computer science for expert validity purposes. Accordingly, the experts were asked to assess the measure properties in the questionnaire to identify any item that was either ambiguous or difficult to understand. Following that, minor refinements were then made to the questionnaire based on the feedback from the experts.

6.2.3 Experiment Tasks with Children with Dyslexia

Children with dyslexia were requested to perform learning content based on their reading level in this study. Children with dyslexia between the ages of 7 to 12 years old are selected by their special education teachers. The first task requires children to recognise the letters, and the second task requires them to spell the words based on the picture displayed on the computer. The purpose is to evaluate the effectiveness of constructed design guideline of TUIs for children with dyslexia learning to read in Malay using the TUIs prototype.

The questionnaire captured the experience of the children with dyslexia with the TUIs prototype including software and 3D tangible letters for each learning task. After they have completed their task, they need to answer the questionnaires with assistance from a researcher, children with dyslexia are required to indicate their recommendations for the next design features of TUIs in the future. The results analysis and discussion were covered in the next section.

6.3 Results and Discussion

The questionnaire captured the experience of the children with dyslexia with the TUIs prototype including software and 3D tangible letters for each learning task. After they have completed their task, they answered the questionnaires with assistance from a researcher, children with dyslexia are required to indicate their feedbacks for the next design features of TUIs in the future. The results analysis and discussion were covered in the next section.

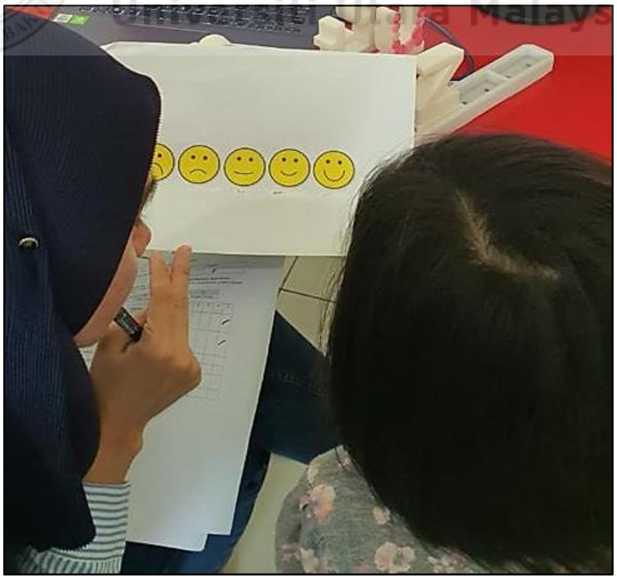

Figure 6.15. *Smileyometer scale used to acquire children's opinion.*

6.3.1 Effectiveness

The result of effectiveness of TUIs are shown in Table 6.2. Five items are used to assess effectiveness: a) letter recognition task achievement (E1); b) progress of children with dyslexia differentiating mirrored letters (E2A); c) spelling task achievement (E3); d) spelling words progress of children with dyslexia (E4A); and e) task performance of children with dyslexia (E5).

Table 6.2
Descriptive Statistics of Effectiveness of TUIs

	Items	Code	N	Min	Max	Mean	SD
1.	Letter recognition task achievement	E1	16	4.00	5.00	4.6250	.50000
2.	Progress of children with dyslexia differentiating mirrored letters	E2A	16	3.00	5.00	4.0625	.99791
3.	Spelling task achievement	E3	16	4.00	5.00	4.5625	.51235
4.	Spelling words progress of children with dyslexia	E4A	16	4.00	5.00	4.4375	.51235
5.	Task performance of children with dyslexia	E5	16	4.00	5.00	4.5625	.51235
		Valid N (listwise)	16				

As shown in Table 6.2, the mean score for effectiveness of TUIs ranging from 4.06 to 4.62, reflected the eliciting children's opinions level of agreement by the children with dyslexia. The letter recognition task achievement (E1) had the highest mean values at 4.62 while the standard deviations are within the range from 0.50 to 0.99 for all items. The results found that most of the children with dyslexia completed the learning task using the TUIs prototype. Figure 6.16 exhibits the child doing spelling tasks. Meanwhile, Figure 6.17 shows the child doing letter recognition task.

Figure 6.16 Letter recognition Task with a Participant

Figure 6.17 Spelling Task Session with a Participant

6.3.1.1 Other Results of Effectiveness

The validation results of effectiveness of mirrored letter demonstrated confusion by children with dyslexia (E2B) during learning sessions. Most of the children had difficulties reading the mirrored letter especially the letters of (b, d, p, q, n, u, m, w) as summarised in Table 6.3.

Table 6.3
Other Validation Results of Effectiveness

	Mirrored Letters Confusion by Children with dyslexia(E2B)	Children with dyslexia (DC)
1.	b, d	DC3
2.	b, d, n, u, m, w	DC11
3.	b, d, p, q, m, w	DC16
4.	p, q	DC1
5.	p, q	DC12
6.	p, q, n, u	DC7

The result showed that out of the sixteen children with dyslexia, six of them had difficulty in distinguishing mirrored letter shapes. For example, the letters "p" and "q" was difficult to be recognised by DC1 and DC12. Meanwhile, DC 11 was confused with the letters "b, d, n, u, m, w," DC 16 was confused with the letters "b, d, p, q, m, w," and DC 7 was confused with the letters "p, q, n, u".

The use of selected letters with no mirror effects has been proposed by Aziz et al. (2013). As a result, lowercase 3D tangible letters were produced with specific font types (e.g., *Papan sintok*) to assist the children with dyslexia overcome mirrored letters such as "b, d, p, q, n, u, m, w" for effective reading outcomes.

Meanwhile, the total number of words that children with dyslexia had successfully spelled using the TUIs prototype are shown in Table 6.4. They were able to accurately spell up to 13 words using the TUIs prototype. Most of them were capable of placing the 3D tangible letters on the spelling board. When they mistakenly spelled the words, they managed to figure it out and try to find other letters based on the hints triggered by the software. It can be concluded that the majority of children with dyslexia can complete the learning task given to them and spell the words accurately.

Table 6.4
Total Words Spelled by Children with Dyslexia

Children with dyslexia (DC)	Total Words Spelled by Children with Dyslexia
DC1	4 perkataan: ubi,isi,meja,pasu-qasu
DC2	4 perkataan: ba,paku,uli,meja
DC3	3 perkataan: ibu, buku, ubi-udi
DC4	3 perkataan: meja,buku,bola
DC5	4 perkataan: ibu,api,paku,bola
DC6	3 perkataan: bu,isi, buku-puku
DC7	3 perkataan: ba,bo,api
DC8	4 perkataan: ba,be,ubi,buku
DC9	5 perkataan:bo,bi,ibu,bola, meja-mefa
DC10	2 perkataan: pasu,meja
DC11	13 perkataan: ba,be,bi,bo,bu,ubi,ibu,api,uli, buku,meja,paku,bola
DC12	2 perkataan: ba,api
DC13	1 perkataan: ibu
DC14	3 perkataan: ba.bi,ubi 4 perkataan: ibu,api,paku,bola
DC15	3 perkataan: buku,pasu,paku
DC16	3 perkataan: ibu,ubi,bola

Initially, a few children with dyslexia indicated that they could only recognise letters. However, the researcher convinced them to try and assist them in the spelling task by using the pictures and audio hints displayed on the screen. Hence, they were successfully spelled up to 13 words using the prototype of TUIs.

In addition, the study demonstrated that DC5 and DC8 found ways to arrange 3D tangible letters in lines to do their tasks easily. For instance, DC8 first picked the three letters he would need to construct the word "ubi," laid them out in front of him, and then attempted to arrange them on the spelling board as shown in Figure 6.18.

Figure 6.18. A Participant picked the three letters he would need to construct the word "ubi”

The majority of children with dyslexia able to arrange the 3D tangible letters on the spelling board, and they felt delighted when the audio feedback from the system applauds them whenever the words were spelled correctly. If they missed to spell the words, they typically figured it out and discovered alternative letters by using the hints provided in the system.

The result found that only four children with dyslexia missed spelling the words during spelling tasks. According to Lachmann and Geyer (2003), reading performance can be examined independently for static reversals (e.g., *b-d*) and consonant errors (e.g., *pig* for *pik)*. DC1 spelled the words (*pasu-qasu*) based on the static reversals, while DC3 spelled the other words (*ubi-udi*). Meanwhile, the word spelled (*buku-puku*) by DC6 and DC9 (*meja-mefa*), respectively, based on the consonant error problems.

The study concluded that the TUI prototype supported children with dyslexia learning to read in Malay by using physical 3D letters with the interaction of digital space. The total number of words that children with dyslexia spelled correctly revealed that their reading performance improved significantly during learning sessions.

6.4 Design Features of TUIs

There are three design features including 3D tangible letters, texture cues, and font type suggested to facilitate the children with dyslexia in learning to read. Design features of TUIs were measured by using six items. Table 6.5 shows the mean, standard deviation, minimum and maximum scores of the design features of TUIs validation. The results demonstrated that higher mean values in 3D tangible letters preference (F1), 3D tangible letters are helpful for DC in learning to read in Malay (F2), texture cues preference (F3), texture cues are helpful for DC in learning to read in Malay (F4), font type preference and font type are helpful for DC in learning to read in Malay range between 4.43 and 4.75, with standard deviations range between 0.44 and 0.89, respectively.

Table 6.5
Descriptive Statistics for Design Features of TUIs

	Items	Code	N	Min	Max	Mean	SD
1.	3D tangible letters	F1	16	4.00	5.00	4.7500	.44721
2.	3D tangible letters support in learning to read in Malay	F2	16	4.00	5.00	4.5625	.51235
3.	Texture cues	F3	16	3.00	5.00	4.4375	.89209
4.	Texture cues support in learning to read in Malay	F4	16	3.00	5.00	4.5000	.89443
5.	Font type	F5	16	4.00	5.00	4.6875	.47871
6.	Font type support in learning to read in Malay	F6	16	4.00	5.00	4.7500	.44721
		Valid N (listwise)	16				

The design features of TUIs had high mean values and standard deviations indicating a level of happiness among the majority of children with dyslexia. As a result, the design features of TUIs are suitable for assisting children with dyslexia in learning to read in Malay. The majority of children with dyslexia prefer 3D tangible letters, and they mentioned that all of these 3D letters assist them to learn to read using the TUIs prototype. They felt comfortable moving and grabbing the letters before and while performing learning tasks with the researcher as depicted in Figure 6.19.

Figure 6.19 The participants playing with the 3D tangible letters.

In a similar vein, several different types of materials were used to explore the texture cues on 3D tangible letters for children with dyslexia. The following materials are used for 3D tangible letters: a) *d* - fur ball; b) *w* – tie rope; c) *h* – microfibre cloth; d) *u* – decoration button; e) *p* – sandpaper. Figure 6.20 depicted texture cues and without texture cues preferred while validation sessions with children with dyslexia. Most of children with dyslexia preferred the texture cues.

Figure 6.20 Texture Cues on 3D Letters tested for Children with Dyslexia

6.4.1 Other Results of Design Features of TUIs

In addition to the survey results, children with dyslexia provided their feedbacks regarding the TUIs prototype features. The feedbacks of children with dyslexia are analysed based on other features prototype of TUIs are presented in Table 6.6.

Table 6.6
Other Validation Results of Design Features of TUIs

	Children with dyslexia (DC)	Other Features of TUIs Prototype those children with dyslexia like
1.	DC2, DC3	"Suka huruf 3D yang ada tekstur"
2.	DC4	"Suka huruf 3D yang ada tekstur daripada yang tidak ada tekstur"
3.	DC5	"Tidak suka huruf 3D yang ada tekstur"
4.	DC11	"Tidak suka huruf 3D yang ada tekstur kerana mempunyai tactile issues"

In terms of additional features, DC2 and DC3 preferred the 3D tangible letters with texture cues. DC4 preferred 3D tangible letters with texture cues over non-textured ones, whereas DC5 was not comfortable with the 3D letters with texture cues. Due to tactile difficulties or sensitivities, DC11 did not prefer 3D tangible letters with texture cues.

Regarding the suggestion for next features of TUIs, feedbacks from children with dyslexia were summarised in Table 6.7. In addition, DC2 and DC4 suggested to incorporate the colour cues like embedded led lights in 3D tangible letters to draw their attention while they perform learning tasks. They requested all the letters had a texture so that they could touch and feel the letters. Furthermore, DC5 stated that he preferred colour cues with LED lights embedded in 3D tangible letters but did not prefer letters with texture cues. On the other hand, DC14 and DC15 suggested to include only texture cues for all letters.

Table 6.7

Suggestion for next features of TUIs

	Children with dyslexia (DC)	Suggestion for next features
1.	DC1, DC12, DC13, DC16	"Nak ada colour cues seperti lampu led pada huruf 3D"
2.	DC2, DC4	a) "Nak ada colour cues seperti lampu led pada huruf 3D" b) "Nak semua huruf ada texture boleh sentuh dan rasa"
3.	DC5	"Nak ada colour cues guna led pada huruf 3D tetapi tidak suka huruf 3D yang ada texture"
4.	DC14, DC15	"Nak semua huruf 3D ada texture"

In a similar vein, DC2 and DC4 suggested to add colour cues like led lights embedded in 3D tangible letters and also want all the letters to have a texture that they can touch and feel the letters. Besides, DC5 mentioned that he like if the colour cues using led lights embedded in 3D tangible letters but not preferred the letters with texture cues. On the other hand, DC 14 and DC15 recommended to add texture cues for letters. This can attract their attention while doing learning tasks.

According to Jamali et al. (2019), physical representation, such as a 3D tangible letter with texture cues, improved the learning of children with dyslexia. TUIs demonstrated the use of various textures by integrate them with two or more different modalities (Malley & Fraser, 2004). According to Fan et al. (2016b), multisensory methods recommend the utilisation of colour cues and tactile cues to facilitate the learning of letter-sound correspondences. In light of these comments, the next research refined TUIs prototype further in terms of colour cues and texture cues on all 3D tangible letters. Therefore, it is required to develop other suitable TUI features.

6.5 User Interface Experience

User interface experience (UIE) are measured by using six items. Based on Table 6.8, the result revealed that the mean values of the UIE namely touch-based user interfaces experience (UIE1), TUIs experience (UIE2), prototype features (UIE3), prototype is helpful for children with dyslexia learning to read (UIE4), prefer to continue using the prototype (UIE5), easy to use the prototype (UIE6) range between 3.71 and 4.42, with standard deviations 1.14 and 0.50 respectively.

Table 6.8
Descriptive Statistics of User Interface Experience

Items	Code	N	Min	Max	Mean	SD
1. Touch-based user interfaces experience	UIE1	16	1.00	5.00	4.3750	1.14746
2. TUIs experience	UIE2	16	3.00	4.00	3.0625	.25000
3. Prototype features	UIE3	16	4.00	5.00	4.6875	.47871
4. Prototype is helpful for children with dyslexia learning to read	UIE4	16	4.00	5.00	4.6875	.47871
5. Prototype is helpful in learning to read	UIE5	16	4.00	5.00	4.6875	.47871
6. Prefer to continue using the prototype	UIE6	16	4.00	5.00	4.6250	.50000
	Valid N (listwise)	16				

The study found that one of children with dyslexia never experienced using touch-based user interfaces, such as tablets or smartphones. In a similar vein, most children with dyslexia have never experienced using a TUIs where a physical object is linked to digital information. Consequently, this was their first time utilising the TUIs prototype.

Meanwhile, the majority of the children with dyslexia showed their satisfaction and happiness when using the TUIs prototype to support learning to read. The children mentioned that they prefer to use the prototype during their learning sessions.

The findings showed that the average mean value and standard deviations for the user interface experience indicated a moderate level of agreement among the children with dyslexia. Hence, the results concluded that user interfaces experience is important.

6.6 Summary

The TUIs prototype that was developed based on the constructed TUIs design guideline specifically for children with dyslexia learning to read in Malay are discussed in this chapter. The process of design guideline validation that was performed by target users was covered in this chapter, along with the findings of the design guideline validation. The validation by the target user possesses the result of descriptive analysis. The other result from the questionnaire, which is based on suggestions and comments from children with dyslexia was explained. The results demonstrated that the experiment session to validate the design guideline of TUIs using the prototype supports children with dyslexia learning to read in Malay by utilising 3D tangible letters with the interaction of digital space (software) agreed by children with dyslexia. The overall number of words that children with dyslexia successfully spelled during learning sessions showed that they made great progress on their spelling tasks. As a result, the TUI prototype supports children with dyslexia learning to read in Malay by using physical 3D letters with digital space interaction.

CHAPTER SEVEN

CONCLUSION AND FUTURE RECOMMENDATIONS

7.0 Recapitulation of the Research Findings

This chapter concludes the research by highlighting the objectives achieved in the study. The main objective of this study is to propose a TUIs design guideline that is designed for children with dyslexia learning to read in Malay. Specifically, the study is aimed at achieving the following objectives, as stated in Chapter 1, Section 1.3:

1. To analyse the TUIs design components specifically for children with dyslexia learning to read in Malay.
2. To construct a TUIs design guideline for children with dyslexia.
3. To evaluate the effectiveness of the constructed TUIs design guideline.

The study proposed and developed design guideline based on the TUIs framework to fulfil user requirements and evaluate the TUIs effectiveness in assisting children with dyslexia reading in Malay.

Following that, the limitations of the study are discussed followed by recommendations for future research. Finally, the chapter ends with the concluding remarks of the study. Therefore, three specific objectives were defined to achieve the primary objective that has been fulfilled is summarised in the following subsections. The research questions are: 1) Which TUIs design components are mainly suitable for children with dyslexia learning to read in Malay? 2) What would be the TUIs design guideline for children with dyslexia? 3) How effective is the design guideline of TUIs to assist children with dyslexia in learning to read in Malay? The following subsections concludes the research questions and research objectives that have been achieved.

7.0.1 The TUIs Design Components for Children with Dyslexia Reading in Malay

To achieve this objective, a literature review and focus group discussion with special education teachers were performed. A comprehensive literature review was conducted to obtain information about the potential TUIs design components in learning to read specifically for children with dyslexia. It provided an overview of the learning support for children with dyslexia provided by TUI design features such as 2D and 3D tangible letters, dynamic colour cues, texture cues, and other features. To reinforce evidence from the comprehensive literature review, eight design features of TUIs were examined in focus groups session with special education teachers.

Meanwhile, a focus group discussion was conducted to analyse suitable design components for designing TUIs in learning to read in Malay. Focus groups were performed for approximately one hour per session at Sekolah Kebangsaan Kayang. As per discussed in the analysis and findings in Chapter 4, Section 4.1, the results are divided into eight categories based on the themes identified through the thematic analysis including characteristics features of children with dyslexia, challenges of children with dyslexia in learning, subjects and personal interests of children with dyslexia, learning content, learning styles, design features of TUIs, interaction design and universal design principles.

Following the identification of TUIs design components in Chapter 4, Section 4.1, the focus group sessions explored the efforts to develop a TUIs design guideline for children with dyslexia. This provided detailed insight into children with dyslexia and TUIs design components in terms of suitable design features of TUIs based on IxD and UD principles, learning contents, learning styles, and children with dyslexia's reading levels. Regarding reading difficulties, the relationship between UD and IxD in the guideline is to produce a good design for children with dyslexia. The results indicated the ability of tangible technology or TUIs to support the learning of children with dyslexia through analysed TUIs design components including IxD and UD principles.

7.0.2 The TUIs design guideline development for children with dyslexia

The second research questions and the second research objective are achieved with the TUIs framework and design guideline development based on the main components and sub-components for children with dyslexia. This study identified the TUIs design components through focus group sessions with special education teachers after reviewing previous research on the TUIs framework for developing suitable framework components. To support children with dyslexia learning, the TUIs framework was developed. It involved a multisensory interaction with different sensory modalities, including visual, audio, and kinesthetic. The suitable design mapping (sub-components) with TUIs framework components was presented.

TUIs framework and design guideline were reviewed by seven experts with backgrounds in HCI, art, and design throughout a verification session. This was performed to ensure the proposed framework and design guideline meets the requirements before the TUIs prototype is developed. Framework and design guideline verification is divided into four sections in the questionnaire. The verification of tangible representations is presented in the first section, the next intangible representations, followed by digital information, and finally the verification of the framework review. A five-point Likert scale ranging from (1) strongly disagree; (2)

disagree; (3) neutral; (4) agree; (5) strongly agree was used for experts to verify a set of statements related to the framework and design guideline: Section 5.4 discussed the results in further explanation.

The verification process led to modifications of the TUIs framework and design guideline, based on expert feedback as described in Section 5.5 of Chapter 5. The revised framework was visually redesigned to better demonstrate its process flow, and modifications were made to the design guideline ' sub-components to ensure their suitability for supporting children with dyslexia reading in Malay. As a result, the third objective was achieved through the construction of the updated TUIs framework and design guideline based on the results of the expert review.

7.0.3 The effectiveness of the constructed TUIs design guideline

After the expert review and modification of the TUIs framework and design guideline, the final but important research question was addressed by achieving the third objective was to validate them with children with dyslexia. The TUIs prototype, featuring letter recognition and spelling activities, was used in the validation process. The experimental sessions involved 16 children with dyslexia between the ages of 7 and 12 and took place at Sekolah Kebangsaan Kayang and Pusat Dyslexia Malaysia (PDM) Sungai Petani. The goal of these sessions was to evaluate the effectiveness of the TUIs design guideline in supporting children with dyslexia learning to read in Malay.

The primary objective of this study is to assess the effectiveness of the TUIs design guideline through an experimental study. A set of 18 questions was used during the experiment sessions, as listed in Appendix C. To obtain the children's opinions about the software or hardware products used, the Smileyometer scale was employed, as suggested by Read and Fine (2005). This approach helps to provide valuable feedback on the effectiveness of the TUIs design guideline in supporting children with dyslexia learning to read in Malay.

The overall responses from the children with dyslexia who participated in the experiment sessions were positive, indicating that they enjoyed using the TUIs prototype to complete their tasks. Most of the participants were able to successfully place the 3D tangible letters on the spelling board. The results of the descriptive analysis indicated that the TUIs prototype supported children with dyslexia in completing learning tasks related to letter recognition and spelling during the experiment sessions.

However, some issues were identified during the learning sessions, specifically with distinguishing mirrored letter shapes for letters such as "b, d, p, q, n, u, m, w." Six out of sixteen participants had difficulty with these letters. To address this issue, it is recommended to continue using lowercase 3D tangible letters with specific font types, (e.g., Papan Sintok), to aid children with dyslexia in overcoming confusion with mirrored letters and achieve more effective reading outcomes.

The study found that the TUIs prototype, which included 3D tangible letters, texture cues, and specific font types, was effective in supporting children with dyslexia in learning to read in Malay. The children with dyslexia participants enjoyed using the prototype and were able to successfully complete learning tasks, including letter recognition and spelling. The results indicated high mean values of design features of TUIs. The results of the study suggest that the TUI prototype was effective in supporting children with dyslexia in learning to read in Malay. Even when children with dyslexia misspelled words, they were able to figure out alternative letters using hints provided by the software, and with the help of pictures and audio hints, they improved significantly on their spelling tasks during learning sessions. This highlights the potential of combining physical 3D letters with digital space (software) to support children with dyslexia in their learning outcomes. Overall, the TUIs prototype appears to be a promising tool for supporting children with dyslexia learning to read in Malay.

In addition to the questionnaire results, the feedback and suggestions given by children with dyslexia are analysed in line with other features that they like on the TUIs prototype outlined in Section 6.4.1. The study also revealed suggestions for better improvement of features, such as incorporating embedded LED lights in the 3D tangible letters and providing texture on all letters, based on the comments and feedback from the children with dyslexia. Overall, the design guideline was deemed suitable for children with dyslexia, and the study successfully achieved its third objective of validating the guideline through an experimental study with children with dyslexia.

7.1 Contributions of Study

This study contributes to theoretical and practical knowledge in the field of IxD, particularly in TUIs specifically for dyslexic children. The present study supports the effort of Malaysian government to provides inclusive education to all students, including those with special needs and learning disabilities, in accordance with international best practices and current national agenda. The Malaysia Education Blueprint 2013-2025 reported that the MoE aimed to have 75 percent of students with special needs enrolled in inclusive programs by 2025. In addition, The Persons with Disabilities Act 2008 of Malaysia, under Article 28, mandated that special needs children have to receive necessary support and care to enable their full and equal participation in education. This is further reinforced by the Zero Reject Policy, which was introduced by the MoE in December 2018.

As a developing country, the Malaysian government is very concerned about achieving sustainable development through education to ensure inclusive and equitable quality education and promote lifelong learning opportunities for all can be sustained. According to the Sustainable Development Goals 4 and COVID-19 report in 2020, the quality of education in Malaysia has remained stagnant and has even worsened due to school closures during the pandemic. The impact of COVID-19 on education is expected to have significant global implications. Recently, the Malaysia Grand Challenge (MGC) was launched by the Ministry of Science, Technology, and Innovation (MOSTI) to promote local product innovation and creativity. The MGC has provided funding to technology-related start-up companies affected by the pandemic to develop innovative products that can accelerate the future development of the country.

Meanwhile, the main contributions consisted of the TUIs framework and TUIs design guideline for better reading outcomes among children with dyslexia. Additionally, children with dyslexia can benefited from the TUIs prototype, which was developed based on the constructed design guideline. Children with dyslexia also expressed their interest to use the TUIs prototype in the future and they suggested further features of TUIs be developed because it is appealing and influences their learning to read. As a result, it will be beneficial for researchers and developers to develop the TUIs system based on the design guideline which according to user requirements and evaluate the TUIs effectiveness. The following subsections elaborate on the contributions of this study.

7.1.1 The TUIs Framework

This study constructed a framework of TUIs specifically for children with dyslexia. TUIs framework demonstrated the process started with children with dyslexia holding or grasping the 3D tangible letters with their hands. The 3D tangible letters were placed on the designated spelling board. The system delivered auditory feedback once the children spelled the correct words or place the correct letter, depending on the learning content (e.g., letter recognition or spelling).

Besides, it facilitates reading for children with dyslexia by having multisensory experiences such as visual, auditory, kinesthetic, and tactile to stimulate their senses and hence enhance their learning outcomes. TUIs framework comprised of three main components: 1) tangible representation; 2) intangible representation; and 3) digital information. For instance, tangible representations consist of seven types of sub-components: (a) 3D tangible letters, (b) texture cues, (c) dynamic colour cues, (d) font type, (e) low physical effort, (f) size and space for approach and use, and (g) equitable use. Meanwhile, intangible representations consist of four sub-components: (a) audio feedback; (b) colour; (c) simple and intuitive use; and (d) perceptible information. On the other hand, digital information outlines six types of sub-components: (a) letter recognition; (a) syllables spelling; (b) linear navigation; (c) help icon button with audio; (d) static images and (e) tolerance for error. On the other hand, the TUIs framework was verified by experts and TUIs design guideline were created based on the TUIs framework to improve learning experiences for children with dyslexia and thus provide an effective reading outcome. Therefore, developers can also use the validated framework as a reference to develop a tangible system for children with dyslexia to cater for their multisensory needs in learning.

7.1.2 The TUIs Design Guideline

In addition, the TUIs prototype developed in this study provides a practical implication of how the design guideline can be implemented in a real-world context. The positive responses from the children with dyslexia who participated in the validation experiment support the effectiveness of the TUIs prototype in supporting their learning to read. The feedback and suggestions provided by the participants also offer insights into potential future improvements to the TUIs system. Overall, this study contributes to the field of human-computer interaction by providing a useful and practical design guideline for the development of TUIs to support learning to read for children with dyslexia in Malay.

Ultimately, the TUI design guideline helps developers or researchers to understand the requirements of children with dyslexia in facilitating their learning sessions. This can contribute to improving the education outcomes of children with dyslexia and empowering them to overcome their learning difficulties. The TUIs design guideline was developed based on a comprehensive literature review, focus group discussions, and expert verification. It was then validated through an experimental study with children with dyslexia. The positive feedback and improvement in learning outcomes from the children with dyslexia validate the effectiveness of the TUIs design guideline. Therefore, it can be regarded as an effective tool for designing user-friendly tangible systems for children with dyslexia to improve their learning outcomes.

7.1.3 A TUIs Prototype as a Proof of Concept

TUIs prototype was developed to validate the design guideline. Some features were not embedded due to limited time and have constraint to implement. The features such as dynamic colour cues embedded in 3D tangible letters can be considered for future development to attract children's attention to the moment when letters' sounds change. In addition, 3D tangible letters with rattling sound at the base of letters was not embedded. However, developers can refine these potential features to be added to enhance the learning experience of children with dyslexia using TUIs.

On the other hand, special education teachers can benefit from the TUIs prototype developed based on the design guideline can be used as a tool for special education teachers to enhance their teaching of children with dyslexia. By incorporating the TUIs system into their teaching, it can make learning more engaging and enjoyable for children with dyslexia, which can lead to improved learning outcomes. Furthermore, the TUIs prototype can serve as a starting point for further research and development with other features to improve children with dyslexia's reading in Malay.

7.3 The Limitations of Study and Future Recommendations

This study discovered the following limitations, which must be addressed in future research:

1) The TUIs prototype developed was restricted to three levels of syllable spelling difficulties in Malay. The spelling content was focused on three levels: easy (CV), medium (V+CV), and hard (CV+CV). It is recommended that other types of syllable patterns need to be included based on the (*Buku Panduan Pengajaran dan Pembelajaran Program Pemulihan Khas Bahasa Melayu*). This is vital for discovering children with dyslexia in early learning potential and improved their reading for better outcomes.

2) The study found that several designs of the TUIs design guideline, such as dynamic colour cues and a hollow base for 3D letters (to put something in the hollow that

triggered a rattling sound) are not implemented. This is due to scarcity of time and information when designing these features in TUI's prototype. Nevertheless, developers or researchers may explore in detail about these features because they could grab the attention of children with dyslexia when they are learning to read and fulfilled their requirements in terms of evaluating the effectiveness of the TUIs.

Based on the findings of the validation of the design guideline, the study concluded that the TUI design guideline can assist developers to develop a prototype for children with dyslexia. This is a result of the high preference from children with dyslexia, that tends to explore this type of tangible technology because it allows them to engage their sense of touch, which can help them better understand and retain information. Future research can focus on developing and integrating these additional features into the TUIs prototype to further enhance its effectiveness in supporting children with dyslexia's learning to read. The further effort could be feasible to enhance this study in terms of developing the dynamic colour cues embedded in 3D tangible letters and adding the rattling sound on each letter that could draw the attention of children with dyslexia.

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Appendix A: Focus group with Special Education Teachers

UNIVERSITI UTARA MALAYSIA
AWANG HAD SALLEH GRADUATE SCHOOL OF ARTS AND SCIENCES, SCHOOL OF COMPUTING

Bahagian A: Latar Belakang

Nama	
Pengalaman mengajar kanak-kanak dyslexia (tahun)	
Nama Sekolah/Pusat Disleksia	SK Kayang
Umur/Tahun kanak2 disleksia yang dipertanggungjawabkan/ atau pernah dikendalikan oleh cikgu	
No. telefon	

Bahagian B (Profil - Kanak-kanak Disleksia)
Soalan

1. Apakah perbezaan mengajar kanak-kanak normal dengan kanak-kanak disleksia?

2. Adakah kanak-kanak disleksia itu mempunyai cabaran dari segi perhatian (*attention*)? Sila jelaskan contoh-contoh yang khusus mengenai cabaran tersebut? *(cabaran dari segi fungsi kognitif; perhatian, tumpuan, penyelesaian masalah, membuat keputusan, ingatan, peniruan)*

3. Apakah jenis sikap kanak-kanak disleksia (*introvert*; pendiam, jarang bercerita, suka memerhati keadaan sekeliling/*extrovert*; ingin tahu, kompetitif, bermotivasi) dan kemahiran lain (visual-spatial) *(Eye-contact masa pembelajaran, mengikuti arahan, memahami arahan, mengekalkan interaksi yang baik- try to relate TUI design)*

4. Apakah cabaran pembelajaran kanak-kanak disleksia dalam literasi (keupayaan membaca dan menulis dalam Bahasa Melayu (BM)?

5. Adakah cabaran mengajar dalam Bahasa Melayu (BM) berbeza dengan subjek-subjek lain?

6. Apakah subjek dan minat peribadi kanak-kanak disleksia (pengkomputeran, permainan dan lain-lain)? *(Adakah terdapat sebarang peralatan khas seperti permainan, perisian (software) atau alatan di rumah seperti peralatan dapur yang digunakan untuk pembelajaran?)*

7. Apakah maklum balas *(feedback)* daripada kanak-kanak disleksia semasa mengajar?
(Masa yang diambil oleh kanak2 disleksia untuk memahami ketika pembelajaran? (Reaksi-lisan/fizikal)) (Reaction-verbal/physical)

Bahagian C
Aktiviti pembelajaran dan Gaya Pembelajaran *(Learning Content and Learning Styles*)

Soalan
1. Bagaimanakah tahap bacaan (*reading level*) bagi kanak-kanak disleksia? *(learning content)/aktiviti pembelajaran)*

2. Apakah jenis aktiviti pembelajaran (*learning content*) dalam Bahasa Melayu (BM) yang sesuai bagi kanak-kanak disleksia yang berpotensi untuk menggunakan TUIs?

i. Pengenalan huruf (Letter recognition)
ii. Ejaan suku kata (Syllables spelling)
iii. Lain-lain. (Sila nyatakan)

____

3. Apakah jenis suku kata *(syllable)* Bahasa Melayu (BM) dalam perkataan yang sesuai untuk kanak-kanak disleksia?
(Sumber: Program Pemulihan Khas: Buku Panduan Pengajaran dan Pembelajaran Bahasa Melayu)

No.	**Suku kata BM dalam perkataan**	
1.	V+KV (vokal + konsonan vokal)	
2.	KV+KV (konsonan vokal + konsonan vokal)	
3.	KV+KV+KV (konsonan vokal + konsonan vokal + konsonan vokal)	
4.	KVK (konsonan vokal konsonan)	
5.	V+KVK (vokal + konsonan vokal konsonan)	
6.	KV+KVK (konsonan vokal + konsonan vokal konsonan) - cawan	
7.	KVK+KV (konsonan vokal konsonan + konsonan vokal)	
8.	KVK+KVK (konsonan vokal konsonan + konsonan vokal konsonan)	
9.	KV+KV+KVK (konsonan vokal + konsonan vokal + konsonan vokal konsonan)	
10.	KVK+KV+KVK (konsonan vokal konsonan + konsonan vokal + konsonan vokal konsonan)	
11.	KVKK (konsonan vokal konsonan konsonan)	
12.	KV+KVKK (konsonan vokal + konsonan vokal konsonan konsonan)	
13.	V+KVKK (vokal + konsonan vokal konsonan konsonan)	
14.	KVK+KVKK (konsonan vokal konsonan + konsonan vokal konsonan konsonan)	
15.	KVKK+KV (konsonan vokal konsonan konsonan + konsonan vokal)	
16.	KVKK+KVK (konsonan vokal konsonan konsonan + konsonan vokal konsonan)	
17.	KVKK+KVKK (konsonan vokal konsonan konsonan + konsonan vokal konsonan konsonan)	
18.	KV+KV+KVKK (konsonan vokal + konsonan vokal + konsonan vokal konsonan konsonan)	
19.	KV+KVK+KVKK (konsonan vokal + konsonan vokal konsonan + konsonan vokal konsonan konsonan)	
20.	KVK+KV+KVKK (konsonan vokal konsonan + konsonan vokal + konsonan vokal konsonan konsonan)	
21.	KVKK+KV+KVK (konsonan vokal konsonan konsonan + konsonan vokal + konsonan vokal konsonan)	
22.	KV+KVKK+KVK (konsonan vokal + konsonan vokal konsonan konsonan + konsonan vokal konsonan)	
23.	Perkataan yang melibatkan diftong dan vokal berganding	
24.	Perkataan yang melibatkan huruf konsonan bergabung (digraf)	

4. Apakah perkataan yang sesuai untuk ejaan mengikut suku kata seperti di bawah?

Tahap merujuk kepada: **Tahap 1 (Tahun 1-3) dan Tahap 2 (Tahun 4-6)**

Suku kata BM dalam perkataan	Tahap	Contoh
1) V+KV		
2) KV+KV		
3) KV+KV+KV		
4) KVK		
5) V+KVK		
6) KV+KVK		
7) KVK+KV		
8) KVK+KVK		
9) KV+KV+KVK		
10) KVK+KV+KVK		
11) KVKK		
12) KV+KVKK		
13) V+KVKK		
14) KVK+KVKK		
15) KVKK+KV		
16) KVKK+KVK		
17) KVKK+KVKK		
18) KV+KV+KVKK		
19) KV+KVK+KVKK		
20) KVK+KV+KVKK		
21) KVKK+KV+KVK		
22) KV+KVKK+KVK		
23) Perkataan yang melibatkan diftong dan vocal berganding		
24) Perkataan yang melibatkan huruf konsonan bergabung (digraf)		

5. Apakah jenis gaya pembelajaran (*learning style*) yang sesuai untuk kanak-kanak disleksia?

i. Aktiviti berstruktur (*Structured activities*). Aktiviti berstruktur menerangkan objektif pembelajaran khusus (*specific*) seperti bermain dengan tujuan *(play with purpose).*

ii. Arahan yang jelas (*Clear instruction*) - Arahan yang jelas dan mudah untuk kanak2 disleksia mengikuti aktiviti seperti pengecaman huruf (*letter recognition*).

iii. Aktiviti ulangan (*Repetition activities*) – Aktiviti ulangan dapat menguatkan ingatan mereka dalam melaksanakan kerja.

iv. Langkah demi Langkah (*Step by step*) - membantu kanak-kanak disleksia menyelesaikan tugasan tersebut, seperti menyusun huruf untuk membina perkataan.

v. Aktiviti Fleksibel (*Flexible Actvities*). Membantu kanak-kanak disleksia untuk mempraktikkan aktiviti pembelajaran berdasarkan keperluan individu kanak-kanak itu.

vi. Pembelajaran aktif (*Active learning*) - *Pembelajaran aktif ialah sebarang aktiviti pembelajaran di mana pelajar mengambil bahagian atau berinteraksi dengan proses pembelajaran, berbanding dengan mengambil maklumat secara pasif.*

vii. Lain – lain

____

____

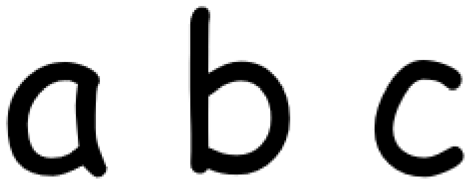
Bahagian D

Ciri Reka Bentuk Interaksi Nyata & Antara Muka Pengguna Nyata

(Design Features of Tangible Interaction & Tangible User Interfaces)

Soalan

1. **Huruf nyata berbentuk 2 dimensi *(2D Tangible Letter)***

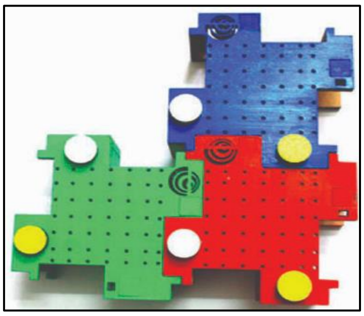


a) Adakah bentuk huruf seperti dalam gambar di atas ini sesuai atau tidak bagi kanak-kanak disleksia?
b) Jika ya, saiz (ukuran) apakah yang sesuai untuk huruf tersebut?
   Panjang ___________
   Lebar _____________
c) Jika tidak, sila cadangkan bentuk yang lebih sesuai untuk huruf tersebut.
d) Warna apakah yang sesuai untuk menarik perhatian dan membantu memudahkan kanak-kanak disleksia mengenal huruf dan membaca?

2. **Huruf nyata berbentuk 3 dimensi *(3D Tangible Letter)***

a) Adakah huruf nyata berbentuk 3 dimensi seperti dalam gambar di atas ini sesuai atau tidak bagi kanak-kanak disleksia?
b) Jika ya, saiz (ukuran) dan bentuk apakah yang sesuai untuk huruf tersebut?
   Panjang ___________
   Lebar _____________
c) Jika tidak, sila cadangkan bentuk yang lebih sesuai untuk huruf tersebut.
d) Warna apakah yang sesuai untuk menarik perhatian dan membantu memudahkan kanak-kanak disleksia mengenal huruf dan membaca?

3. ***Blok elektronik interaktif yang dapat merakam dan memainkan semula suara pra-rakaman sehingga 10 saat (Tangible Block)***



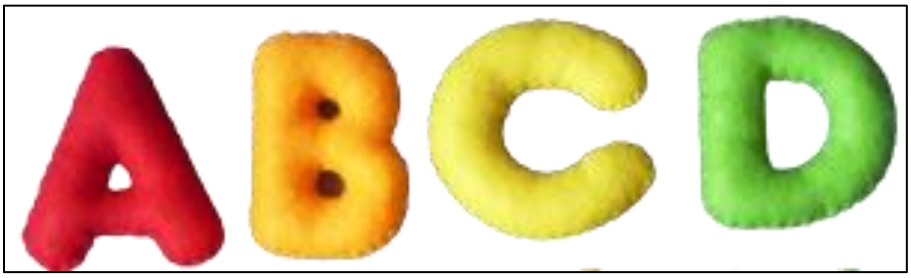
a) Adakah bentuk blok seperti dalam gambar di atas ini sesuai atau tidak bagi kanak-kanak disleksia?

b) Jika ya, saiz (ukuran) apakah yang sesuai untuk blok interaktif tersebut?
Panjang ___________
Lebar ____________

c) Jika tidak, sila cadangkan bentuk yang lebih sesuai untuk huruf tersebut.

d) Warna apakah yang sesuai untuk menarik perhatian dan membantu memudahkan kanak-kanak disleksia mengenal huruf dan membaca?

4. ***Tekstur atau yang tiada tekstur pada permukaan huruf 3 dimensi (3D) atau 2 dimensi (2D) (Texture Cues and Non-Texture Cues)***
**Tekstur pada huruf adalah untuk membezakan orientasi huruf bercermin atau terbalik.*



a) Adakah huruf yang mempunyai tekstur seperti dalam gambar di atas ini sesuai atau tidak bagi kanak-kanak disleksia?

b) Jika ya, tekstur jenis apakah yang sesuai untuk huruf tersebut?
   i. kain felt
   ii. kain guni
   iii. kertas pasir
   iv. lain-lain

c) Adakah kanak-kanak disleksia mempunyai masalah dengan sensori?

5. **Warna Dinamik di dalam Huruf 3D *(Dynamic Colour Cues)***

***** Warna berkelip yang boleh menarik perhatian kanak-kanak pada saat huruf bertukar bunyi/ *Colour flashing that can attract children's attention to the moment that letters change sounds*

a) Adakah warna dinamik di dalam huruf 3 dimensi seperti dalam gambar di atas ini sesuai atau tidak bagi kanak-kanak disleksia?

b) Jika ya, saiz (ukuran) dan bentuk apakah yang sesuai untuk huruf tersebut?

Panjang ____________

Lebar ______________

Tebal ______________

c) Jika tidak, sila cadangkan bentuk yang lebih sesuai untuk huruf tersebut.

d) Warna apakah yang sesuai untuk menarik perhatian dan membantu memudahkan kanak-kanak disleksia mengenal huruf dan membaca?

e) Warna apakah yang mengganggu *(distract)* kanak2 disleksia untuk fokus semasa belajar?

6. **Huruf surih udara menggunakan blok mainan dan bola**

(Air trace alphabets using toy blocks and balls (physical objects))

a) Adakah huruf surih udara menggunakan blok mainan dan bola seperti dalam gambar di atas ini sesuai atau tidak bagi kanak-kanak disleksia?

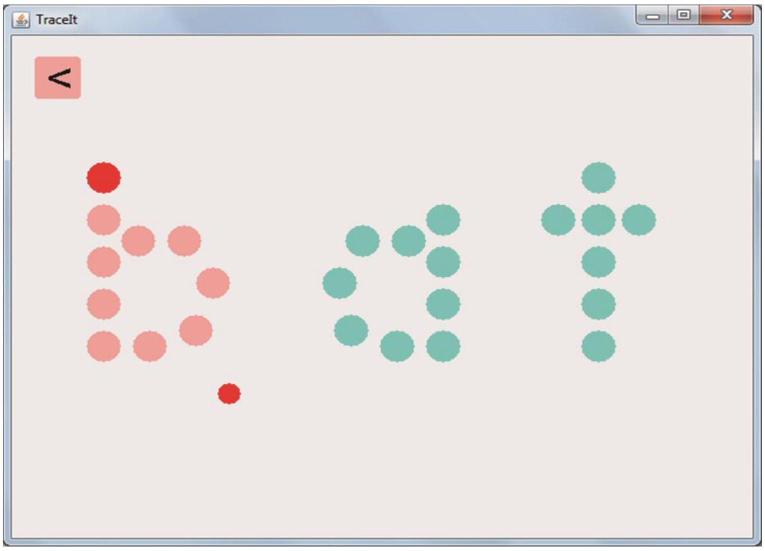
b) Jika ya, saiz dan bentuk apakah yang sesuai untuk huruf tersebut?

Panjang ____________

Lebar ______________

c) Jika tidak, sila cadangkan bentuk yang lebih sesuai untuk huruf tersebut.

7. **Pengecaman berasaskan warna untuk mengesan pergerakan tangan**
(Colour-based recognition to detect the hand motion)



a) Adakah pengecaman berasaskan warna untuk mengesan pergerakan tangan seperti dalam gambar di atas ini sesuai atau tidak bagi kanak-kanak disleksia?
b) Jika ya, saiz (ukuran) dan bentuk apakah yang sesuai untuk huruf tersebut?
Panjang ___________
Lebar _____________
Ketebalan __________
c) Jika tidak, sila cadangkan bentuk yang lebih sesuai untuk huruf tersebut/nyatakan sebab kenapa.

7. Adakah huruf kecil atau huruf besar yang lebih sesuai untuk kanak-kanak disleksia?

8. Adakah perlu untuk menambahkan ciri reka bentuk antara muka pengguna nyata (TUIs) (*design features of TUIs*) selain yang dinyatakan di atas? Sekiranya ya, berikan justifikasi cadangan anda.

Bahagian E
Reka Bentuk Interaksi & Prinsip Reka Bentuk Universal
(Interaction Design & Universal Design Principles)

Soalan

1. Apakah jenis maklum balas (*feedback*) yang sesuai daripada sistem yang akan digunakan untuk kanak-kanak disleksia?

i. Bunyi *(Audio)*
ii. Gambar *(Images/Graphics)* (Bentuk dalam 2 Dimensi atau 3 Dimensi)
iii. Pujian *(Praises)* - Meningkatkan motivasi kanak2 disleksia untuk mencapai dan meningkatkan kepuasan mereka dengan pencapaian mereka
iv. Markah *(Point)*
v. Lain – lain

____

2. Jika jawapan yang diberikan kanak-kanak disleksia adalah salah, apakah cara yang sesuai untuk memberitahu bahawa mereka salah dan perlu menjawab semula? Sila berikan pandangan atau cadangan anda.

3. Apakah elemen reka bentuk dan struktur sistem (*design element and structure of the system*) () yang sesuai untuk kanak-kanak disleksia?

i. Antara Muka Berwarna-warni *(Colourful Interface)*
ii. Navigasi Linear atau navigasi fleksibel atau kedua-duanya *(Linear Navigation or flexible navigation or both)*
iii. Ikon Bantuan (membaca) vs bantuan audio atau kedua-duanya *(Help (reading) vs audio help or both)*
iv. Skrin sentuh atau menggunakan tetikus *(Touch screen or using mouse (platform))*
v. Ikon vs label teks atau kedua-duanya (Icon vs text label or both)
vi. Animasi vs imej statik atau kedua-duanya (Animation vs static images or both)
vii. Pengecaman gerak isyarat menggunakan tangan *(Hand Gesture Recognition)*
viii. Lain – lain.

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4. Berdasarkan prinsip reka bentuk universal (Universal Design Principles) di bawah, prinsip reka bentuk universal yang manakah sesuai untuk kanak-kanak disleksia? Tandakan (a) untuk reka bentuk yang sesuai.

Prinsip	Reka bentuk yang sesuai	✓
a) Penggunaan yang Sama *(Equitable Use)*	i) Menetapkan reka bentuk untuk kanak-kanak disleksia mesti merangkumi semua keperluan pembelajaran kanak-kanak yang lain yang sempurna tanpa memisahkan mereka ke dalam kumpulan atau individu.	
b) Fleksibel dalam penggunaan *(Flexibility in Use)*	i) Gaya pembelajaran yang fleksibel akan membantu kanak-kanak disleksia untuk mempraktikkan pembelajaran berdasarkan keperluan individu kanak-kanak itu. Contohnya, membolehkan kanak-kanak disleksia mengintegrasikan apa yang ingin dipelajari mengikut keperluan/kebolehan mereka.	
c) Penggunaan Sederhana dan Intuitif *(Simple and Intuitive Use)*	i) Membuat reka bentuk antara muka pengguna (*user interface design*) yang mudah dipelajari. Susun atur reka bentuk (*interface design layout*) sistem harus sederhana dan bersih, navigasi (*navigation*) harus mudah dan konsisten, dan dapat dilihat sepanjang masa. ii) Menggunakan ikon dengan jelas untuk reka bentuk antara muka pengguna. iii) Elakkan teks yang banyak pada skrin antara muka pengguna (*user interface design*).	
d) Maklumat yang dapat difahami *(Perceptible Information)*	i) Menggunakan pelbagai kaedah multisensori - visual, audio, dan sentuhan untuk penyampaian maklumat penting. Sebagai contoh, penggunaan kaedah yang berbeza untuk kanak-kanak disleksia dalam belajar membaca dapat merangsang otak mereka sehingga meningkatkan pembelajaran dengan mempunyai tekstur pada huruf untuk menarik perhatian kanak-kanak ketika belajar. ii) Menyampaikan maklumat yang mudah dan cepat difahami tanpa sebarang gangguan.	

	iii) Menggunakan fon yang sesuai untuk kanak-kanak disleksia	
e) Toleransi untuk Ralat *(Tolerance for Error)*	i) Membolehkan kesalahan diundurkan atau diminimumkan, misalnya, mengeluarkan mesej (*the audio feedback message*).	
f) Usaha Fizikal Rendah *(Low Physical Effort)*	i) Arahan direka bentuk *(instruction is designed)* untuk mengurangkan usaha fizikal yang berterusan untuk membolehkan perhatian maksimum terhadap pembelajaran. Contohnya, mengurangkan tindakan yang berulang-ulang. Reka bentuk boleh digunakan dengan cekap dan selesa dan mengurangkan keletihan *(minimum of fatigue).* ii) Ciri reka bentuk huruf nyata berbentuk 3 dimensi *(3D tangible letter)* mestilah: • bersaiz tangan dan dibuat daripada bahan yang ringan dan selamat, mudah diambil dan mudah dipegang oleh kanak-kanak disleksia • Huruf mesti ditegakkan supaya kanak-kanak disleksia dapat mengaturnya dengan mudah di ruang yang disediakan (platform).	
g) Ukuran dan Ruang untuk Pendekatan dan Penggunaan. *(Size and Space for Approach and Use)*	a) i) Saiz huruf ketara 3D hendaklah mudah dimanipulasi, diatur dan dikawal oleh kanak-kanak disleksia. ii) Papan ejaan hendaklah mempunyai ruang yang mencukupi untuk meletakkan huruf. Guru dapat membantu kanak-kanak disleksia untuk fokus ketika memasukkan huruf 3D ke dalam ruang yang disediakan.	

Appendix B: Questions for Expert Review

A Tangible User Interfaces Design Guideline for Children with Dyslexia

EXPERT REVIEW FRAMEWORK AND DESIGN GUIDELINE VERIFICATION FORM

Dear Prof./Assoc. Prof./Dr/Ts. /Sir/Madam,

My name is Nurul Izzah Abdul Aziz, a PhD of Information Technology (IT) candidate at Universiti Utara Malaysia. Firstly, I would like to thank you for agreeing to be part of this study as an expert to verify a newly proposed framework and design guideline attempting to construct effective tangible user interfaces (TUIs) specifically for children with dyslexia. Further information on the proposed framework and design guideline is provided.

The questionnaire consists of FIVE (5) sections; expert demographic, tangible representations, intangible representations, digital information and framework components of the proposed framework and design guideline. Kindly review the framework and design guideline and complete the questionnaire. All the information will only be used for research purposes, and feel free to give suggestions after the review.

Confidentiality

All information treated as highly CONFIDENTIAL and used for academic purposes only.

My supervisors can be reached via their e-mails or by mobile phone numbers:

1) Name: Assoc. Prof. Dr. Husniza Husni	2) Name: Assoc. Prof. Ts. Dr. Nor Laily Hashim
Email: husniza@uum.edu.my	Email: laily@uum.edu.my
Office number: +604-9285184	Office number: +604-9285173
Mobile Phone Number: +6017- 4707954	Mobile Phone Number: +6019- 5110666

Thank you in advance for your precious time and cooperation.

Nurul Izzah Abdul Aziz
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nurulizzahabdulaziz@gmail.com
PhD (IT) candidate,
Universiti Utara Malaysia

The Proposed Framework of TUI for Children with Dyslexia

This review aims to verify the proposed framework and design guideline of TUIs. This study proposes a TUIs framework and design guideline with a primary focus on the tangible representation to facilitate learning to read in Malay for children with dyslexia. The TUIs framework as shown in Figure 1 is proposed based on Ulmer and Ishii's framework (Ullmer & Ishii, 1997; Ullmer & Ishii, 2008).

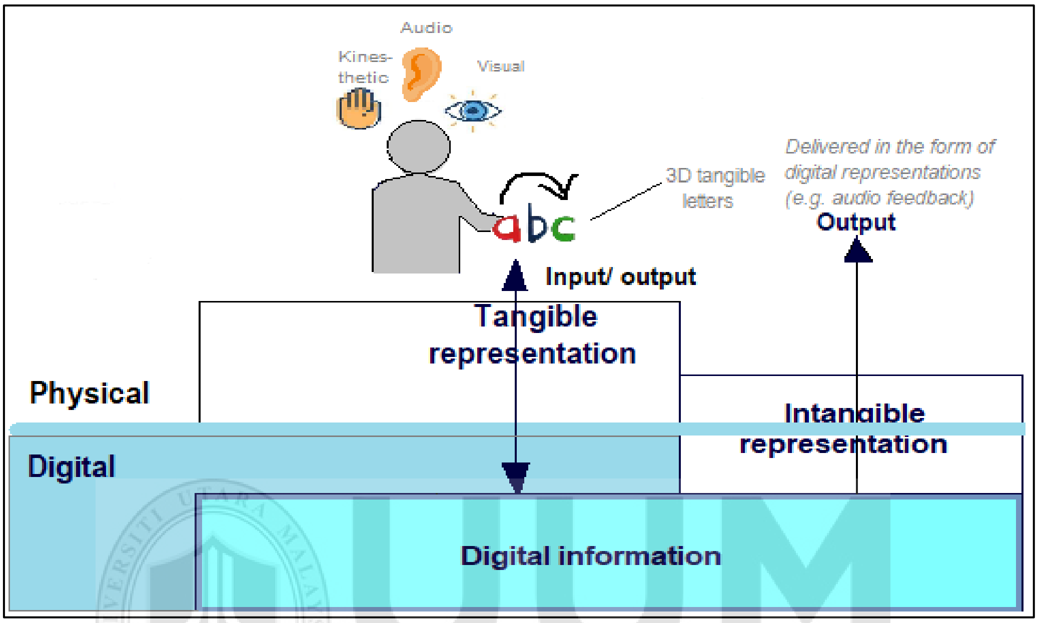

Figure 1 *Overview of the TUIs framework*

The construction of the design guideline of TUIs is based on the analysed framework components i.e., tangible representations, intangible representations, and digital information in order to ensure that the design guideline is suitable for supporting children with dyslexia learning to read in Malay. The description of the framework and design guideline is provided together with the verification forms.

The design guideline was constructed based on framework components of TUI, as shown in Figure 2. Table 1 describes the framework components and sub-component designs for the proposed design guideline.

The Proposed Design Guideline of TUIs for Children with Dyslexia

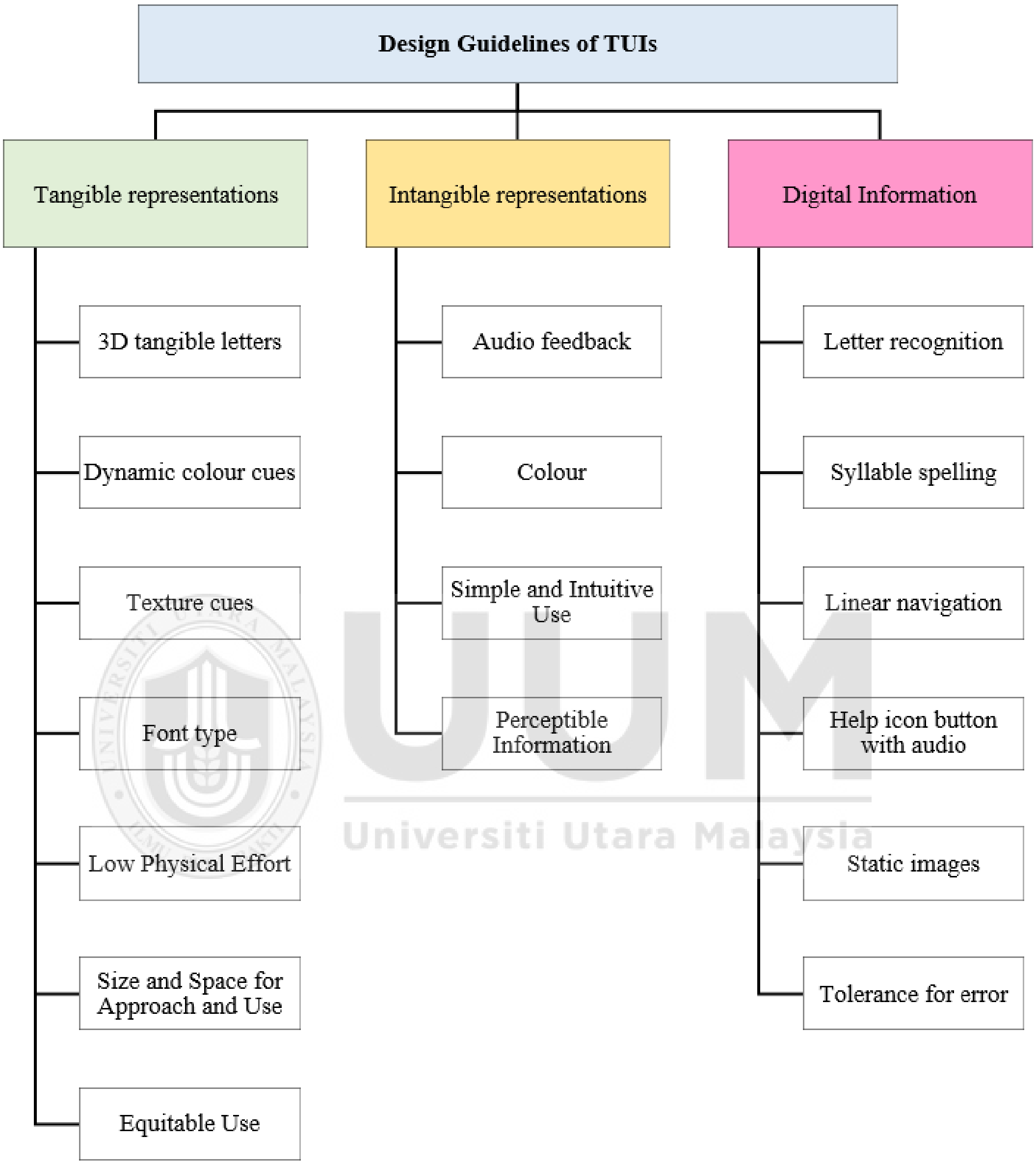

Figure 2 Overview *of the TUIs design guideline*

Table 1 Description of proposed TUIs Design Guidelines

Design Guideline of TUIs		
Framework Components	**Sub. components**	**Description**
Tangible representations *The tangible representations of TUIs function as an interactive physical control.*	1) 3D tangible letters	Use a three-dimensional (3D) letter that can allow children to easily organise them in space (spelling board).
	2) Texture cues	Use felt fabric on letters to invoke touch sensory response for children with dyslexia.

It can be physically inert, moving solely as manipulated by a user's hands.	3) Dynamic colour cues	Use dynamic colour cues on 3D tangible letters to draw attention to the point when the sounds of letters change.
	4) Font type	i) A special font type using '*papan sintok'* letter shapes. ii) Use lowercase letters to avoid mirrored letters.
	5) Low Physical Effort	i) Instruction is designed to reduce the constant physical effort to allow maximum attention to learning. ii) The design can be used efficiently and comfortably and reduces fatigue. The design features of 3D tangible letters must be: – Hand-sized and made of a lightweight and safe material. – Letters should be easy for children with dyslexia to pick up and handle. – Letters must stand up on their own so that the children can easily organize them in space. – Have plenty of space on the table to place all the letters
	6) Size and Space for Approach and Use	i) The size of 3D tangible letters should be easy for children with dyslexia to manipulate, arrange, and control. ii) The spelling board should have adequate space for the letters to be placed.
	7) Equitable Use	Setting up a design of hand-size physical object for children with dyslexia is perfectly cover all the learning needs of normal children without separating them into groups or individuals.
Intangible representations *Intangible representations are computationally mediated displays that are perceptually observed in the world but are not physically embodied, and thus "intangible" in form.* *The intangible representation of TUI, primarily the visuals and audio, disseminates sufficient dynamic information provided by the underlying computation.*	**1)** Audio feedback	i) Use audio feedback, for example, voice-over to read instructions. ii) Use a signal sound like "try again" for them to get motivated to do the question again when they make a mistake. iii) Use applause sound (praise).
	2) Colour	i) Use colourful interface background colour code. ii) The colour of the letters should be in contrast to the background.
	3) Simple and Intuitive Use	i) Create a user interface layout that is easy to learn. The system's user interface should be simple and clean, with easy, consistent, and visible navigation at all times. ii) Use icons clearly for user interface design. iii) Avoid a lot of text on the user interface design.

	4) Perceptible Information	i) Use different multisensory modalities to deliver important information, such as visual, audio, and tactile. For example, adding textures on the letters to engage the child can stimulate their brains, thus enhancing learning). ii) Provide and deliver easy and quick information to understand without interruption. iii) Use fonts type that is suitable for children with dyslexia.
Digital Information *Digital information is directly manipulatable with our hands and perceptible through our peripheral senses by physically embodying it. TUI attempts to embody the digital information in physical form, maximizing the directness of information by coupling manipulation to the underlying computation*	1) Letter recognition	Identify vowel and consonant letters which helps children with dyslexia recognise letters and associate them with images of the letters while learning.
	2) Syllables spelling	Identify syllables based on letter sounds. In this learning content, the children with dyslexia are able to arrange and use different senses to manipulate the tangible letters.
	3) Linear Navigation	Use linear navigation in the TUI prototype.
	4) Help icon button with audio	Provide a help icon button with audio (audio help)
	5) Static images	Use a static image in the learning contents for children with dyslexia.
	6) Tolerance for error	Allows errors to be reversed or minimised; for example, audio feedback message

Dear Prof./Assoc. Prof./Dr/Ts. /Sir/Madam,

Please complete the evaluation form as attached for verification purposes of the proposed framework and design guideline.

Section A: Expert Demographic

*Name (Optional) :
Qualification :
Specialization :
Years of Experience :

Section B: Tangible representations

This section is for verification of the proposed design guideline of TUIs. The tangible representations include font type, texture cues, dynamic colour cues, 3D tangible letters, low physical effort, size and space for approach and use, and equitable use.

There are a set of statements using a five-point Likert scale. A rating of 1 indicated strong disagreement with the statements, a rating of 3 indicated neutral opinion of the statement, whereas a rating of 5 indicated strong agreement with the statements.

1= Strongly disagree, 2= Disagree, 3= Neutral, 4= Agree, 5 =Strongly Agree

Please tick the scale accordingly.

No.	Tangible representations	1	2	3	4	5	Remarks
1.	3D tangible letters as specified in the design guideline are suitable for children with dyslexia.						
2.	Texture cues (felt fabric) as specified in the design guideline are suitable for children with dyslexia.						
3.	Dynamic colour cues as specified in the design guideline are suitable for children with dyslexia.						
4.	Font type as specified in the design guideline is suitable for children with dyslexia.						
5.	Low physical effort where the design of 3D tangible letters can be used efficiently, and comfortably and reduces fatigue.						
6.	Size and space for approach and use where the design of 3D tangible letters are light, easy to touch, move, arrange, and control on the spelling board.						
7.	Equitable Use - setting up a design (hand-size physical object) for children with dyslexiais perfectly cover all the learning needs of normal children.						

8. Does the proposed design guideline need to add/drop any of the proposed tangible representations? If yes, please provide your point of view.

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Section C: Intangible representations

This section is for verification of the proposed suitable design based on intangible representations. There are a set of statements using a five-point Likert scale. A rating of 1 indicated strong disagreement with the statements, a rating of 3 indicated neutral opinion of the statement, whereas a rating of 5 indicated strong agreement with the statements.

1= Strongly disagree, 2= Disagree, 3= Neutral, 4= Agree, 5 =Strongly Agree

Please tick the scale accordingly.

No.	Intangible Representations		1	2	3	4	5	Remar
9.	Audio feedback	i) Use audio feedback such as a voice-over for each instruction.						
		ii) Use a signal sound like "try again" to motivate them to do the question again when they						
		iii) Use applause sound (praise).						
10.	Colour	i) Use colourful interface background colour code.						
		ii) The colour of the letters should be in contrast to the background.						
11.	Simple and Intuitive Use	i) Create a user interface layout that is easy to learn.						
		ii) Use icons clearly for user interface design.						
		iii) Avoid a lot of text on the user interface design.						
12.	Perceptible Information	i) Use different multisensory modalities such as visual, audio, and tactile to deliver important information.						
		ii) Provide and deliver easy and quick information to understand without						
		iii) Use font types that are suitable for children with dyslexia.						

13. Does the proposed design guideline need to add/drop any of the proposed intangible representations? If yes, please provide your point of view.

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Section D: Digital Information

This section verifying the digital information proposed in the guideline. Hence, there are a set of statements using a five-point Likert scale. A rating of 1 indicated strong disagreement with the statements, a rating of 3 indicated neutral opinion of the statement, whereas a rating of 5 indicated strong agreement with the statements.

1= Strongly disagree, 2= Disagree, 3= Neutral, 4= Agree, 5 =Strongly Agree

Please tick the scale accordingly.

No.	Digital Information	1	2	3	4	5	Remarks

14.	Letter recognition as specified in the design guideline is suitable to enhance children with dyslexia in learning to read in Malay.						
15.	Spelling, which identifies the syllables based on the sound of letters, as specified in the design guideline is suitable for improving children with dyslexia learning to read in Malay.						
16.	Linear navigation as specified in the design guideline is suitable for children with dyslexia.						
17.	The help icon button with audio (audio help) as specified in the design guideline is suitable for children with dyslexia.						
18.	Static images in the learning contents as specified in the design guideline are suitable children with dyslexia.						
19.	Tolerance for error allows errors to be reversed or minimized; for example the audio feedback message.						

20. Does the proposed design guideline need to add/drop any of the proposed digital information? If yes, please provide your point of view.

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Section E: Framework Review

This section is for verification of the proposed framework of TUIs for children with dyslexia. There are three components: tangible representation, intangible representation, and digital information.

There are a set of statements using a five-point Likert scale. A rating of 1 indicated strong disagreement with the statements, a rating of 3 indicated neutral opinion of the statement, whereas a rating of 5 indicated strong agreement with the statements.

1= Strongly disagree, 2= Disagree, 3= Neutral, 4= Agree, 5 =Strongly Agree

Please tick the scale accordingly.

No.	Framework Review	1	2	3	4	5	Remarks
21.	The whole framework is clearly presented.						
22.	The framework components in the TUIs framework are defined clearly.						
23.	All relations of the framework components are clearly presented.						

24.	The design of tangible representations as specified in the framework are suitable for children with dyslexia.						
25.	The design of intangible representations as specified in the framework are suitable for children with dyslexia.						
26.	The design of digital information as specified in the framework are suitable for children with dyslexia.						

27. Does the proposed TUIs framework need to add/drop any of the proposed framework components? If yes, please provide your point of view.

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Comments:

Thank you.

Appendix C: Penerangan Tugasan untuk Kanak-kanak Disleksia

Objektif: Kenalpasti huruf 3D dan susun pada papan ejaan

	Tugasan	Penerangan
1.	Kenalpasti huruf 3D	Berikan arahan dan panduan kepada murid untuk cuba bermain dengan memegang dan menyebut satu persatu huruf 3D.
2.	Letakkan huruf di papan ejaan	Berikan arahan kepada murid untuk meletakkan huruf di papan ejaan
3.	Kenalpasti huruf di paparan skrin	Perhatikan murid tersebut sama ada mereka dapat mengenal dan menyebut huruf yang dipaparkan pada skrin Tunjukkan kesemua 26 huruf pada skrin computer selama 8 saat untuk setiap satu huruf.
4.	Susun huruf di papan ejaan berdasarkan arahan dan panduan di paparan skrin	• Apabila murid telah bersedia dan boleh menyusun huruf di papan ejaan, Arahkan murid untuk meletakkan huruf yang betul berdasarkan arahan serta panduan di paparan skrin bermula dari huruf ‘a’ sehingga huruf ‘z’. • Berikan arahan untuk menyebut dan membunyikan setiap huruf tersebut. • Setiap murid disleksia yang menjalani kajian ini adalah berdasarkan tahap bacaan dan dipilih oleh guru program pendidikan khas integrasi (PPKI) yang tahu tahap bacaan setiap murid yang dipilih.

5.	Eja perkataan berdasarkan suku kata:
	
	i. KV
	ii. V+KV
	iii.KV+KV
		Tugasan ini hendaklah berdasarkan tahap bacaan murid tersebut.
		
		• Eja perkataan mengikut suku kata KV yang dipaparkan di skrin:
		  • **ba/be/be/bo/bi/bu**
		• Eja perkataan mengikut suku kata V+KV yang dipaparkan di skrin:
		  • **ubi/uli/ibu/ api/isi**
		• Berikan arahan dan panduan jika mereka tidak dapat mengenalpasti gambar yang dipaparkan pada skrin.
		• Eja perkataan mengikut suku kata V+KV yang dipaparkan di skrin:
		  • **buku/meja/pasu/paku/bola**

		• Berikan arahan dan panduan kepada murid jika mereka tidak dapat mengenalpasti gambar dipaparan skrin.

Appendix D: Soal Selidik untuk Peserta (Kanak-kanak Disleksia)/

Questionnaire for Participants (Children with Dyslexia)

Bahagian A: Demografi Peserta

Nama	Umur	Jantina

Bahagian B: Pengalaman Antara Muka Pengguna *(User Interface Experience)*
Sila tandakan jawapan yang paling sesuai yang menunjukkan pengalaman peserta dengan antara muka pengguna.

1	**2**	**3**	**4**	**5**
Awful	Not Very Good	Good	Very Good	Brilliant

Soalan	**1**	**2**	**3**	**4**	**5**
1. Pernahkah kamu mempunyai pengalaman menggunakan antara muka pengguna berasaskan sentuhan *(touch-based user interfaces)*, seperti tablet atau telefon pintar?					
2. Pernahkah kamu mempunyai pengalaman menggunakan antara muka pengguna yang ketara *(tangible user interfaces)*, di mana objek fizikal bersambung dengan maklumat digital?					
3. Adakah kamu berpuas hati dengan ciri prototaip?					
4. Adakah prototaip membantu kamu belajar membaca?					
5. Adakah kamu berminat untuk terus menggunakan prototaip ini pada masa akan datang?					
6. Adakah prototaip ini mudah digunakan?					

Section C: Keberkesanan (*Effectiveness*)

1	2	3	4	5
Awful	Not Very Good	Good	Very Good	Brilliant

Soalan	1	2	3	4	5
7. Bagaimanakah kamu mencapai tugasan (mengenal huruf) menggunakan prototaip TUI ini?					
i) Sejauh manakah kamu boleh membezakan huruf bercermin (mirrored letters) ?					
ii) (b, d, p, q, n, u, h, m, w)					
8. Bagaimanakah kamu mencapai tugasan mengeja (spelling) dengan menggunakan prototaip TUI ini?					
9. i) Sejauh manakah kamu dapat mengeja perkataan-perkataan ini?					
ii) Jika ya, berapa banyak perkataan yang boleh kamu mengeja dengan menggunakan prototaip TUI ini?	_______________ perkataan				
10. Sejauh manakah prestasi kamu untuk menyelesaikan tugasan dengan menggunakan prototaip TUI ini?	**1**	**2**	**3**	**4**	**5**

Section D: Ciri Reka Bentuk TUIs (*Design Features of TUIs)*

Sila tandakan jawapan yang paling sesuai yang menunjukkan pengalaman peserta dengan ciri reka bentuk TUI.

1	2	3	4	5
Awful	Not Very Good	Good	Very Good	Brilliant

Soalan	1	2	3	4	5
11. Adakah kamu suka huruf ketara 3D *(3D tangible letters)*?					
12. Adakah kamu rasa huruf ketara 3D membantu anda belajar membaca dalam bahasa Melayu?					
13. Adakah kamu suka isyarat tekstur *(texture cues)* pada huruf 3D?					
14. Adakah kamu rasa isyarat tekstur pada huruf 3D tersebut membantu kamu belajar membaca dalam bahasa Melayu?					
15. Adakah kamu suka jenis fon ini?					
16. Adakah kamu rasa jenis fon ini membantu kamu belajar membaca dalam bahasa Melayu?					

17. Apakah ciri-ciri lain prototaip TUIs yang kamu suka/tidak suka dan mengapa?

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18. Cadangan untuk ciri reka bentuk seterusnya.

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Appendix E: Focus Group Transcribe Data

PART A: TEACHER'S BACKGROUND

Pengalaman mengajar kanak-kanak dyslexia (tahun) : 2-5 Tahun

Nama Sekolah/Pusat Disleksia: SK Kayang

Umur/Tahun kanak2 disleksia yang dipertanggungjawabkan/ pernah dikendalikan oleh cikgu : Tahun 1 -Tahun 6

PART B: PROFILE CHILDREN WITH DYSLEXIA

Q1: Apakah perbezaan mengajar kanak2 normal dengan kanak2 disleksia?

Cikgu Aizat: Kanak2 normal nie nak beza dia dgn disleksia, tak boleh nak kata disleksia sb murid masih lagi dalam proses nak belajar semua, Jadi dalam tahun 2, dah belajar jadi murid tahu mana huruf kecil atau besar. Disleksia nie bila kita dah ajar dia tetap buat kesalahan. darjah 1 dah ajar, tapi darjah 2/3 masih buat kesalahan yang sama. Bneda dah diajar tapi tetap dia buat kesalahan.
Huruf p dgn b keliru. tak boleh nak beza mana huruf p, mana satu huruf b. cikgu boleh tau ciri2 keberangkalian disleksia. Cuma yang boleh sah kan disleksia nie cuma doktor. bila jumpa doctor, terus masalah pembelajaran, yang plus dengan hyperactive.kebanyakan nya bukan disleksia saja, dia dah campur2 dgn penyakit lain. Ada juga masalh pembelajaran disleksia saja pun ada tapi tak banyak, kalau disleksia + hyper/autism tu banyak jugak dah kat sekolah. Dari segi harian, kadang2 pakai kasut kanan kiri pun xtau, tarikh lahir tak ingat.

Cikgu Hamidah: Kalau ajar harini esok kita tanya tak ingat dah.
Cikgu Aizat: masa menulis huruf kecik besar, patut huruf kecil jadi huruf besar, yang huruf besar jadi huruf kecil.

Cikgu Suhaila: Murid disleksia slow sikit daripada budak normal, kena ikut tahap dia untuk ajar, tak boleh ikuit silibus perdana, walapupun darjah 6 dia xboleh membaca kita kenal ajar dia membaca, kalua tak kenal huruf kita kena ajr dia untuk kenal huruf semula. kalau budak normal tu xsemestinya darjah 6 tak kenal huruf kalau disleksia ada yang tak kenal huruf lg. Tu saja perbezaan dia dengan budak normal.

Cikgu Hamidah: Dia focus sekejap saja, setengah jam ja dia boleh. lepas tu dia nampak tulisan macam menari nari..berombak..dia tak selesa, lepas setengah jam dia nak bergerak dari tempat dia, nak mainan ...bila kita nak ajar, dia buat perangai lah, jadi kami cikgu kena sediakan mainan ka apa bagi dia behave..tak begerak merata.

Cikgu Aizat: Kalau depa masuk kelas biasa/perdana depa kena marah bila buat silap tapi cikgu class perdana tak tau kata depa disleksia. tapi bila dah pkp masa covid nie , budak normal pun saya nampak ada ciri2 disleksia, ramai dah..mungkin dekat rumah kita tak tau dia belajar betul ka dak,ada mak ayah bantu ka tidak jadi bila dtg sekolah kita dapat kesan nak membaca tak boleh, menulis pun tak reti..banyak lupa tak ingat.

Q2: Adakah kanak-kanak disleksia itu mempunyai cabaran dari segi perhatian (attention)? Sila jelaskan contoh-contoh yang khusus mengenai cabaran tersebut? (cabaran dari segi fungsi kognitif; attention, concentration, problem solving, decision making, memory, imitation)

Cikgu Aizat: Kalau macam disleksia nie, dia belajar ikut sukatan perdana aliran untuk budak biasa.Contoh dia xboleh menulis dengan betul, tu cabaran utk budak.

Yang kedua, cikgu pulak pada masa yang sama kena habis sukatan, tapi budak xboleh nak membaca, nak bg boleh membaca dulu kita dah terikat dengan sukatan.lepas tu budak2 nak kena ambil UPSR masa dulu pulak, kalau budak2 tak terlibat dengan UPSR takpa, boleh cikgu2 ajar dulu, dah boleh baca sikit boleh selit2 tajuk lain. kalau ajar pun nak baca tak boleh tak guna jugak.Jadi cikgu terpaksa buat kelas membaca untuk dia seorang. lepas tu budak2 lain kena ajar jugak. kalau cabaran untuk budak disleksia pulak, aku dah tak boleh membaca, cikgu ajar kata sendi pulak , macam mana pulak nak pahamkan. Cikgu memang nak kena ajar jugak sebab sukatan silibus perdana.

Kalau PPKI sepenuh masa memang dah ada sukatan/silibus khas untuk dyslexia. Jadi kita terpaksa turunkan aras untuk budak disleksia nie. Kalau darjah 6 tak boleh membaca, nak buat pemahaman cikgu kena tolong baca arahan, makan masa kat situ, soalan tak boleh baca, cikgu kena tolong baca jugak.

Dari segi tingkah laku, ada yang aktif, yang slow learner tu nampak lah ada yang jenis pasif, tak mau berkawan dengan orang. kena seorang2. sekarang kelas inklusif separa, jadi yang pasif memang tak boleh join yang kelas perdana.

Kami disini ajar yang subjek teras saja, macam Bahasa Melayu dengan Matematik. jadi kalau seubjek Pendidikan Islam tu yang disleksia nie taknak pergi ke kelas perdana biasa, jenis tak boleh bercampur dengan kelas biasa, bila kita beritahu esok masuk kelas sana untuk subjek agama esok dia tak mau datang sekolah. Dia buat perangai. tak nak orang dtg ramai2 kat dia

Cikgu Hamidah: nak masuk ke kelas biasa tu disleksia nie macam susah bagi dia nak biasakan diri. tak sampai masa lagi dia nak masuk kelas normal. dia akan berubah jugak slow2. Cuma masa belum sampai lagi.

Contoh darjah 6, murid nama Nabil. masuk darjah 5 cikgu slow2 hantar ke kelas biasa, lama2 dia boleh jugak terima.

Cikgu Aizat: Tapi bila disleksia nie sepenuh masa kat PPKI, kita kena bagitahu parent, sepatutnya kena belajar di kelas biasa, skrg orang rekod tahap pencapaian, jangan pertikai kalau cikgu bagi tahap 1, kalau parent kata tahap tak penting asalkan anak mau dtg sekolah, tapi jangan pertikai kenapa anak saya dapat tahap 1 takpa dah.

Cikgu Suhaila: Cabaran paling utama sekali kesabaran kena tinggi sebab budak2 pendidikan khas nie dia tak kan tau kita nak marah..dia tak kan tau..kalau dia buat silap apa kita tak boleh marah..kena faham sb dia bukan budak normal, kena bagitahu apa yang silap. walaupun kita terankan esok dia buat silap lagi.dia tak boleh nak jangka kita akan amrah bila dai boelh buat silap.

Cikgu Aizat: Kalau yang jenis hyperactive bila kita marah dia duduk tak diam balik. kita sebagai cikgu ada cara lah kita kena buat bagi dia behave. Kita sebagai cikgu kena faham dan tak boleh nak marah sangat

Cikgu Hamidah: Saya pernah ajar kelas normal ada seorang student nama Fakhrul dia jenis hyperactive. tapi lepas masuk class ppki dia berubah..slow2 dah makin kurang hyperactive, dia boleh control diri dia bila masuk darjah 3.. Dia boleh focus dah..sb makin matang..

Cikgu Muhairi: Kalau hyperactive nie makin besar diam akan kurang dah. makin meningkat ke skolah menegah akan kurang sendiri.

Cikgu Aizat: Bila kita jaga budak2 di skolah kan.. balik sekolah parents pulak kena jaga. kita nampak beza budak2 kalau parent ambil berat..dari segi pelajaran nampak perbezaan dengan budak2 yang parent tak ambil berat ..kalau yang parent jenis jaga anak masa pdpr haritu..dari segi kerja cikgu bagi mereka buat..ada perkembangan..boleh membaca dah. bila tanya sapa ajar? adik beradik tolong ajar baca..kalau yang parent tak ambil tahu.. mmg tak boleh sangat lah nak membaca..

Q3: Apakah jenis sikap kanak-kanak disleksia (*introvert*; pendiam, jarang bercerita, suka memerhati keadaan sekeliling/*extrovert*; ingin tahu, kompetitif, bermotivasi) dan kemahiran lain (visual-spatial)

Cikgu Aizat: Ada. Nama Raisya dengan Aqil Rifqi.. Di sekolah lama cikgu bagitau dia suka Lukis bendera..Tingkah laku dia lain..Bila tengok bendera sekolah koyak ..dia akan tanya kenapa tak tukar bendera baru? Dia akan marah bendera tak elok dan Nampak buruk..Raisya suka nyanyi..suka menari..ikut tarian dalam video youtube yang dia tengok kat rumah..

Cikgu Hamidah: Raisya nie macam duduk dekat dunia khayalan dia..Kat rumah mak dia suka tunjuk video2 dalam youtube..

Cikgu Suhaila: Imaginasi dia terlalu tinggi..dia boleh duduk bercakap sorang2 1 atau 2 jam..

Cikgu Hamidah: Dia macam dalam dunia kanak2..macam dalam umur 4 tahun yang suka cakap sorang2 nie..padahal dah umur 10 tahun.

Cikgu Aizat: Ada lagi dua orang dia jenis family yang jenis speaking. Sebelum nie ingat dua orang nie jenis pendiam. Tapi rupanya bila jumpa dua orang nie dia boleh sembang berdua speaking..Saya pernah pergi rumah dia memang family jenis tengok channel CNN, baca surat khabar pun Bahasa Inggeris. memang jenis persekitaran dia dalam Bahasa Inggeris..Dia siap tanya kawan2 kat sini siapa lagi yang boleh cakap BI? Memang kalau cakap melayu pun ada slang BI.

Cikgu Hamidah: Dalam kelas dua2 senyap sebab kelas lain2. Tapi bila jumpa time rehat dua2 akan speaking bersembang.

Q4: Apakah cabaran pembelajaran kanak-kanak disleksia dalam literasi (keupayaan membaca dan menulis dalam Bahasa Melayu (BM)?

Cikgu Aizat: Budak2 lambat boleh membaca. Ada yang laju membaca okay lah. Dia bnyak tahap.. Ada yang mengeja baru boleh membaca..ada yang baca terus..ada yang kita kena tolong membaca baru boleh ikut. kalua nak membatang sukukata pun tak boleh..ada yang huruf pun tak kenal lagi..tahap membaca suku kata kv. berbeza setiap budak..ada yang boleh KVK..yang darjah 6 boleh membaca..4 daripada 6 orang darjah 6 boleh membaca dah..nak kata lancar tu tak lah sangat..kalau kita bagi buku cerita tu dia boleh habiskan membaca lah..

Cikgu Hamidah: Kalau ayat pun yang mudah2 saja. yang susah2 memang tak boleh lagi..

Cikgu Suhaila: Ada yang tak kenal huruf..darjah 6 lagi dua orang tu tak boleh.. tahap tak sama setiap budak.

Cikgu Muhairi: macam tahun 5 ada 10 orang. Ada sorang boleh membaca..yang lain tu memang banyak tahap lah aklau satu class tu.Kita kena bantu semua..kena ulang2 banyak kali..silibus memang tinggi,kita kena turun aras..untuk tolong budak2..

Cikgu Aizat: Budak2 boleh bertutur saja..kalau suruh baca menulis tak berapa sangat..bila suruh menulis dia lemah..ada yang boleh membaca menulis tak boleh..ada yang boleh membaca menulis tak boleh..

Cikgu Hamidah: Ada yang pandai bercakap..bila suruh menulis tak nak...

Cikgu Suhaila: Budak disleksia nie tak suka membebankan diri dia. Jangan bagi kerja banyak2 , kalau banyak dia tak nak buat terus.

Cikgu Muhairi: Latihan tak mau banyak2. sikit2 ja..kalau Latihan banyak dia mula boring dan tak mau buat dah.

Q5: Adakah cabaran mengajar dalam Bahasa Melayu (BM) berbeza dengan subjek-subjek lain?

Cikgu Aizat: Saya ajar Matematik Tahun 6, Kalau tengok Buku teks Tahun 6, bagi saya buku teks darjah 6 tu memang tak sesuai langsung untuk disleksia..sebab samapai nilai juta..darab pun tak boleh ingat konsep..hafal sifir lagi lah tak susah, tengok 1000 x 200 tu masing2 dah lain muka tengok buku..Saya ajar sains pun ada..lepas sekolah kami banyak bukak video youtube..budak2 suka tengok..lebih tertarik video . yang mencabar masa pkp lah..

Cikgu Hamidah: kita boleh ajar asas2 yang mudah..yang boleh bdk2 terima..kalau susah Sangat bdk2 tak focus..kalau tak kita yang seronok sendiri..

Cikgu Muhairi: yang penting asas lah untuk budak2 boleh terima..

Cikgu Aizat: yang mencabar masa pkp lah..masa budak di rumah.kita bagi video rujuk soalan. ada yang hantar kerja sekolah ada yang tak masuk langsung..Cuma kita kurang puas sebab tak boleh face 2 face kita tak tau betul ka dia yang buat kerja sekolah tu..kita nak suruh mengeja membaca pun dah tak leh masuk online..macam amtematik lagi susah lah untuk disleksia ..

Cikgu Suhaila: apa pun asas dia budak2 mesti boleh membaca. kalau tak boleh membaca ilmu yang kita nak sampaikan budak2 susah nak terima.

Q6: Apakah subjek dan minat peribadi kanak-kanak disleksia (pengkomputeran, permainan dan lain-lain)? (Are there any special appliances such as games, software, or home objects such as kitchen utensils used for learning? / Adakah terdapat sebarang peralatan khas seperti permainan, perisian atau alatan rumah seperti peralatan dapur yang digunakan untuk pembelajaran?)

Cikgu Aizat: Media elektronic...budak2 lebih kepada yang tu.. bukan sekadar papan putih. Kaedah emlalui..tikotok /video budak2 lebih tertarik..quizzies budak2 suka..walaupun markah rendah dia kan buat lain..ulang2 buat pun takpa. interactive memang budak2 suka..

Cikgu Hamidah: Dia suka benda2 yang fizikal..badminton..

Cikgu Suhaila: Macam tanaman2 nie semua buat2 yang buat..ikat bata semua budak2 disleksia yang tolonbg buat sebab mereka suka aktiviti macam tu..

Cikgu Aizat: Belajar 5 minit pun tak apa..kalau duduk luar lama2 lagi suka..

Cikgu Hamidah: Kalau haritu berkebun, mereka tak belajar pun takpa..dia lagi suka..

Cikgu Aizat: Persekitaran budak2 yang buat kan mereka tu pandai..ada yang parent contractor, kerja bendanh..jadi masing2 pandai bancuh simen/tanam2 tanaman..beza pulak dengan budak2 yang jenis okay2(pandai baca) nie dia segan pulak nak masuk tempat2 panas, peluh2 kotor2 tak nak..yang jenis slow belajar nie dia rajin nak tolong aktiviti2 yang libatkan fizikal nie..Mintak cabut rumput mintak sarung tangan dulu tak nak tangan kotor..aktiviti2 nie tak ada pun dalam jadual.tapi kita ajar sejam dalam class..15 minit terakhir kita bawak budak2 keluar class..budak2 suka..

Cikgu Hamidah: esok bdk2 akan tanya lagi esok berkebun lagi takk..sebab bdk2 suka aktiviti macam nie..

Cikgu Suhaila: Kalau budak2 yang tak datang sekolah 2 minggu dengar esok ada berkebun semua akan dating sebab suka aktiviti2 melibatkan fizikal.

Q7: Apakah maklum balas (feedback) daripada kanak-kanak disleksia semasa mengajar? Masa yang diambil) oleh kanak2 disleksia absorb learning? (Reaction-verbal/physical)/ Time spent).

Cikgu Aizat: Soalan jangan berbelit..macam sekarang KBAT..walaupun susah kami akan tanya direct terus..kami akan ikut tahap.

PART C Learning Content and Learning Styles

Q1. Bagaimanakah tahap bacaan (*reading level*) bagi kanak-kanak disleksia?
Cikgu Aizat: Budak kebanyakan daripada tak kenal huruf sampai suku kata. Semua jenis suku kata ada yang tak tau lagi. Tapi ada yang 4 orang (Tahun 6) saja boleh baca bila kita bagi buku cerita. Semua tahap ada. Sejak covid nie ada pertandingan e-cerita secara online, kena rakam budak2 bercerita jadi saya sebagai cikgu terpaksa tulis nak bagi depa boleh membaca masa nak rakam video, tapi dari situ saya tau kata ada yang boleh membaca lancar.

Cikgu Muhairi: Semua tahap ada. Tak kenal huruf pun ada.
Cikgu Hamidah: Semua tahap ada. Lain2 budak lain2 tahap dia.
Cikgu Suhaila: Semua tahap ada.
Q2. Apakah jenis aktiviti pembelajaran (*learning content*) dalam Bahasa Melayu (BM) yang sesuai bagi kanak-kanak disleksia yang berpotensi untuk menggunakan TUIs?

iv. **Pengenalan huruf (Letter recognition)**
v. **Ejaan suku kata (Syllables pattern)**
vi. **Lain-lain. (Sila nyatakan)**

Cikgu Aizat: Ada setengah budak dia keliru huruf kecil dengan huruf besar, bila menulis dia ada campur2 huruf kecil dan besar. Kalau bentuk lebih kurang sama dia akan keliru. Ada satu lagi untuk disleksia, menggugurkan dan menambahkan perkataaan, tapi saya tak pernah jumpa lagi kat sini. Contohnya, Ali suka makan nasi goreng. Tapi dia akan tulis Ali makan nasi goreng. Suka tu dia akan buang sebab dah terbiasa dengar Ali makan nasi, tu ciri2 disleksia jugak. Yang jenis suka tambah pun ada jugak, Kita suruh tulis Ali suka makan nasi. Dia tambah Ali suka makan nasi lemak. nie pun kita panggil ciri2 disleksia jugak. Menggugur dan menambah perkataan tu ciri2 disleksia jugak lah.

Cikgu Muhairi: Tapi tak pa sangat sebab janji dia boleh baca betul.

Cikgu Suhaila: Kalau dari segi huruf boleh tak buat huruf budak boleh kenal huruf mana yang kaki dia di bawah garisan. Kadang2 g kaki duduk di atas garisan. dia tak boleh nak adjust huruf bagi ke bawah garisan. tu ciri2 disleksia jugak.

Cikgu Aizat: Dari segi nak membaca, dia baca kepala jadi kelapa. Tapi kalua nak ikut kan tahap budak2 kat sekolah kami dua nie sesuai sangat lah. Pengenalan huruf dan ejaan suku kata.

Cikgu Suhaila: darjah 6 pun ada lagi tak kenal huruf. jadi sesuai dah dua nie.

Cikgu Aizat: Dari segi pengenalan huruf nie, budak2 dah kenal huruf Cuma keliru bentuk jadi dai confused huruf2 nie. Bila kita tunjuk budak2 nie kenal huruf tapi bila tulis mesti dia buat terbalik jugak huruf tu.

Cikgu Muhairi: Selalu terbalik huruf tu.

Q3. Apakah jenis suku kata *(syllable)* Bahasa Melayu (BM) dalam perkataan yang sesuai untuk kanak-kanak disleksia? Tandakan (/) untuk suku kata *BM* yang sesuai.
(Sumber: Program Pemulihan Khas: Buku Panduan Pengajaran dan Pembelajaran Bahasa Melayu)

Cikgu Aizat: Semua jenis suku kata nie.

Cikgu Suhaila: Vocal dengan konsonan dulu saya rasa sesuai. lepas tu baru V+KV.

Cikgu Aizat: Bagi dia kenal dulu huruf lepastu boleh kenal pulak nie vocal dan konsonan. Huruf tu dia kena kenal dulu.

Cikgu Muhairi: Semua suku kata

Cikgu Hamidah: Semua suku kata sebab tahap lain2 walaupun umur sama.

Q4. Apakah jenis gaya pembelajaran (learning style) yang sesuai untuk kanak-kanak disleksia?

Cikgu Muhairi: Kena ada aktiviti ulang2 untuk disleksia.

Cikgu Aizat: Kena direct dengan budak disleksia.

PART D DESIGN FEATURES

Huruf nyata berbentuk 3 dimensi *(3D Tangible Letter)*

e) Adakah huruf nyata berbentuk 3 dimensi seperti dalam gambar di atas ini sesuai atau tidak bagi kanak-kanak disleksia?

f) Jika ya, saiz (ukuran) dan bentuk apakah yang sesuai untuk huruf tersebut?
   Panjang __**_7 inch_____**
   Lebar __**_2.5 inch___**
   Ketebalan **__1.5 inch___**

g) Jika tidak, sila cadangkan bentuk yang lebih sesuai untuk huruf tersebut.

Cikgu Hamidah: Boleh pilih banyak2 design atau 1 design, saya rasa huruf 3D sesuai.

Cikgu Suhaila: Size kalau boleh yang senang budak2 disleksia nak pegang.

Cikgu Muhairi: 3D sesuai budak2 boleh pegang dan rasa..Huruf nie ada panjang ka macam mana..slot nak letak huruf nie boleh muat berapa huruf..

Cikgu Hamidah: Platform ada satu kan..munngkin kena tambah banyak set huruf konsonan dengan vocal.

5. **Warna Dinamik di dalam Huruf 3D *(Dynamic Colour Cues)***
***** Warna berkelip yang boleh menarik perhatian kanak-kanak pada saat huruf bertukar bunyi/ *Colour flashing that can attract children's attention to the moment that letters change sounds*

f) Adakah warna dinamik di dalam huruf 3 dimensi seperti dalam gambar di atas ini sesuai atau tidak bagi kanak-kanak disleksia?

g) Jika ya, saiz (ukuran) dan bentuk apakah yang sesuai untuk huruf tersebut?

Panjang ___________

Lebar _____________

Jika tidak, sila cadangkan bentuk yang lebih sesuai untuk huruf tersebut

Cikgu Suhaila: Saya rasa okay kalau ada warna warni sebab budak lebih tertarik dengan warna2 nie..

Cikgu Muhairi: Boleh adjust kan colour nie. kalau vocal warna lain..contra dengan konsonan kalau boleh.

Cikgu Hamidah: Kalau boleh warna yang menarik..guna color yang lembut2 saya rasa okay jangan terang sangat.

Cikgu Suhaila: Kalau boleh warna kena contra dengan background kena bg terang sikit colour huruf..

Cikgu Muhairi: Bagi terang sikit huruf bagi contra dengan latar belkang tu.

Cikgu Hamidah: Warna tu tak terganggu sangat

Cikgu Muhairi: Kalaua banyak sangat colour atau benda2 kat background dia macam terganggu sikit nak focus. Jangan banyak sangat tulisan sebab akan terganggu..

Cikgu Suhaila: Jangan kecil sangat huruf dan banyak budak2 memang distract.

Q7. Adakah huruf kecil atau huruf besar yang lebih sesuai untuk kanak-kanak disleksia?

Cikgu Hamidah: Kalau buat ayat memang huruf kecik. Cuma permulaan ayat saja huruf besar kat depan.

Cikgu Suhaila: Huruf kecik sesuai..

h) Jika tidak, sila cadangkan bentuk yang lebih sesuai untuk huruf tersebut.

Cikgu Muhairi: Ikut huruf papan sintok nie

Cikgu Suhaila: Ikut huruf papan sintok nie

Cikgu Hamidah: Huruf q okay dah macam nie.

Bahagian E Reka Bentuk Interaksi & Prinsip Reka Bentuk Universal

(Interaction Design & Universal Design Principles)

Q1. Apakah jenis maklum balas (*feedback*) yang sesuai daripada sistem yang akan digunakan untuk kanak-kanak disleksia?

vi. **Bunyi *(Audio)***
vii. **Gambar *(Images/Graphics)* (Bentuk dalam 2 Dimensi atau 3 Dimensi)**
viii. **Pujian *(Praises)* - Meningkatkan motivasi kanak2 disleksia untuk mencapai dan meningkatkan kepuasan mereka dengan pencapaian mereka. *Intrinsic motivation***
ix. **Markah *(Point)***
x. Lain – lain (Sila nyatakan)

Cikgu Suhaila: Kalau salah ada bunyi lain, kalau betul ada bunyi lain.

Cikgu Hamidah: kalau betul ada bunyi tepuk tangan ka..

Cikgu Suhaila: Gambar dalam 2D pun takpa..kalau animation terganggu pulak bergerak- gerak

Q2 Jika jawapan yang diberikan kanak-kanak disleksia adalah salah, apakah cara yang sesuai untuk memberitahu bahawa mereka salah dan perlu menjawab semula? Sila berikan pandangan atau cadangan anda.

Cikgu Muhairi: Kalau salah budak2 boleh buat lagi sekali..

Cikgu Hamidah: Kalau salah ada audio cuba lagi bagi budak tertarik nak buat lagi sekali.

3. Apakah elemen reka bentuk dan struktur sistem (*design element and structure of the system*) () yang sesuai untuk kanak-kanak disleksia?

ix. Antara Muka Berwarna-warni *(Colourful Interface)*
x. **Navigasi Linear** atau navigasi fleksibel atau kedua-duanya *(Linear Navigation or flexible navigation or both)*
xi. Ikon Bantuan (membaca) vs bantuan audio atau ***kedua-duanya (Help (reading) vs audio help or both)***
xii. Skrin sentuh atau menggunakan tetikus *(Touch screen or using mouse (platform))*
xiii. Ikon vs label teks atau **kedua-duanya** (Icon vs text label or both)
xiv. Animasi vs **imej statik** atau kedua-duanya (Animation vs static images or both)
xv. Pengecaman gerak isyarat menggunakan tangan *(Hand Gesture Recognition)*
xvi. Lain – lain. (Sila nyatakan)

____

Cikgu Hamidah: Saya prefer colour yang sedang2 tapi colourful.

Cikgu Muhairi: Perlu ada bantuan untuk baca arahan..macam voice over setiap arahan.

Cikgu Suhaila: Gambar saya prefer static sebab kalau bergerak gerak akan ganggu budak2 nak focus.

4. Berdasarkan prinsip reka bentuk universal (Universal Design Principles) di bawah, prinsip reka bentuk universal yang manakah sesuai untuk kanak-kanak disleksia? Tandakan (a) untuk reka bentuk yang sesuai.

Prinsip	Reka bentuk yang sesuai	(a)
a) Penggunaan yang Sama *(Equitable Use)*	i) Menetapkan reka bentuk untuk kanak-kanak disleksia mesti merangkumi semua keperluan pembelajaran kanak-kanak yang lain yang sempurna tanpa memisahkan mereka ke dalam kumpulan atau individu.	a
b) Fleksibel dalam penggunaan *(Flexibility in Use)*	i) Gaya pembelajaran yang fleksibel akan membantu kanak-kanak disleksia untuk mempraktikkan pembelajaran berdasarkan keperluan individu kanak-kanak itu. Contohnya, membolehkan kanak-kanak disleksia mengintegrasikan apa yang ingin dipelajari mengikut keperluan/kebolehan mereka.	a
c) Penggunaan Sederhana dan Intuitif *(Simple and Intuitive Use)*	i) Membuat reka bentuk antara muka pengguna (*user interface design*) yang mudah dipelajari. Susun atur reka bentuk (*interface design layout*) sistem harus sederhana dan bersih, navigasi (*navigation*) harus mudah dan konsisten, dan dapat dilihat sepanjang masa. ii) Menggunakan ikon dengan jelas untuk reka bentuk antara muka pengguna.	a

	iii) Elakkan teks yang banyak pada skrin antara muka pengguna (*user interface design*). iv) Menggunakan maklum balas (*feedback*) audio, misalnya, teknik penceritaan (*narration technique*) untuk membaca arahan.	
d) Maklumat yang dapat difahami *(Perceptible Information)*	i) Menggunakan pelbagai kaedah multisensori - visual, audio, dan sentuhan untuk penyampaian maklumat penting. Sebagai contoh, penggunaan kaedah yang berbeza untuk kanak-kanak disleksia dalam belajar membaca dapat merangsang otak mereka sehingga meningkatkan pembelajaran dengan mempunyai tekstur pada huruf untuk menarik perhatian kanak-kanak ketika belajar. ii) Menyampaikan maklumat yang mudah dan cepat difahami tanpa sebarang gangguan. iii) Menggunakan fon yang sesuai untuk kanak-kanak disleksia - ***digital intervention interface***	a
e) Toleransi untuk Ralat *(Tolerance for Error)*	i) Membolehkan kesalahan diundurkan atau diminimumkan, misalnya, mengeluarkan mesej amaran (*popup the warning message*).	a
f) Usaha Fizikal Rendah *(Low Physical Effort)*	i) Arahan direka bentuk *(instruction is designed)* untuk mengurangkan usaha fizikal yang berterusan untuk membolehkan perhatian maksimum terhadap pembelajaran. Contohnya, mengurangkan tindakan yang berulang-ulang. Reka bentuk boleh digunakan dengan cekap dan selesa dan mengurangkan keletihan *(minimum of fatigue).* ii) Ciri reka bentuk huruf nyata berbentuk 3 dimensi *(3D tangible letter)* mestilah: - ***conventional method*** • bersaiz tangan dan dibuat daripada bahan yang ringan dan selamat, mudah diambil dan mudah dipegang oleh kanak-kanak disleksia • Huruf mesti ditegakkan supaya kanak-kanak disleksia dapat mengaturnya dengan mudah di ruang yang disediakan (platform). • Mempunyai banyak ruang di atas meja untuk menempatkan semua huruf untuk memastikan kedua-dua kekangan fizikal (biasanya di bahagian bawah) dan tanda visual (di bahagian atas) dapat ditempatkan dan diatur dengan mudah oleh kanak-kanak disleksia di sesuatu ruang	a
g) Ukuran dan Ruang untuk Pendekatan dan Penggunaan. *(Size and Space for Approach and Use)*	a) Huruf 3D harus ringan, senang disentuh, mudah digerakkan, disusun dan dikendalikan. Guru dapat membantu kanak-kanak disleksia untuk fokus ketika memasukkan huruf 3D ke dalam ruang yang disediakan. - ***conventional method***	a

Cikgu Muhairi/Cikgu Suhaila/Cikgu Aizat/Cikgu Hamidah: Flexible okay sesuai ikut tahap budak2 tu. Mana yang xkenal huruf buat latihan untuk tak kenal huruf. mengeja pun boleh ikut taahp membaca mereka