Designing for Dyslexia: Challenges and Insights into Interaction Design in Augmented Reality

Emy Hazlinda Mohammad Ridzwan*, Husniza Husni, and Nuramalina Mohamad Na'in

School of Computing, Universiti Utara Malaysia, Kedah, Malaysia
Email: emy.hazlinda.uum@gmail.com (E.H.M.R.); husniza@uum.edu.my (H.H.); mn.nuramalina@uum.edu.my (N.M.N.)
*Corresponding author
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***Abstract*—Children with dyslexia have difficulty recognizing letters, spelling, and understanding sounds, which affects their learning. Hence, augmented reality has the potential to support learning, but many applications do not adapt the interaction design to their needs, causing increased cognitive load and reduced learning effectiveness. Therefore, this study aims to identify the challenges faced by children with dyslexia in using augmented reality-based learning applications and to assess the efficacy of interaction design dimensions in supporting their needs. This study used an observational approach on eight children with dyslexia interacting with a digital learning application, ARLexia, that combined spelling, video watching, and letter writing activities. Data were collected through direct observation and analysis based on five main dimensions of interaction design: words, visual representations, physical objects or space, time, and behavior. The results showed that although ARLexia can increase user engagement in learning, several challenges still exist. Therefore, this study suggests improvements in interaction design, such as individual adaptation, immediate feedback, and the integration of game elements to enhance the learning experience. This study also identifies the potential for a new dimension in interaction design: emotional engagement, which focuses on motivation and self-confidence during learning. The results of this study can contribute to the development of more user-friendly and inclusive digital educational applications for children with dyslexia.**

***Keywords*—interaction design, augmented reality, dyslexia, children, challenges**

I. Introduction

According to Alghabban and Hendley [1], and the Malaysian Ministry of Education, dyslexia is a neurological learning disorder that affects students with great difficulty mastering reading, writing, and spelling skills. In Malaysia, the number of students with dyslexia has been increasing on average 10% every year since 2021. Dyslexia is always identified during the developmental stage of childhood and is not a disease [2–4].

A study by Alghabban and Hendley [1] saying that the most specific cause of reading disabilities is phonological deficits. This affects children's ability to associate sounds with letters and words. The phonological deficit indicates that dyslexia often originates from genetic or brain differences, particularly in the perisylvian region of the left hemisphere and other cerebral areas. This theory explains that phonological coding, which involves the systematic relationship between an alphabet and its sound, is impaired in individuals with dyslexia. As a result, children with dyslexia experience difficulties in identifying sequences and sounding out words, often confusing similar sounds and struggling with nonword repetitions [5–7].

Previous studies also have identified several challenges that children with dyslexia go through during their learning process. A study by Torres-Carrión *et al*. [5] and Norudin and Baba [6] showed that students with dyslexia often have difficulty recognizing letters, spelling correctly, and identifying speech sounds. These challenges cause them to fall behind in learning to read and write, which are fundamental to other academic skills. Aborokbah [8] in 2021 also asserted that students with dyslexia find it difficult to draw and write, whether in lines, words, or other forms. This lack of fine motor skills makes it difficult for them to communicate ideas visually, which is often crucial in everyday learning activities. Children with dyslexia also usually experience short-term memory problems, as reported by Ahmad *et al*. [3], Aborokbah [8], and Fei *et al*. [9]. They need more time than their peers to understand and complete tasks.

From a social point of view, a study by Lazo-Amado and Andrade-Arenas [10] shows that children with dyslexia often feel insecure when answering the teacher's questions. They tend to isolate themselves from their surroundings because of their low self-esteem. They are also easily distracted, as stated by Lazo-Amado and Andrade-Arenas [10]. The inability to focus for long periods makes their learning process more challenging, especially in activities requiring sustained attention. These identified problems show that children with dyslexia need a more flexible and inclusive learning approach. By understanding these challenges, educators and educational technology developers can design learning strategies and tools that are more appropriate to support their unique needs. This approach can improve their academic achievement and help build self-confidence and better social engagement. Therefore, appropriate educational technology, such as Augmented Reality (AR), can potentially reduce this difficulty [11, 12].

AR is increasingly recognized as a valuable teaching aid for children with dyslexia. AR offers a positive effect on student engagement, motivation, satisfaction, long-term memory retention, and learning [13–15]. Rasalingam *et al*. [16] suggest AR as an effective and fun educational tool for young children's early education, as the results show that children respond positively to AR technology. In the study by Hassan *et al*. [15], AR-based mobile games help children memorize places through 3D visualization, make spelling easier, and manage time to complete tasks on time. This feedback helps assess students' readiness to adopt and use this new technology in learning. These align with the government's support for innovation in pedagogy that the ministry will ensure all students not only

learn to use Information and Communication Technology (ICT) but can also utilize it effectively to improve their learning, as mentioned in Chapter 6 of Malaysia Education Blueprint 2013–2025. To succeed in the government's vision, students with special needs are not excluded. The positive reception of AR in education prompted its expansion to special education.

AR can provide valuable support and enhance educational experiences for students with special needs [11, 17]. AR can provide a more prosperous and inclusive user experience through multisensory engagement with auditory cues, haptic feedback, or tactile elements for those with visual or auditory impairments [18]. It is also able to create personalized user experiences tailored to individual needs. AR also offers accessibility features, real-world contextual learning, and interactive simulations to support inclusive learning. Hence, studies have been done on the direction of AR usage in education in Malaysia to cater to the unique requirements of students with special needs [19]. However, some studies address only specific parts of the AR design space, and poor Interaction Design (IxD) is reported, leading to difficulties in using AR [20]. Therefore, this study seeks to identify the challenges children with dyslexia face when interacting with AR applications and analyze the effectiveness of IxD dimensions in meeting children with dyslexia requirements.

Seeking the challenges children with dyslexia face when interacting with AR applications is essential in establishing a baseline understanding of usability issues, which will inform improvements in AR application design. Without a thorough observation of these challenges, any intervention or optimization may not effectively address the needs of children with dyslexia. The findings will then be assessed on how IxD dimensions can be adjusted or improved to support the unique learning needs of the children for designing accessible and engaging AR applications. These goals promote a data-focused strategy to enhance the AR learning experience, resulting in more effective, inclusive, and engaging applications for children with dyslexia.

II. Literature Review

In recent years, AR technology has started to be used as an assistive technology for supporting children with dyslexia in their education. Shilbi *et al*. [21] introduced the AlphAR application, an interactive AR learning tool designed to help children with dyslexia recognize symbols and letters. This AlphAR integrates a multisensory learning approach by combining auditory elements to represent text, interactive buttons, visuals in 3D form, physical interaction such as tactile interaction, and immediate feedback display to improve children's ability to recognize symbols and letters. Through interactive animations and voice commands, AlphAR helps children connect phonetic sounds with symbols more effectively, overcoming this group's phonological deficit problems.

The next application is EducaDyslexia, developed by Lazo-Amado and Andrade-Arenas [10] to support the learning of children with dyslexia at the primary education level. This study focuses on the user-friendly design, emphasizing the unique needs of children with dyslexia. The application integrates interactive elements such as animation, phonetic audio, and engaging visuals to help users understand basic learning concepts, including recognizing letters and building words. EducaDyslexia's design approach also uses multisensory learning principles, which combine visual, auditory, and kinesthetic stimuli to improve user experience and learning effectiveness. However, using a picture as a text background has been noted to cause confusion, leading to a loss of focus. This design choice increases cognitive load rather than lessens it, hindering learning.

Although many AR applications are developed to support the learning of children with dyslexia by focusing on using multisensory learning principles in AR technology, they pay less attention to the IxD aspect. In contrast, Poobrasert *et al*. [22] studied IxD and AR techniques as support technologies for students with special needs. This study emphasizes the importance of integrating IxD dimensions, such as easy-to-understand visual representation and responsive interaction elements, in building inclusive applications. The developed AR, Kids Can Read, is designed to support the learning of students with various ability levels, focusing on visual and auditory elements to facilitate understanding abstract concepts. Research findings show that applications developed with the IxD approach can improve user experience through intuitive navigation, individual customization, and user-friendly interactivity. This study emphasizes the need to balance the needs between technical functions and user suitability to ensure the effectiveness of technology in improving learning outcomes.

Moreover, Rahman *et al*. [23] focused on effective User Interface (UI) design for AR-based mobile learning applications, BADANKU, for children with learning difficulties. This study underlines the importance of UI elements such as font size, color, and animation in creating an engaging and user-friendly learning environment. Through a user-centered design approach, researchers emphasize that easy interaction, clear visual guidance, and immediate feedback are key to improving children's learning abilities [24]. The application aims to help children with various learning difficulties, including dyslexia, by paying particular attention to individuals' multisensory and adaptive needs. This study proves that carefully designed UI elements can not only improve understanding but also motivate children to continue engaging in learning activities.

Many previous studies have primarily focused on the challenges faced by children with dyslexia without exploring how IxD dimensions integration can help overcome these challenges. Therefore, this study aims to fill this gap by examining the five IxD dimensions: words, visual representations, physical objects or space, time, and behavior of AR applications specifically designed for children with dyslexia, in minimizing the challenges children face when interacting with AR.

IxD is the design of interactive products or system behavior to support how people communicate and engage with one another in their daily lives and at work [22]. AR is about blending the virtual elements overlay interactively in the real world with 3D objects. So, without a well-designed AR to guide children with dyslexia interaction, children with dyslexia would have difficulties interpreting the information and navigating between virtual elements and the real world involving 3D objects [25]. Hence, considering IxD when designing AR applications is essential to ensuring that

children with dyslexia have a smooth and excellent experience.

IxD is concerned with five dimensions: (a) words, (b) visual representations, (c) physical objects or space, (d) time, and (e) behavior [26, 27]. Words encompass text, such as button labels. Visual representations are graphical elements such as images, diagrams, and icons. Physical objects or space refers to the layout or medium through which users interact with the application. Time relates to media such as sound, video, and animation, which changes with time or the time the user spends using the application. Behavior is described as the mechanisms of the application. It is concerned with how applications perform feedback actions with the users.

In the context of AR for children with dyslexia, the IxD dimensions could help in creating applications that are not only interesting but also appear to reduce the challenges faced. However, previous studies show a lack of IxD approaches that integrate all these dimensions comprehensively [28, 29]. If all dimensions are not considered, the AR may fail to provide a balanced learning experience, potentially overwhelming children with dyslexia with complex interactions or insufficiently supporting their cognitive needs [4]. This gap can lead to increased cognitive load, confusion, and frustration, ultimately hindering the learning process rather than facilitating it.

While Universal Design for Learning (UDL) is a widely accepted framework for inclusive education [30], this study focuses on IxD dimensions as they offer a targeted approach to understanding how children with dyslexia interact with AR applications. UDL provides general guidelines for creating accessible learning environments, emphasizing multiple means of representation, engagement, and action and expression [31]. However, UDL does not specifically address the interaction-related challenges that children with dyslexia face when using AR applications. IxD, in contrast, provides a structured framework for evaluating the usability and effectiveness of interactive digital environments, making it more suitable for this study's aims. Focusing on IxD dimensions aims to provide practical insights into optimizing AR interfaces for children with dyslexia, ensuring a user-centered approach that directly addresses their unique interaction needs.

III. Materials and Methods

An observation is conducted to observe how children with dyslexia interact with an AR application designed specifically for their learning needs. This study is centered on applying IxD dimensions to ensure that AR is tailored to improve learning experiences for children with dyslexia. By observing children with dyslexia as they engage with AR applications, this study seeks to gather insights into how the unique characteristics of children with dyslexia affect their learning using AR [15]. This observation is relevant because it will help propose an IxD framework and identify areas for improvement.

A. Participant Information

Eight children with dyslexia, four female and four male, aged 9 to 11, are the participants in this observation. According to Diane and Casey [32], a sample of five to ten participants is adequate for this qualitative study. This approach guarantees in-depth insights regarding the design of the AR application and addresses interaction challenges faced by children with dyslexia. These children have been diagnosed with dyslexia and have been selected because of their diverse learning difficulties in Bahasa Melayu (Malay Language), which provide a broad spectrum of challenges to be addressed by the AR application. Parental consent is obtained before their involvement in this research.

B. Observation Site

The observation occurred in a controlled classroom environment at the Sekolah Kebangsaan Jalan Datuk Kumbar, Alor Setar, Kedah, Malaysia. This school has one dyslexia classroom under the Integration Special Education Program (Program Pendidikan Khas Integrasi, PPKI). The classroom is significant because it mirrors the natural learning setting of children with dyslexia, allowing the observer to observe their interactions with AR in a familiar environment. The classroom is equipped with tables and chairs as shown in Fig. 1. Also, cameras for video and audio recorders for capturing verbal interactions.

The AR application is installed on a smartphone. While tablets provide larger screens, the smartphone is often preferred for its portability and convenience. Smartphones offer ease of handling, which is lightweight compared to tablets, making them easier for children to handle and carry around [33] (Fig. 2). This was proved through the pilot test held and supported by Falth and Svensson [34], where children with dyslexia showed a preference for using smartphones over tablets.

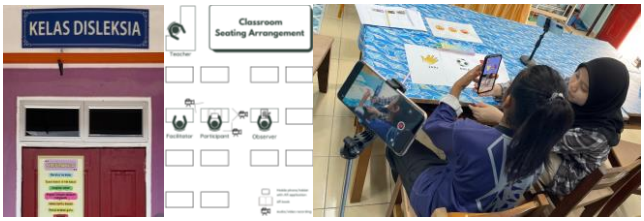

Fig. 1. Classroom setting for observation session.

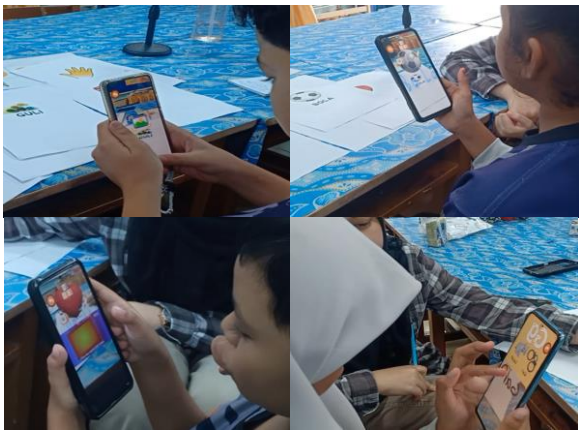

Fig. 2. The observation session.

This observation chooses an individual approach to the experimental setting. The observer will remain nearby to observe. At the same time, the facilitator will sit next to the children with dyslexia to assist with technical issues or if the child requires help with the device. Teacher support is good for reinforcing the learning but in later stages of the implementation. This is because this observation focuses on

the struggles and detailed analysis of children's interaction patterns when interacting with AR applications on smartphones to refine IxD dimensions. The interaction pattern is important to see how to design a better application to support the use before collaborative learning sessions with teachers' support can happen in the classroom.

C. Duration and Timing

The observation is conducted for one day, with each session lasting approximately 15 to 30 minutes as children with dyslexia have a limited attention span. Given this constraint, necessary design modifications can be identified and implemented to improve their engagement, making the AR experience more effective. The sessions occurred during regular school hours to ensure minimal disruption to the participants' schedules. Each child with dyslexia engages with the AR application in one-to-one sessions with the facilitator, ensuring individual attention.

D. Observation Techniques

A combination of direct observation and video recording is used to gather data. The observer observes the children's behaviors, reactions, and engagement with the AR application, taking notes on critical aspects of the IxD dimensions: words, visual representations, physical objects or space, time, and behavior. The sessions were recorded for detailed post-observation analysis.

E. The Instrument

The instrument used in this observation is the Again-Again table from the Fun Toolkit (Fig. 3) because it has more validity due to the shift in the emphasis of the evaluation [35]. In this study, it explores children's engagement by asking if they would interact with the AR interface again, as young children are generally less susceptible to suggestibility. This instrument was previously used by Jamali *et al.* [36] to test the tangible interface of AR with children with dyslexia. To ensure understanding among the children, the items were asked verbally in Malay without changing the original meaning, using a 3-point Likert scale of 'Yes, Maybe, No' (Ya, Tidak pasti, Tidak). In addition to this study, this table was modified by adding one feedback column for observation note-taking for each interface based on IxD dimensions. This table and the observation checklist have been validated by the experts. The observation approach is a semi-structured observation with a checklist as a guide. The data collected was subsequently categorized according to the IxD dimensions as the primary focus themes.

Would you like to do it again?

	Yes	Maybe	No
clock			
dive			

Fig. 3. Again-Again table [35].

F. The Application

The AR application chosen for this observation is ARLexia. ARLexia is an initial AR application designed to facilitate reading, writing, and spelling for children with dyslexia. The application leverages AR technology to create an engaging and interactive learning experience. ARLexia is currently at the phase of experiential prototyping for the purpose of detailed analysis of the interaction and the difficulties of each of the individual children might shown during the session.

The interfaces of ARLexia are shown in Fig. 4. ARLexia features three main functions: Eja Perkataan (Word Spelling), Tonton Video (Watch Video), and Tulis Huruf (Letter Writing). The "Eja Perkataan" feature is designed to help children with dyslexia improve their spelling skills through auditory reinforcement. The "Tonton Video" feature provides visual reinforcement by displaying a short video or animation related to the selected word. The "Tulis Huruf" feature allows children to practice writing letters or words directly on the screen using their fingers or a stylus.

The application uses Unity 3D and Vuforia for development, providing a monolingual "Bahasa Melayu" and a user-friendly interface tailored to children with dyslexia. The font type used in ARLexia is OpenDyslexic because of the unique font characteristics that consider the learning difficulties among children with dyslexia [37].

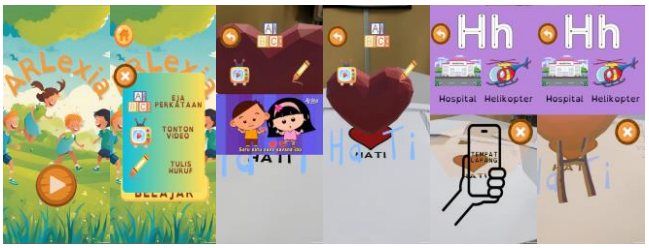

Fig. 4. Modules in ARLexia.

G. Ethical Guidelines

All ethical guidelines established by the Ministry of Education Malaysia (*Kementerian Pendidikan Malaysia*, KPM), the Kedah State Education Department (*Jabatan Pendidikan Negeri Kedah*, JPN), and school administrators are fully complied with, including obtaining informed consent from the children's parents or guardians. The participant's data were anonymized to maintain confidentiality, and the observation was conducted respecting the children's privacy and dignity.

IV. Result and Discussion

The objective of this study is to identify the challenges children with dyslexia face when interacting with AR applications. From the findings, the next objective is to analyze the effectiveness of IxD dimensions in meeting the children's requirements. Based on the observation performed, this section discusses the results.

A. Challenges in Interacting with AR

In this study, observational notes were utilized to capture the children's difficulties and behavior while interacting with ARLexia. This study relates to the work of Jamali *et al.* [36], which used enjoyment and engagement as metrics to quantify

children's emotions while interacting with ARLexia. The enjoyment is analyzed from the observation, and then the engagement is explored through the Again-Again table. During the observation session, it was noted that each child demonstrated different abilities in responding to the application. The difficulties are organized by the five IxD dimensions: words, visual representations, physical objects or space, time, and behavior, as shown in Table 1.

Table 1. Challenges children face when using ARLexia

IxD Dimensions	Challenges
Words	• Difficulty reading text instructions. Some children understand instructions through icons because they cannot read text instructions fluently. • Children need help understanding written instructions, indicating a challenge in their literacy ability. • Difficulty spelling words. Respondents reported challenges spelling long words due to small display space and small-sized letters.
Visual representations	• Some children cannot understand certain icons, such as those on the Petunjuk (Pop-up Legend) page. • Some children gave positive feedback to the blue font color, but some preferred yellow or red for a visual representation to read.
Physical objects or space	• Difficulty finding a suitable space to activate the writing area. • Children kept adjusting the smartphone forward and backward to scan the AR marker. • Some children experience challenges holding the phone for long periods, requiring stability. • Children face hand coordination problems during writing and spelling activities. They used to use their thumb instead of index finger when writing. • There are repeating physical interactions that might be challenging for children with dyslexia who experience motor difficulty.
Time	• Some children reported stopping before the end of the video. Their attention span is short, which was caused by the video's duration. • Some children need more time to complete each activity. However, long activities challenged their patience. • The optimal interaction duration for most children is around 15–20 minutes before they lose interest.
Behavior	• The application does not provide feedback to help children when they are unsure of what to do next. • The absence of interactive rewards featuring visuals and sounds upon task completion disengages and diminishes student interest.

Next, the frequencies of the scales were calculated from the Again-Again table to analyze the activities of each module. As shown in Table 2, the frequency of children's interactions with activities in ARLexia varies depending on the type of activity. Activities such as Laman Utama (Main Menu), Petunjuk (Pop-up Legend), Mari Belajar (Let's Learn), and Imbas Imej (Magic Scanner) received high "Yes" responses. This shows that the IxD dimensions applied in those activities effectively attract interest and facilitate the interaction of children with dyslexia. For instance, on the "Laman Utama" page, the Play button helps children understand the next step easily. The attractive, colorful background picture and the icons are familiar to the children. Without looking at the text, children would not know its purpose. These aligned with the words and visual representations dimensions, providing clear visual instructions and making the interaction smooth.

In contrast, activities such as **"Tonton Video"** and **"Tulis Huruf"** show a lower frequency of interaction. This deficiency reflects challenges in applied IxD dimensions. For instance, as reported through observation, the **"Tonton Video"** duration might be too long to be the main factor in children losing focus. This is related to the time dimension, which does not take into account the attention span of children with dyslexia. On the **"Tulis Huruf"** page, children's difficulties in hand coordination and the small display space reflect weaknesses in the physical objects or space dimension, which requires improvements in the design of physical interaction to facilitate writing activities.

Table 2. Frequency response to Again-Again table on ARLexia

Activity	Do you want to interact with this page again?	Frequency
Laman Utama (Main Menu)	Yes	8
	Maybe	-
	No	-
Petunjuk (Pop-up Legend)	Yes	7
	Maybe	1
	No	-
Mari Belajar (Let's Learn)	Yes	8
	Maybe	-
	No	-
Imbas Imej (Magic Scanner)	Yes	8
	Maybe	-
	No	-
Eja Perkataan (Word Spelling)	Yes	5
	Maybe	3
	No	-
Tonton Video (Watch Video)	Yes	4
	Maybe	-
	No	4
Imbas dan Tulis (Activate Writing Area)	Yes	5
	Maybe	3
	No	-
Tulis Huruf (Letter Writing)	Yes	5
	Maybe	2
	No	1

B. Effective IxD Dimensions

Based on the observation of eight children with dyslexia and the analysis of the Again-Again table, the IxD dimensions applied in ARLexia have shown particular effectiveness through positive feedback from them, as listed in Table 3. These dimensions play an important role in creating a user experience that is fun, effective, and tailored to their specific unique needs.

The findings show that using child-friendly colors and fonts helps attract attention and increase children's involvement in learning activities. Also, attractive, simple, and intuitive visual representations improve children's understanding of the application's functions. A physical activity that involves direct interaction with the smartphone increases engagement, provided the design is not overly complex. Moreover, activities with short duration and immediate feedback help maintain children's interest and motivation, and fun interactive elements help increase children's emotional involvement and motivation to continue interacting with ARLexia.

IxD dimensions: words, visual representations, physical objects or space, time, and behavior have given significant positive feedback from the children. The effectiveness of these dimensions proves that user-friendly, flexible, and fun IxD can better support children's learning. Although there is room for improvement, these findings show the potential of

ARLexia as an effective and inclusive learning tool.

Table 3. Effective IxD dimensions in ARLexia

IxD Dimensions	Effective applications
Words	• Children can recognize letters through the OpenDyslexic type of font. • Children said the blue font was an interesting font color. • Some children prefer to read in yellow and red font colors. This shows that each child has different preferences in reading mood. • Activity like "Eja Perkataan" helps children learn to spell despite challenges with long words. Children wanted to continue interacting with this activity because it was supported by easy-to-understand text and helpful audio guides.
Visual representations	• Children reported that clear and straightforward icons made it easier for them to understand activities such as "Mari Belajar" page and "Imbas Imej" page. • Visual elements in the application, such as 3D animation on the "Imbas Imej" page, increase children's excitement when they see the animation after a successful scanning process.
Physical objects or space	• Children are happy when the animation appears after the markers are scanned correctly and accurately. • Even if there are challenges during scanning for the writing area, this process allows children to interact actively with their spaces.
Time	• Children show high interest in short activities like the "Eja Perkataan" page. • Interaction of around 15 to 20 minutes is considered optimal before children start to lose focus.
Behavior	• Children are more excited when the elements such as animation and sound are used. For instance, they show excitement with the Love 3D animation on the "Eja Perkataan" page.

C. Discussion and Insights

There is potential for enhancement to make the ARLexia design more user-friendly and better to address the specific needs of children with dyslexia. Here is an analysis of each dimension of IxD, along with suggestions for more effective designs.

1) Words

Word dimension plays an important role in attracting the attention of children with dyslexia through font types and color. Children gave positive feedback to font colors such as blue and red because they are more attractive and easier to read. It also helps children feel excited and desire to engage in the next activity. To increase the effectiveness of this dimension, ARLexia can provide font size and color options that can be changed according to user preferences. These personalization options allow children to choose their preferred fonts and colors, providing a more comfortable reading experience [38]. This facilitates readability and helps meet the specific needs of children with different visual abilities. These recommendations align with the specific requirements for children with dyslexia, which emphasize the importance of providing clear and flexible visual elements to improve text comprehension [3].

2) Visual representations

This dimension involves the usage of icons, graphics, and other visual elements. Observation showed that some children face difficulties understanding too complex or too small icons. It is critical to balance the use of visual stimuli to avoid overwhelming users and ensure that cognitive load is minimized. Therefore, ARLexia must be designed with moderate visual, recognizable, limited decisions per screen, and maintaining clear and distinguishable graphics is essential for creating dyslexia-friendly interfaces. For instance, the icon for Pop-up Legend can be redesigned to be more intuitive and child-friendly by providing verbal instructions to enhance children's understanding [9]. For "Eja Perkataan", using color-coded letters based on their sounds might improve recognition and memorization, making the learning process more effective [39]. This can help children to understand better and increase ARLexia abilities. ARLexia might consider prioritizing visually intuitive designs that integrate auditory and tactile feedback, providing an inclusive, engaging, and effective learning environment.

3) Physical objects or space

The main challenges identified are the difficulties of scanning AR markers and holding a smartphone for an extended period. Hence, ARLexia can try to reduce complex movement by ensuring the markers are easily identified without excessive angle or distance changes. Auto-focus technology might be considered to help detect markers automatically and facilitate physical interaction for children who face motor difficulties [40]. In addition, ergonomic designs such as audio and visual instructions for a more stable position can help reduce physical fatigue [41].

4) Time

The time dimension becomes a big challenge when activities in ARLexia take too long, causing children to lose focus. Children were more interested in short-duration activities and quick and interactive feedback [42]. Therefore, ARLexia can limit the duration of each activity to 2 minutes, as recommended by Hussain *et al*. [4]. The researchers also suggest providing immediate feedback, such as animations or fun sounds of a message, to monitor the time the children takes to solve tasks. This can help motivate children and increase their engagement.

5) Behavior

This dimension involves children's reactions and behavior while using ARLexia. Based on the literature, children are more interested when interactive elements such as rewards or small games are included in the application [43]. Therefore, ARLexia might consider adding gamification elements such as points collection or animated icons after each achievement for each activity. This will help children increase their engagement and motivate them to continue using the application. In addition, writing and spelling activities can be facilitated by providing visual guides such as letter outlines that can be followed while helping to improve children's hand coordination [18, 38].

Based on these findings, it is clear that the IxD dimension in ARLexia offers an opportunity to support the learning of children with dyslexia. However, there are still challenges that need to be addressed. As discussed above, some improvements must be made to make this application more inclusive and effective. With this adaptation, ARLexia has the potential to have a more significant impact in helping children with dyslexia succeed in learning.

In addition, the observations made suggest a new

dimension that can be considered: emotional engagement. This dimension focuses on interactive elements that stimulate positive emotions, increase motivation, and create a fun and meaningful learning experience. Due to learning difficulties, children with dyslexia face emotional challenges such as frustration, stress, and low self-esteem [36, 44, 45].

Research indicates that positive emotions are crucial for enhancing learning effectiveness, particularly among students with special needs. For instance, based on this observation, some children enjoy watching educational videos, smiling, and singing along. This makes them feel excited and motivated to try ARLexia and download it. This is because emotions can significantly influence motivation, engagement, and memory retention, which are essential components of effective learning. However, in contrast, some of them are frustrated during writing activities because of the difficulty in scanning the writing area to start writing. In this context, emotional engagement provides an opportunity to reduce emotional barriers and increase self-confidence through fun and rewarding interaction elements.

V. Conclusion

This study identified the challenges faced by children with dyslexia in using AR-based learning applications and assessed the effectiveness of interaction design elements in supporting their needs. Based on the observations conducted, the results of the study showed that although AR applications have the potential to increase children's engagement in learning, several key challenges still need to be overcome, including difficulties in reading text instructions, understanding visual icons, operating the device stably, and maintaining focus over long periods of interaction. The application's lack of interactive feedback and reward elements also affects user motivation.

From an IxD perspective, five main dimensions: words, visual representations, physical objects or space, time, and behavior, play an important role in ensuring a more effective and user-friendly learning experience. Therefore, this study suggests several improvements in application design, including integrating immediate feedback, gamification elements, and individual customization options to meet the different learning needs of children with dyslexia.

In addition, this study identified the potential for a new dimension in IxD, namely emotional engagement, which emphasizes the role of interactive elements in increasing user motivation and self-confidence. This dimension could be important in designing more inclusive and practical AR applications for special education.

For future studies, further research could be conducted to explore the effectiveness of more dynamic IxD and how artificial intelligence and adaptive learning elements can be used to tailor the user experience based on individual needs. With a more comprehensive approach, AR applications have the potential to be more effective learning tools in helping children with dyslexia overcome their learning challenges.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

EHMR conducted the observation, analyzed the results, and wrote the entire manuscript. The discussion section was developed collaboratively with HH and NMN; all authors had approved the final version.

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