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Accessibility Evaluation of Interactive Learning Mobile Applications for Individuals with Intellectual Disabilities

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***Abstract*—In today's education sector, mobile technologies, including tablets and smartphones, have become integral tools, enabling the implementation of mobile learning in pedagogical activities. However, accessibility issues in mobile applications pose challenges, particularly for individuals with disabilities, contradicting the goals of Sustainable Development and the Convention on the Rights of Persons with Disabilities. This paper aims to investigate the extent to which the industry considers accessibility in designing mobile learning applications for this specific user group. We evaluate the accessibility of interactive mobile applications designed for reading and alphabet learning, employing two different guidelines, by conducting heuristic evaluation based on research-based guideline and a design standard introduced by The World Wide Web Consortium. Three experts, each bringing a unique perspective and background, were engaged in the evaluation process. The heuristic evaluations were executed based on the criteria outlined in the selected guidelines. This involved identifying violations and employing a scoring system to quantify the findings. Subsequently, the experts engaged in discussions to achieve consensus and establish final scores for each checkpoint. The results provided a quantitative basis for our analysis. The results of the evaluation performed in this study expose a prevalent disregard for guideline checkpoints among these interactive mobile learning apps. Only two applications could be considered highly inclusive, indicating the need of improvement. Based on the results, the accessibility criteria were also categorized into four primary groups, highlighting the requirements that were least and most addressed by the applications.**

***Keywords*—accessibility evaluation, intellectual disability, mobile applications, interactive learning apps, research-based guideline, design standard**

I. INTRODUCTION

Nowadays, the use of mobile technologies including tablets or smartphones has become an essential part of the education sector. The elevated functionality of these portable technologies has made it possible to apply mobile learning in pedagogical activities. Several studies have reported positive attitudes towards intention in using mobile learning [1, 2]. Various mobile applications have been identified as effective ways to enhance the teaching and learning activities for different types of students [3–5]. Besides, employing mobile learning in educational institutions allows the students to develop positive outcomes in constructivist learning, self-directed learning, and collaborative learning [6]. When the mobile learning system is designed according to students' needs, their performance can be significantly improved, especially with the frequent assistance provided by teachers [7]. Unfortunately, the issues of accessibility are still found in mobile applications, which can adversely affect individuals with disabilities [8]. This situation contradicts the Sustainable Development Goals which perceives the Information Communication Technology (ICT) accessibilities as critical elements to increase the access for persons with disabilities [9]. Additionally, Convention on the Right of Person with Disabilities (CRPD) also promotes UN countries to support the design of accessible ICT for all people, including persons with disabilities [10]. If ICT is not designed to be inclusive, it could raise the circumstances where individuals with disabilities are left out [11]. Especially when the ability of individuals to understand the application design affects the interaction to carry out the task required by the apps [12].

In order to address the accessibility issues found in mobile applications, multiple sources providing guidelines for Mobile Accessibility have been listed, which cover both generic guidelines and platform-specific ones, such as BBC Standards and Guidelines for Mobile Accessibility, Web Content Accessibility Guidelines (WCAG) 2.0, iOS Human Accessibility by Apple and Android User Interface by Google [8]. The World Wide Web Consortium (W3C), which develops the WCAG 2.0 and the Web Accessibility Initiative (WAI) guideline for a broader range of people with disabilities, does not restrict its efforts solely to enhance web content accessibility. W3C also describes that the principles and success criteria of WCAG 2.0 and other W3C-WAI guidelines related to mobile can be applied to mobile content and native applications [13]. Several related guidelines for mobile accessibility which focus on people with specific disabilities like cognitive disabilities, visual impairment, and intellectual disabilities have been developed as well [14–16].

Even though a comprehensive collection of design principles has been proposed, there has been no assessment of the degree to which they are integrated throughout the process of designing mobile applications which specifically aimed at facilitating learning activities for intellectual disability students. A similar investigation to this study has been carried out to evaluate the accessibility of mobile applications in different domains. Four e-government mobile applications were evaluated in Brazil using WCAG 2.0 [17]. The same method was also adopted in another recent study to investigate mobile applications of Brazilian municipalities for disabled users [18]. Other studies established their own accessibility checklist before evaluating the applications available in the market. A checklist based on a literature study was developed to analyze three mobile apps designed for elderly users [19]. Another research study proposed a set of indicators prior performing a cognitive walkthrough evaluation toward five mobile applications in Portuguese local and regional press [20]. Generally, those studies

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primarily involved assessing mobile apps against specific guidelines. In addition to these approaches, the utilization of the Accessibility Scanner tool is utilized for the evaluation of air quality monitoring, e-governance, and various other categories [21–23].

Hence, this paper aims to understand the extent how the industry considers accessibility aspects to design mobile applications for learning which are suitable for individuals with intellectual disabilities. Therefore, we explore the accessibility of several interactive mobile applications that were designed to facilitate reading and alphabet learning for users based on two different standard guidelines. The evaluated mobile applications are selected by choosing the applications from Google Play Store based on keywords of reading, or alphabet learning. The selected standards used consist of a research-based guideline which addresses intellectual disabilities, as well as a standard guideline introduced by W3C. The research-based guideline provides a user interface design technology that was developed specifically for developers of mobile applications interfaces for people with Intellectual and Developmental Disabilities (IDD) [15]. The recommendations provide guidance on how to design mobile interfaces that are accessible and usable for individuals with IDD. Given that this study aims to assess the accessibility of mobile applications for individuals with intellectual disabilities, this guideline was selected as highly relevant for the evaluation process. On the other hand, the standard guideline introduced by W3C offers principles and success criteria applicable to various types of mobile interfaces, including mobile web apps, native mobile apps, and hybrid apps [13]. According to the objectives of W3C, the guidelines aim at creating standards and recommendations to enable individuals to construct system that adheres to the principles of accessibility. Unlike the research-based guideline, this W3C guideline has a broader applicability, catering to a diverse audience of users with disabilities. Therefore, we chose this guideline to provide a distinct perspective compared to the preceding one. The evaluation was conducted by three experts with diverse backgrounds, each performing heuristic evaluations based on the checkpoints in selected guidelines. Individually searched for violations of these guidelines and used a scoring system. Subsequently, discussions were held to reach a consensus and determine the final scores for the checkpoints. The results provided checkpoint scores for each application, which were further analyzed.

II. LITERATURE REVIEW

As education becomes more inclusive, we're exploring how to enhance the learning experiences of individuals with intellectual disabilities. This endeavor emphasizes the importance of equitable education and pedagogical approaches tailored to the distinct needs of these students. Two possible approaches to support these students in their learning are constructivist learning and technology-based learning. In constructivist learning, students are encouraged to relate new experiences based on the previous knowledge that they have acquired in the past. It is recommended to present students with intellectual disabilities with real-life situations, as this can make the learning experience more meaningful for them [24]. The teacher also can help students to explore and figure out what's happening by doing activities on their own [25]. This approach empowers students to become more self-directed in their learning journey. Thus, technology can play a supportive role in facilitating this learning process [26]. A recent study found that using multimedia technologies in the education of students with disabilities could offer benefits for them [27]. Leveraging multimedia-game learning serves as an effective strategy for improving the capabilities of individuals with intellectual disabilities in both academic and non-academic domains [28]. Given that the learning process is made more tangible and enjoyable, multimedia educational games also have the ability to aid students in comprehending the subject material [29].

Looking at ways to improve education for individuals with intellectual disabilities through technology, it's also important to consider another aspect. Fifty-one percent of individuals with Intellectual Disabilities (ID) were found to frequently encounter difficulties in accessing touch interfaces [30]. In the last few decades, there have been studies focused on evaluating the accessibility of mobile applications across a wide range of areas and users. An accessibility evaluation conducted by Serra *et al.* [17], which evaluated e-government mobile applications in Brazil found that none of the applications evaluated in the study passed the success criteria in WCAG 2.0. Both Android and iOS applications were tested and discovered that the applications built in Android platforms tend to violate more accessibility criteria. This also implies that the various Android apps versions introduced a greater variety of issues that users with disabilities may encounter.

Another accessibility examination involved ten mobile applications of Brazilian municipalities that were tested to perceive whether these interactive applications applied in smart cities have been designed in accordance with accessibility guidelines [18]. This assessment revealed several issues related to non-textual labeling, headings, color contrast, text adaptation in the image, and more. It was strongly recommended to incorporate accessibility considerations into the design of these applications to ensure that people with disabilities can fully leverage their potential to enhance their lives.

In a separate assessment, WCAG 2.0 was also used to evaluate 20 e-governance based mobile applications by using Google Accessibility Scanner [22]. This study revealed several major issues related to the lack of labels and descriptions, color contrast, button size, lack of help features, and several other related concerns. It is highly advisable to integrate accessibility into the development of these applications to ensure that individuals with disabilities can use them with ease, and minimize any error they might encounter. A similar methodology was also employed to assess ten mobile applications designed for air quality monitoring [21]. The results obtained were expected to provide valuable insights for the development of inclusive mobile applications.

In a different context, an accessibility assessment was conducted on five mobile applications of local Portuguese press using guidelines derived from the project's indicators checklist [20]. This assessment revealed several issues related to presenting search tools, accessibility symbol visibility, color contrast, flashing-screen, identifiable language, and numerous other issues. This assessment concluded that there were still significant accessibility issues regarding providing support for other special needs of the elderly and people in disadvantaged social groups.

Furthermore, an analysis of over thousands of Android applications revealed that the majority of these applications have accessibility issues, neglecting the needs of people with disabilities [23]. The investigation into developer sentiments indicated that, for the most part, developers lacked awareness of accessibility design principles and analysis tools. Additionally, it was observed that relying on user ratings and app popularity cannot serve as reliable indicators of accessibility problems in applications due to the limited number of users with disabilities.

While the previous research in this field often focused on general disabled users to promote more inclusive design practices, there is a noticeable gap in the literature when it comes to addressing the unique accessibility requirements of individuals with intellectual disabilities. In this study, we have emphasized the need for continued exploration and innovation in the realm of accessibility evaluation to ensure individuals with intellectual disabilities can access and use apps effectively. Therefore, our study differs from the previous studies by highlighting the unique needs of this particular user group according to the selected accessibility guidelines. Our study also contributes to identify the areas where accessibility can be enhanced in the context of interactive mobile learning applications, which makes it a valuable addition to the existing literature on mobile application accessibility. Knowing which accessibility principles are commonly implemented in applications provides a valuable foundation for assessing and improving digital accessibility. It also emphasizes the need for inclusivity in mobile learning applications and offers actionable insights for developers and designers.

III. METHODS

A. Selecting Guidelines and Defining Checkpoints

We selected two guidelines from distinct sources: research-based guidelines and design standard guidelines. Both sets of guidelines encompass the list of design recommendations which must be adhered to ensure an accessible mobile interface. Subsequently, the recommendations list guidelines were streamlined to obtain the checkpoints which are feasible and relevant to be carried out when evaluating mobile applications for this study.

1) Research-based guideline

The research-based guideline is derived from indicators that were formulated within an academic framework that aims to provide mobile design interface requirements for intellectual disability users. Dekelver *et al.* [15] focused on accessibility to make the designed elements accessible for everyone that were based on universal design ideas, which also addressed the usability aspects related to effectiveness, efficiency, and satisfaction concerns. Several recommendations in the study have been categorized into three dimensions: navigation and graphic design, text requirements, and personalization. All these dimensions are aligned to the accessibility standard known as WCAG 2.0 [13]. Navigation encompasses how users move through a digital interface, highlighting the importance of making it accessible for individuals with disabilities to effortlessly discover items on each page. This dimension is in line with the 'operable' principle in the WCAG 2.0 standard, which ensures that the design of the interface component guarantees ease of navigation. Conversely, graphic design recommendations are related to the 'perceivable' principle, emphasizing the visual presentation of information and user interface elements to enhance their perceptibility for all users with disabilities. Moreover, the dimension of text, which includes the use of images to describe text, employing clear language, indicating elements, positioning content thoughtfully, and providing instructional aids, aligns with various principles outlined in the WCAG 2.0 standard. By incorporating these practices, the goal is to ensure that individuals with disabilities can access and comprehend digital content more easily and inclusively. Last, the requirement of personalization, which specifically limits application functions to avoid overwhelming users is indirectly related to 'understandability' principle. This way, it helps users with disabilities better understand and navigate their digital experiences for better usability.

Initially, the guideline included 19 recommendations, but for this study, we refined it to encompass 16 checkpoints. This refinement excluded the general mobile device requirements that are irrelevant to the specific instructions which interface designers must follow. Table 1 summarizes the final set of checkpoints of research-based guideline utilized in this study.

Table 1. Research-based guideline checkpoints

Dimension	Checkpoint	Code
Navigation and Design	Add pictures or symbols to controls so the users know what they should do.	R-01
	Keep warnings and feedback on the screen until the users do something.	R-02
	Reduce the users' input.	R-03
	Use simple gestures to interact within the application.	R-04
	Keep the user interface in a consistent structure.	R-05
	Manage the user interface in a simple structure.	R-06
	The mobile application should detect and show errors.	R-07
	The mobile application should take preventive action to avoid any issues occurring.	R-08
	Provide labels or instructions for users' input.	R-09
	Increase the "clickable" areas.	R-10
	Provide high contrast between text and background.	R-11
Text	Use related pictures to help the users have a better understanding.	R-12
	Keep the language simple and straightforward.	R-13
	Provide text alternatives for non-text content.	R-14
	Titles should be short and simple.	R-15
Personalization	Limit the application functions to avoid overwhelming users.	R-16

2) Design standard guideline

Design standards refer to the principles or guidelines established by industry or organizations to promote best practices in the field of interface design. This study employs WCAG 2.0 standards released by W3C that can be applied to mobile applications design [13]. W3Cs carry 4 main dimensions to develop the guideline: perceivable, operable, understandable, and robust. The perceivable dimension entails that information and user interface components must be presentable to users in ways they can perceive. Operable means that user interface components and navigations must be operable. Understandable focuses on making the information and operation of UI components to be understandable. Robust ensures that the content can be reliably interpreted by a wide variety of user tools, including assistive technologies. These principles contain more detailed checkpoints which were subsequently employed in this study. However, certain checkpoints were exempted due to concerns regarding their applicability and the evaluation mechanism. Magnification, which is typically controlled through accessibility settings, was not considered in this study since it does not require the designers or developers to perform a particular task. Contrast was also not considered, as it requires a specific tool to measure the contrast ratio. The requirement of using an external physical keyboard was not included as this equipment was not feasible to be used to perform the task within the application. Additionally, the guideline of grouping elements that perform the same actions was not applied as native mobile applications do not provide link icons or link text for such actions. Thus, the details of each principle, along with the guidelines used in this study are explained in Table 2.

Table 2. Design standard guideline checkpoints

Dimension	Checkpoint	Code
Perceivable	Put less information presented on each page.	S-01
	Provide a reasonable size for content and touch controls.	S -02
	Adjust the text to fit the viewport width.	S-03
	Put form fields under labels (in portrait layout).	S-04
	Let users adjust the applications' text size based on device settings.	S-05
Operable	Keep application gestures simple (Avoid multi-touch gestures).	S-06
	Wait until the users lift their fingers to trigger an event.	S-07
	Provide a button or control from a keyboard as an alternative control for shake and tilt gestures.	S-08
	Provide an alternative position for the button (for one-hand accessibility).	S-09
Understandable	Adjust the layout to comply with portrait and landscape orientation.	S-10
	Provide consistent layout/order for repeating components.	S-11
	Place important elements before the page scroll.	S-12
	Ensure a clear indication that elements can be clicked or interacted with (buttons, links, etc).	S-13
	Provide instructions (e.g. overlays, tooltips, tutorials, etc.) to explain which gestures control the interface.	S-14
Robust	Set the keyboard type based on the data type in the entry form.	S-15
	Reduce the amount of text entry needed by providing predefined responses (select menu, radio buttons, check boxes, or by automatically filling known information).	S-16

B. Selecting Mobile Applications

We selected several Android mobile applications from the Google Play Store by using these keywords in Bahasa: learning, read, words, and alphabet apps. Thus, these following criteria were also included based on the aim of this study.

- The apps must be designed to teach basic reading for kids. This functionality is considered essential to provide content that is simplified and comprehensible enough for students with intellectual disabilities.
- The app must be updated within a year.
- The app must be free to access the features so that the evaluators are capable of checking all the application screens.

Based on the criteria, 10 mobile applications from various publishers, as shown in Table 3 were selected to undergo the accessibility evaluation.

Table 3. Tested applications

App ID	App Name	Publisher
A-01	Belajar Membaca PAUD TK SD	Dunia Anak Game
A-02	Belajar Membaca Tanpa Mengeja	Solite Kids
A-03	Ayo Belajar Membaca	Annisa Cipta Informatika
A-04	Belajar Membaca	Taman Edukasi
A-05	Learn to Read	Edutalk Indo Studio
A-06	Membaca Bersama Budi	Sriksetra Studio
A-07	Mudah Belajar Abjad	AkitaStudio
A-08	Belajar Membaca	SekarMedia
A-09	GEMAR	Jasa Buat Game
A-10	Belajar Membaca Anak	Qreatif

C. Evaluating Mobile Applications

An expert review was performed to assess the applications based on the selected guidelines. Each checkpoint within these guidelines was tested manually by performing heuristic evaluation on the applications to generate an overall accessibility score. Three evaluators, each with their own expertise, conducted the evaluation. The first evaluator is a user experience researcher specializing in disability-related applications. The second evaluator is a UI/UX designer, while the third is a software engineer experienced in mobile app development. The diversity of their background was expected to uncover a wider range of accessibility issues. Subsequently, each evaluator independently assessed the application, assigning specific scores for the tested applications based on the guidelines' checkpoints. Their findings were later compared and discussed to reach a consensus on the identified issues, resulting in a final score for each checkpoint. A scoring system ranging from 0 to 2 was used for each checkpoint according to the extent of violation observed in the application. A score of 0 indicates that the application violates the checkpoint, followed by 1 for partial violation. The maximum score, which is 2, is given when the checkpoint is fully implemented in the application. Additionally, if a checkpoint cannot be applied to the application due to feature limitations, the application is given an N/A score. The scores for all checkpoints within each application were then summed, to determine the extent of accessibility adopted in the application.

IV. RESULT

In this evaluation, each application received a grade of score based on its adoption of the checkpoint requirements. These scores were then processed to determine the accessibility score and percentage score. The accessibility score represents the accumulated score obtained from all checkpoints for each app, while the percentage score indicates the extent to which each app aligns with the guidelines based on its checkpoint score. The percentage score is derived from the total checkpoint score divided by the maximum possible score if all feasible checkpoints (without checkpoints received N/A score) were fully rated. Then, the accessibility level for an app is assigned based on its percentage score. Table 4 shows the range of the percentage score and the associated accessibility level. Table 5 and Table 6 provide a comprehensive overview of all applications, including their total checkpoints, percentage scores, and the assigned levels of accessibility for both guidelines.

Table 4. Accessibility level baseline

Percentage Range Score (%)	Accessibility Level
0–50	Low
51–60	Low-Moderate
61–70	Moderate
71–80	Moderate-High
81–100	High

Table 5. Research-based evaluation result

App ID	Accessibility Score	Percentage	Accessibility Level
A-01	23 + 1 N/A	77%	Mod-High
A-02	23 + 1 N/A	77%	Mod-High
A-03	16 + 1 N/A	53%	Low-Mod
A-04	16 + 2 N/A	57%	Low-Mod
A-05	15 + 1 N/A	50%	Low-Mod
A-06	22 + 1 N/A	73%	Mod-High
A-07	21 + 1 N/A	70%	Mod-High
A-08	19 + 3 N/A	73%	Mod-High
A-09	20 + 1 N/A	67%	Moderate
A-10	27 + 1 N/A	90%	High

A. *Research-Based Evaluation Results*

According to the evaluation based on research guidelines, only 10% of the apps attained a high level of accessibility, while the majority (60%) fell within the range of moderate to moderate-high accessibility. The remaining 30% of the apps obtained a low-moderate accessibility level.

Looking at the details, Fig. 1 illustrates the portions of applications that were highlighted in different colors based on the score assigned to the checkpoints of research-based guideline. Two out of 16 checkpoints were fully addressed by all applications, namely using brief language (R-13), and providing simple and short titles (R-15). Additionally, four checkpoints were both partially and fully addressed by all the applications. These checkpoints include incorporating images or symbols for controls (R-01), minimizing user input (R-03), providing simple gestures (R-04), expanding clickable areas (R-10), and ensuring high contrast between text and background (R-11).

However, 8 out of 16 checkpoints were violated by at least one of the applications. Those checkpoints were keeping the warnings to stay on screen until the users respond to them (R-02), applying a consistent structure of user interface (R-05), applying a simple structure of user interface (R-06), equipping the errors identification (R-07), equipping preventing mechanism (R-08), providing labels on user input (R-09), using related images to reduce cognitive load (R-12), and limiting number of function to avoid cognitive load as well (R-16). Moreover, one of the checkpoints from research-based guideline that could not be applied in the majority of application designs is a criteria of providing text alternatives for non-text content such as video and audio (R-14).

Fig. 1. Checkpoints measurements of research-based guideline.

B. *Design Standard Evaluation Results*

Following an evaluation conducted in accordance with design standard guidelines, it was observed that a mere 10% of the apps succeeded in achieving a high level of accessibility. A significant portion, constituting 50% of the apps, fell within the range of moderate to moderate-high accessibility. Conversely, the remaining 40% of the apps indicate the accessibility levels ranging from low to low-moderate.

Table 6. Design standard evaluation result

App Name	Accessibility Score	Percentage	Accessibility Level
A-01	16 + 3 N/A	62%	Moderate
A-02	14 + 3 N/A	54%	Low-Mod
A-03	21 + 3 N/A	81%	High
A-04	17 + 2 N/A	61%	Moderates
A-05	12 + 3 N/A	46%	Low
A-06	19 + 1 N/A	63%	Moderate
A-07	14 + 2 N/A	50%	Low-Mod
A-08	19 + 3 N/A	73%	Mod-High
A-09	14 + 1 N/A	47%	Low
A-10	19 + 3 N/A	73%	Mod-High

Similar to Fig. 1, Fig. 2 also depicts which parts of the applications were categorized based on how well they met the guidelines from research. Three out of 16 checkpoints from design standard guideline were fully addressed by all the applications. These checkpoints include adapting the length of the text button to the viewport width (S-03), placing important elements before the page scroll (S-12), and reducing the amount of text entry (S-16). Out of the 16 checkpoints, 3 checkpoints were addressed with a combination of partial and full implementations by the applications. The degree of implementation for app varied for each of these checkpoints. These checkpoints entail providing an acceptable default size for content, including touch control (S-02), avoiding multi-touch gestures (S-06), and providing a clear indication for actionable elements (S-13).

On the other hand, 9 out of the 16 checkpoints were breached by at least one of the applications. Most of the applications overlooked several requirements, including setting the default text size from accessibility settings (S-05), triggering the action on the touch-up event (S-07), providing the alternative position for buttons (S-09), applying both screen orientation (S-10), and presenting instruction or tooltips to explain the gestures for controlling the interface (S-14). Additionally, some checkpoints that could not be applied in the application due to feature limitations were positioning form fields below the label (S-04), providing touch and keyboard as alternative control options (S-08), and setting the type of keyboard based on the data type in the entry form (S-15).

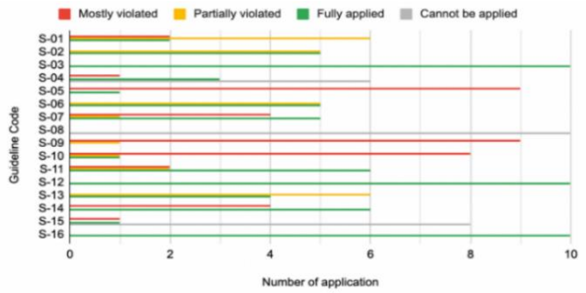

Fig. 2. Checkpoints measurements of design standard guideline.

V. DISCUSSION

When analyzing the results of the accessibility evaluation, it is discovered that the distribution of accessibility levels from both guidelines is quite similar, despite the same application potentially receiving different accessibility levels depending on the guideline applied. Specifically, only 1 out of 10 applications demonstrates a high level of inclusivity for individuals with intellectual disabilities for each guidelines. This application is “Belajar Membaca Anak” which adheres to research-based guideline, while “Ayo Belajar Membaca” follows design standard guideline. Additionally, it is notable that under both guidelines, the majority of applications fall within the moderate to moderate-high accessibility range. This suggests that most learning applications have applied the design recommendation of accessibility guidelines, with only minor violations observed in some areas. However, the results of accessibility evaluations based on the design-standard guideline show slightly lower outcomes than those based on the research-based guideline. While both guidelines can be applied for individuals with intellectual disabilities, the research-based guideline places a stronger emphasis on addressing intellectual disabilities compared to the design standard guideline. This is because the design standard guideline implements principles that aim to cater to all types of disabilities [13]. This discrepancy indicates that the tested learning applications that were primarily designed for kids may not be equally suitable for individuals who have intellectual disabilities along with co-occurring impairments, such as vision disorders, hearing loss, or other physical limitations. Consequently, it is essential to create customized or personalized approaches to support the reading and comprehension skills of individuals with intellectual disabilities who have co-occurring comorbidities [31].

After measuring the adoption levels of checkpoints, as illustrated in Figs. 1 and 2, we have identified four primary categories that can encompass a significant portion of the checkpoints extracted from both sets of guidelines: completely implemented, moderately implemented, minimally implemented, and not feasible for implementation. Table 7 shows the checkpoints that have been grouped into these categories.

Table 7. Checkpoints categories

Category	**Checkpoint IDs**
Completely Implemented	R-13, R-15, S-03, S-12, S-16
Moderately Implemented	R-01, R-04, R-09, R-11, S-01, S-06, S-13
Minimally implemented	R-08, R16, S-05, S-09, S-10
Not feasiblefor implementation	R-14, S-04, S-08, S-15

First, the “completely implemented” category covers all checkpoints that were consistently applied across all applications. This category predominantly aligns with the “Perceivable” and “Operable” principles of the Web Content Accessibility Guidelines (WCAG) [13]. Some of these checkpoints within this category are designed to ensure the readability and clarity aspect for the users. This is achieved by adjusting button text to fit the viewport width and by employing brief language and simple titles to convey information effectively. The use of concise sentences and the avoidance of complex expressions are particularly beneficial for individuals with cognitive impairments, as these measures facilitate their ability to process information [19]. We also noted that reducing the amount of text entry can be included in this category. Educational apps typically offer learning materials and quizzes that are less likely to require users to input text. The quizzes presented within the apps are structured with multiple-choice answers combined with a lot of illustrations as shown in Fig. 3, which may help streamline the cognitive process. This can be particularly effective as people with intellectual disabilities have limitations in the skills of reading, writing, and verbal language skills [32]. Thus, all of these measures ensure that the information is presented in a perceivable manner. Moreover, our observations revealed that all the applications consistently applied the checkpoint of presenting essential elements without requiring users to scroll down the page. This practice aligns with the “Operable” principle, which aims to enhance content navigability and user-friendliness. In a previous study, showing important information without scrolling was one of the least violated accessibility requirements in the case of several popular apps tested using WCAG 2.0 [33].


Ayo kelompokkan 3 benda yang memiliki huruf awal yang sama

Fig. 3. Quiz with multiple-choice answers and illustration.

Next, the "moderately implemented" category incorporates the checkpoints which mostly received a score of 1, or were partially violated by tested applications. The checkpoints encompass actions like providing simple gestures or avoiding multi-touch gestures, minimizing information on a single page, and several checkpoints related to design elements. Notably, "Simple Gestures" is the sole checkpoint related to "Operable", while the remaining checkpoints are more closely associated with the "Perceivable" principles in WCAG [13]. The checkpoints of simple gestures, which appeared in both guidelines, were observed to be partially violated in half of the applications. It was found that 'tapping' was mostly used to interact with the interface, which would not be an issue, since dragging and multi-touch gestures were identified as difficulties during the evaluation of a touch-screen interface for individuals who experience intellectual disabilities [34]. While the checkpoint of minimizing the amount of information on each page was partially violated by 60% of apps and predominantly violated by 20% of apps. This means that only 20% of applications adhered to the checkpoint. Almost all apps present either an excessive number of menus or an excessive amount of learning material on one screen. Nevertheless, information should be presented minimally to reduce the cognitive load of individuals with intellectual disabilities [35]. This approach enables learners to process and understand the information more easily. The other checkpoints which were partially violated by the application that related to the design element such as incorporating images or symbol into interface controls, presenting labels or instructions in user input, and showing high contrast between text and background. As for adding images to interface controls, nearly all apps did not provide icons to the button. In contrast, the visual elements such as images or icons represent a form of visual communication which is crucial for achieving comprehension among individuals with ID [36]. Another checkpoint focused on design elements is adding labels or instructions to accompany the user input. Even so, 80% of applications partially violated this checkpoint. Several buttons were not accompanied by labels, and it was observed that the actions requiring more advanced gestures to take the quiz on apps were not provided with corresponding tutorials or instructional guidance. This result was also observed in a study of accessibility evaluation in m-learning apps for users with disabilities, which found that the input text elements lacked associated labels [37]. The last checkpoint categorized in this group is the high contrast between text and background. Seventy percent of apps partially violated the checklist. These apps typically provide colorful and crowded elements in the background, which are initially designed to attract children to use the apps. On the other hand, implementing a simple graphical interface such as avoiding the distracting background is suggested by Tsikinas and Xinogalos [38], as a means to enhance the users' perception.

The third category, "minimally implemented" is made of the checkpoints which mostly obtained a score of 0, or mostly violated by the majority of tested applications. There are 5 checkpoints which fall into this category: minimizing the app's functions, preventive mechanism, providing default text size, alternate button position, and both device orientation. The majority of these checkpoints can be classified under the "Operable" principle, with the exception of the default text size checkpoints, and minimizing the app's functions which are in line with the "Perceivable" and "Understandable" dimension, respectively [13]. Regarding the overall functionalities, 90% of applications failed to meet the indicator of minimizing the app's functions. These apps featured numerous menus or features and put several actionable elements within a single screen, as illustrated in Fig. 4. This condition could potentially overwhelm users with intellectual disabilities. In consequence, the application's features should maintain a single goal, with the objective of simplifying the overall functionality. Another criterion that was not met by the majority of applications was the preventive mechanism to avoid mistakes or errors made by users. As the tested applications aim to provide educational content in literacy skills, nearly all of the applications feature a functionality to demonstrate the pronunciation of alphabet letters or words as an essential part of the reading experience. However, when the sample pronunciation audio was playing, users were still able to interact with other buttons, thereby causing disruptions within the audio and screen interface. Accordingly, the app's screen should prevent it by remaining inactive during the playback of content material audio to prevent other actionable elements from being clicked until the application finishes playing the content audio. We also noted that the other most violated checkpoints were related to device configurations or users' preference in device usage, which included default text size settings, device orientation, and button placement. In this study, 90% of applications did not adjust the application text size in accordance with the device settings. A similar study found that most applications did not interfere with the default text resizing settings of the operating system [33]. Research findings suggested that when using academic technology, students who have intellectual disabilities could benefit from the capability to customize the font size [39]. Furthermore, in a similar vein, most tested app designs did not provide flexible orientation options. They presented the layout either in landscape or portrait. Even when both orientations were made available, the interface element size was not adjusted when the default orientation was changed, causing issues with the layout. Given this, the screen orientation and design options should not be restricted to a fixed orientation setting. It is also advisable to add a button that allows users to change screen orientation, as suggested by a research study focused on designing applications for individuals with ID [40]. Regarding button placement, most applications typically position the button at the top of the screen, which may decrease the ease of thumb movement. Fig. 5 shows examples of button placement on top, which include functions such as returning to the home screen, enabling sound, changing to "write" mode, changing to grid layout, and automating letter reading. As noted by Cantone, many individuals with ID experienced motor impairment or limited dexterity [41]. Therefore, one-handed use can be proposed to provide more practical and accessible interaction. For right-handed users, it might be suitable to position the buttons at the right of the screen rather than the top [34]. Options should be provided on the applications setting to accommodate left-handed users as well.

The final category, known as "not feasible implementation" consists of the checkpoints that were not enabled to be implemented by over half of applications due to the app's feature limitations. Most of the checkpoints highlight the “Robust” principle, as the checkpoints emphasize the need of mobile interface configuration to be adapted with app functionality, facilitating greater accessibility for assistive technologies [13]. The first checkpoint in this category involves providing text alternatives for non-text content. This checkpoint could not be applied because the tested applications primarily focus on textual content and don’t extensively use non-text elements such as videos or images. The other two checkpoints that were unfeasible to implement are related to form specification: placing form fields beneath the label, and configuring the type of keyboard based on the form’s input data. These checkpoints could not be executed since the majority of tested applications do not incorporate forms within their functionalities. Lastly, providing touch and keyboard as alternatives to control options like shake and tilt was also not implemented in the tested applications. This is because these education applications do not include motion-based controls for interaction within their features.

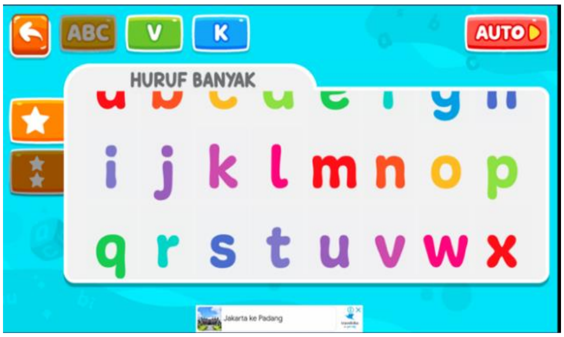

Fig. 4. Numerous actionable in a single screen.

Fig. 5. Button positioned at the top of the screen.

VI. CONCLUSION

This study aims to evaluate the degree how the industry incorporates accessibility considerations into the design of mobile applications for learning that are suitable for individuals with intellectual disabilities. We selected ten relevant applications from the Google Play Store and evaluated them using both a research-based and a design standard guideline. Our analysis indicates that the majority of these interactive mobile learning applications fell into the category where the guideline checkpoints were “moderately” implemented, ranging from partial to full violations. Only two apps can be labeled as providing a high level of inclusivity. We also found that the majority of checkpoints that were implemented in the selected applications aligned with the “Perceivable” and “Operable” principles of WCAG 2.0. In contrast, most of the checkpoints that could not be implemented were related to the “Robust” principle. Areas for improvement include simplifying the app’s functions, implementing preventive mechanisms, adjusting design based on device configuration, and enhancing design elements for better user comprehension within this user group. Besides, we observed that these learning applications may be more suitable for individuals with intellectual disabilities who do not have co-occurring impairments, such as vision disorders, hearing disabilities, or other limitations. Therefore, customized approaches are essential for users with multiple disabilities. However, there are some limitations to consider. First, our evaluation was performed by experts in the field rather than by the end-users themselves. While experts can provide valuable insights, direct input from individuals with intellectual disabilities would offer other perspectives, which may differ from experts. For future work, the accessibility evaluation could involve monitoring the usage of apps by individuals with intellectual disabilities to directly assess their interactions with the applications. Therefore, it can provide insights into how users adapt the applications to suit their individual needs, potentially highlighting the importance of offering design solutions to solve accessibility issues. Second, our evaluation primarily assessed existing applications available on Google Play Store. Given that there are also iOS applications available for similar purposes, future research could expand its scope to conduct a comparative evaluation of both Android and iOS applications to assess their accessibility and inclusivity.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Margareta Hardiyanti writes the paper and infers the evaluation results. Dinar Nugroho Pratomo and Vellya Riona refine the accessibility guidelines. Revandra Aryo Dwi Krisnandaru performs the heuristic evaluation. All authors had approved the final version of the paper.

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