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Research Article

Serious Games Accessibility Design Model for Low-Vision Children

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The evolution in information technology has brought worldwide access to information. Information technology has become an approach for effective learning in the education sector. This development provides an opportunity for people with disabilities. However, many educational software and applications in the market, such as serious games, cannot be accessed by low-vision children due to the visual properties in game design. For instance, small text and graphic sizes, lack of colour contrast, complex visual effects, or reliance on visual cues for instructions are among the visual properties that contribute to these accessibility challenges. They can play serious games as long as they are designed based on their accessibility needs. This paper proposed a serious games design model for low-vision children. The three main components are accessibility, game design, and pedagogy. The serious game accessibility design model is implemented using a low-fidelity prototype that takes the form of a serious game mockup. This prototype allows for basic interaction and testing of the game's features, with a focus on accessibility considerations. The expert validation was conducted on the prototype using heuristic evaluation to assess its usability. Based on the evaluation, the experts agreed on implementing the proposed model to the prototype.

1. Introduction

The evolution of IT has transformed educational opportunities, particularly benefiting individuals with disabilities. In the education sector, IT has become an effective approach for learning. This development provides opportunities for disabled people. Previous research has shown that IT affects the life of disabled people [1]. There are various educational software and applications for disabled people. The disabled people in society should be treated equally in the pursuit of good quality education. There should not be any discrimination against them to ensure they can lead a good life regardless of their social status, race, and background. There are several disabilities, such as physical, mental, and cognitive. Visually impaired people are an example of physically disabled members of society who should have the opportunity of using IT and accessing information. Visually impaired people consist of two categories: blind and low vision. Low-vision people have a visual balance that can be assisted with technology. However, many educational software and applications in the market, such as serious games, cannot be used by low-vision children due to the visual design in the game. Therefore, there is a need to design a serious game that low-vision children can use. According to [1], low vision refers to vision loss that eyeglasses and treatment cannot correct. Low-vision people learn to adjust their residual vision. Visual disability does not mean that they cannot do any activities to learn new ways to perform the activities. Low-vision problems occur when the sight level of a person does not exceed 6/60 or 20/200 [2].

Low-vision children have difficulties accessing graphical elements on the screen [3]. They need to look at the tablet screen from a very close distance due to the small size of the text and graphics besides the low colour contrast. The use of dark colours is unsuitable for them. They also experience difficulties accessing menus and buttons in games. Audio-based instructions should also not be played simultaneously with the background audio because low-vision children can

only focus on one sound at a time. Fast animation movement and the direction of animation movement can also affect their vision. These problems cause them to gain less satisfaction when playing games. Based on a previous requirement study [3], several accessibility requirements are visual, animation, audio, and navigation. Using their remaining vision, low-vision children can play serious games as long as they are designed based on their accessibility needs. Hence, this paper presented the requirements and proposed a conceptual model of accessibility design in serious games for low-vision children. In the following section, Section II discusses related work, while Section III describes the materials and methods. Sections IV and V discuss the results and the discussion, while Section VI presents the conclusion and plans for future work.

2. Related Works

Accessibility refers to how software and ICT applications can be accessed by disabled people [2, 4]. Accessibility is important for developers and organisations to improve the usability of ICT applications. Everyone should use hardware and software applications without thinking about their limitation. Therefore, ICT applications should be designed based on user accessibility needs. When an ICT application meets this aim, it is accessible to users with diverse cognitive abilities, hearing, movement, and sight. The accessibility in ICT applications usually focuses on web accessibility [5]. Web applications are used since the web removes barriers to communication among people around the world. Thus, if websites and other ICT applications are badly designed, they can be challenging. The accessibility to ICT applications involves sensory, physical, and cognitive aspects. Therefore, a visually impaired user would face difficulties accessing graphical-based interfaces in ICT applications. A visually impaired user with low vision can use assistive technology such as screen readers, screen magnifiers, alternative keyboards, and voice recognition when using ICT applications. Assistive technologies such as screen readers and screen magnifiers help users with low vision by reading text-to-speech information and improving text and images. Although many assistive technologies help low-vision users, they are abandoned because they may not support some applications, including digital games and only support text and static information [3].

Disabled users also have difficulties viewing and accessing onscreen information due to the view limitation of the screen magnifier. Based on a study by [6], assistive technologies do not meet users' needs because they struggle to adjust to the changes in visual content when navigating the applications. Besides that, assistive technologies do not provide enough control for users to see the content comfortably. The inefficiency of accessing the technology makes users lose control and leaves them disoriented. Users also feel uncomfortable revealing their disability to normal users.

Furthermore, existing assistive technologies such as screen readers can burden children's cognitive abilities due to their low concentration because assistive technologies need a high concentration level. Assistive technologies are also unable to support certain ICT applications such as games due to their highly interactive systems. Therefore, a design that enhances accessibility to games is required for low-vision users. The accessibility requirements for low-vision children need to be studied to guide the development of serious games. There are several models which are relevant to our study and which consist of three components such as accessibility, serious game, and pedagogy. The next section will discuss on the previous accessibility design model which is essential for accessibility component.

2.1. Accessibility Design Model. Several studies on accessibility, such as [7], proposed a web design model to improve the accessibility to the web for disabled people. This model is based on the three web components of content, navigation, and user interface. This model aims at presenting the design requirements of web accessibility in a developer-oriented format. The accessible content of the web includes text, images, videos, and audio that can be accessed by all users, including disabled people. Navigation is a method of moving within the website and other pages where the navigation is accessible if disabled users can navigate the website easily. The user interface refers to the elements users perceive and use to interact with the applications. Thus, the accessibility of content, navigation, and user interface are the primary goals of web accessibility in this framework.

A design model of educational website accessibility was proposed by [8]. Based on this model, accessibility design is important to design an educational website and should be performed in each phase of the design process. An educational website design team comprises designers, developers, and learners. Learners are usually concerned with technologies and content presentation, while designers and developers focus on the functionality and safety of the educational website. Thus, the web accessibility for navigation, content, language, and links are included in this model to fill in the gaps. Besides that, a study by [9] presented a framework to select the web technology and how web design development can influence web accessibility for disabled users. A hierarchical decision model is applied to represent the design, adaptive technology, and web technology that include attributes and requirements applied to enhance web accessibility.

Furthermore, an assistive courseware model for visually impaired users has also been proposed [10]. The model includes information accessibility, navigation, and the pleasure aspect of the courseware. In addition, the model focuses on the design of content to fulfil the needs of visually impaired learners. Another proposed courseware accessibility model is for hearing-impaired learners [11]. Table 1 shows the analysis of accessibility elements from previous models and frameworks for accessibility design.

Based on the analysis, most of the accessibility models and frameworks focused on the accessibility of the web, which was static compared to ICT applications such as games that are highly interactive systems. As a result, there is a lack of accessibility design models for games. In addition, existing accessibility design models and frameworks did not

Table 1: The analysis of accessibility elements from previous accessibility models and frameworks.

Accessibility elements	Baguma and Lubega [7]	Sun and Zhang [8]	Perrenoud and Phan [9]	Sun and Wen [12]	Aziz et al. [13]	Siti Zaharah and Nor Azan [11]
Navigation	—	—	—	—		
User help	—					
Link		—				
Audio	—	—	—	—	—	—
Text	—		—	—	—	—
Graphic	—	—	—		—	—
Colour		—	—	—	—	
Animation	—			—	—	—
Language		—	—	—		
Translation	—					
Menu					—	
Button					—	
Interactivity						—

focus on game accessibility, especially for low-vision children. However, there are several previous studies on game accessibility.

2.1.1. Game Accessibility. The popularity of games today means that games should be accessible to everyone. However, disabled people encounter challenges while playing games [14, 15]. According to [16], accessibility problems occur when a person cannot receive feedback, determine game responses, and use conventional input devices. Although there are existing game accessibility guidelines (Independent Game Developers Association), the guidelines are only applicable to a specific game context. They do not provide solutions to the accessibility issues. A disability affects the ability of a player to play games. Visually impaired users are unable to see primary stimuli. Thus, it is difficult to determine the game response. Several games are developed or modified for visually impaired people, such as the blind, for entertainment purposes. Most games use audio for visual replacement.

Low-vision children have a residual vision that can be used to play games if the game design fulfils their accessibility requirement. Low-vision children can use computers, software, or applications designed based on their requirements. Several interface design aspects concerning low-vision children include screen design, graphic presentation, text readability, and vivid colour. The visual elements pose a challenge to access existing games such as serious games. Based on previous studies, several accessibility elements should be applied to enhance the accessibility of serious games for low-vision children, as shown in Table 2 [15–24].

Therefore, serious games for low-vision children should be designed based on their needs. The accessibility elements such as screen design (menu, button, and navigation), object movement, multimedia contents, language, and interactivity should be implemented in the game design based on their requirements so that the serious game is accessible to them. In the next section, we discuss on serious game component. There are several game design models that are relevant to this study.

2.2. Serious Game. Abt introduced the first concept of serious games in 1970. This concept was presented in war games during a project conducted by Atari in the 1980s for military training by using board and card games or pen-and-paper games. The American army's use of serious games for tactical and strategic training allowed them to participate in simulated real-world battles [25]. According to [26], a serious game is usually used for entertainment purposes but can educate players. A serious game is usually based on the game user interface and simulations, and its purpose is beyond entertainment such as training, education, healthcare, defence, communication, politics, and others [27–29]. The objective of a serious game is usually to teach users while providing a pleasurable experience. In learning, serious games have motivated users by providing interactive learning [30]. There are several serious game applications for learning language, science, mathematics, and enhancing cognitive skills in solving problems [31].

Serious games are proven to produce more inspirational learning results. In addition, the element of reward in a game can establish the communication with players to continue playing. When the game elements, story narrative, and gameplay are appealing to the players, endorphin is released into their bodies and motivates them to continue playing to gain rewards. The players will continue to play and gain information until stored in the long-term memory [26]. In education, serious games are similar to educational games because both games focus on developing knowledge and skills. However, serious games are different from educational games in which the design of serious games is almost similar to commercial digital games for their gameplay. The educational content is implicit in the gameplay. Studies on available educational game models and frameworks can assist in designing serious games for learning purposes.

2.3. Game Design Models and Frameworks for Learning. Designing and developing of a game is not an easy task, and design models are important to guide developers in developing games. There are several models and frameworks for educational games from previous studies. A model for

Table 2: Accessibility elements for serious game.

Accessibility elements	Descriptions
Screen design	(i) The user interface should be simple to reduce children's cognitive load and easily adapt to low-vision children
Navigation	(i) The menu design should be simple, with a start menu and an audio button so that users can navigate the game easily
Object movement	(i) The animation movement should be slower for low-vision children and can be adjusted (ii) The animation movement should also be in the same direction
Multimedia contents	(i) Audio acts as an important accessibility element; thus, the audio instruction should be clear (ii) Dialogues, menus, and tasks should be incorporated with sound recordings (iii) Low-vision children can only focus on one sound at a time. Therefore, instructions should be included with audio (iv) The task can be repeated if the low-vision children require it (v) Sound is used as an accessibility element and is important for vision problems (vi) Audio instructions must be clear. Sound recordings are incorporated in dialogues, menus, and tasks (vii) One sound should be played at a time because low-vision children can only focus on one sound at a time (viii) Instructions should be provided with audio (ix) The font size should be 18 or more and should use the serif font (x) There should be high contrast among fonts, graphics, and backgrounds, and the graphics should be bigger
Language	(i) Use simple language that low-vision children can understand
Interactivity	(i) Use simple interaction between children and the game

history educational game design using the digital game-based learning (DGBL) approach was proposed by [32]. The main components consist of digital games and pedagogy. The digital game consists of storyline, rules, immersive experience, enjoyment, feedback, multimedia technology, challenge, and reward. The pedagogy component consists of the learning goal, learning theory, educational psychology, curriculum needs, patriotism and moral value, and the memorisation and forgetting theory.

On the other hand, a conceptual model of serious games based on the learning theory was defined by [33]. This model combines gaming requirements with the learning and pedagogy theories. The model's components are game components, game mechanics, game genre, game achievement, capability (cognitive, psychomotor, and affective skills), instructional contents, learning outcomes, and reflection. The component of reflection in this model refers to what a player thinks is the objective of the learning activities and decides the strategy during the next activity.

In addition, the game object model (GOM) was developed by [34] that combines game design with educational theory. This model was based on the constructivist educational theory. The game elements trigger enjoyment and fun, while the pedagogical elements develop a learning environment. Besides, [35] proposed a model that adapted the interaction cycle in a game between users and the game. Based on this model, learners should understand the goal of each task in the game and learn the learning content. The learner also decides the actions which should be taken to accomplish the task, and the game provides feedback to the learner. The learner can evaluate whether he/she has given the correct information and repeat the task or move on to the next task. Table 3 summarises the analysis of the game model according to the game elements.

Based on the analysis, the common game elements used for educational games are storyline, challenge, reward, fantasy, rules, and goal. These elements should be considered when designing educational games. All models stress the importance of combining pedagogical principles with game design elements to create effective serious games. A combination of pedagogical and game design elements should be included in designing serious games for education [39].

In summary, this section has highlighted the evolution of serious games, emphasizing their use in various fields such as training, education, healthcare, defence, communication, and politics. Serious games aim at educating while providing an enjoyable experience and have proven to be effective tools for learning. The section introduced several game design models and frameworks for learning, which are crucial for guiding the development of educational games. These models emphasize the integration of game elements and pedagogical principles, highlighting the importance of combining engaging gameplay with educational content. The next section discusses the pedagogical aspects that underlie the design and development of serious games, enhancing our understanding of how these games can effectively facilitate learning.

2.4. Pedagogy. Pedagogy deals with theory and practice of education as the best way for learning [40]. It facilitates the acquisition of knowledge, skill, and attitudes, and the

Table 3: Analysis of the game model and framework for education (game).

Game elements	Model/framework					
	[32]	[33]	[34]	[36]	[37]	[38]
Storyline	—		—	—		—
Rules	—				—	—
Immersive	—				—	—
Enjoyment					—	
Feedback	—	—		—		—
Multimedia technology	—					
Challenge	—	—	—	—	—	
Reward	—	—				—
Goal		—		—	—	—
Interaction		—	—	—		
Fun			—	—		
Fantasy			—		—	
Mystery			—		—	
Control			—		—	

educational component of games can enhance the learning experience [41]. Table 4 summarises the analysis of the game model for education according to the pedagogy aspects [32–34, 36–38].

Based on the analysis, several learning elements should be considered when designing educational games: learning goal, learning theory, and learning contents. Learning goals should be considered when designing educational game because the game system usually associates with the learning objectives [40]. Learning goals are the specific knowledge and skills that the game is designed to teach and should be aligned with the objectives of the game [42]. Moreover, learning goals are set to promote users' knowledge [41]. Besides, learning theory plays an important role in the design and development of serious games. Learning theory provides a framework for understanding how people learn and how they can be excellently taught. The use of learning theory in serious game design allows developers to design games that are more effective in accomplishing their educational goals [33]. The learning content plays a significant role in accomplishing the game's goal. The learning content provides a user with information, knowledge, and skills related to the game's subject [43]. The game's educational content is designed to meet learning goal and align with the game design such as theme, storyline, and challenges [44]. It offers opportunities for a user to learn new concepts, theories, and skills while playing the game. Well-designed learning content in serious games can develop player engagement [45]. When players are interested in the game's subject, they are more likely to be engaged in the game and invested in achieving its goal. Learning content in serious games can foster skill development by providing players with opportunities to practice and improve their skills in a safe and interactive environment [45]. It is designed to align with the game's objectives and ensure that users can apply what they learn when playing game.

Since most educational games focus on normal players, the accessibility elements need to be included for disabled people to access serious games for learning. Accessibility elements are important for disabled people to access serious games for learning because these elements ensure that the games are equitable and inclusive for all players, regardless of their abilities and facilitating the learning process. Disabled people are not excluded from the learning experience. Disabled people could take control of their learning and choose how they access the content.

Designing games with specific accessibility requirements presents a challenge as it requires a deep understanding of design principles and relevant approaches. In addition, the design principles should be adapted in the game design to ensure serious games are accessible to them. The next section will discuss the design principles of this study.

2.5. Design Approach and Principle. Players are also important in designing a serious game because the game should be designed based on the needs of the target players. A serious game should be developed based on the requirements of players. Developers should focus on users' characteristics during the game design. Design approach and principles should be applied during the design process. Inclusive design is a design approach that aims at designing accessible and useable content for many people, including elderly and disabled people [46]. The inclusive design focuses on user-centeredness because people have different capabilities, skills, experiences, and opinions. Therefore, the product should be functional to satisfy the needs and desires of users. It should also be easy to operate useable products and satisfy users [47]. According to the British Standard Institute in 2005, inclusive design is defined as a design of mainstream products and services accessible and useable to many people, which suggests the inclusion of people with disabilities. By understanding their needs, the inclusive design improves product experience among various users to produce a better design [48]. Thus, inclusive design should be applied in the design and development process. Besides that, in the area of design education, inclusive design is a philosophy that creates beautiful and functional environments which can be used equally by everyone without concerning their age, gender, disability, and the design process that must accommodate different requirements of desires and expectations [49]. The inclusive design also refers to a methodology applied throughout the design and development process to produce better-designed products that are more useable and desirable. Based on the inclusive design process, there are four key stages where evaluation is conducted throughout the design cycle. The initial need should be explored and refined to determine the real need. Figure 1 shows the stages in the inclusive design process [48].

Inclusive design has several similarities with universal design and design for all. Inclusive design, universal design, and human-centered design are overlapping design philosophies [50]. America and Japan use the term "universal design," while the UK uses the term "inclusive design," and Scandinavian countries use the concept of "design for all" [47]. However, we use the term "universal design" in this study. Universal design can guide the process of designing, and it is an approach to ensure that a product is used by everyone, including disabled players [10].

Table 4: Analysis of the game model for education (pedagogy).

Educational elements	Model/framework					
	Nor Azan et al. [32]	Yusoff et al. [33]	Amory [34]	Barendregt and Bekker [36]	Garris et al. [37]	Kiili [38]
Goal	—	—	—	—		
Theory	—	—				—
Content	—	—	—		—	—
Learning outcome					—	
Psychology	—					
Curriculum needs	—					
Patriotism and moral value	—					
Memorisation and forgetting theory	—					
Capability		—				
Critical thinking			—			
Exploration			—			
Challenge			—			
Engagement			—			
Competition			—			
Practice			—			
Motivation			—	—		

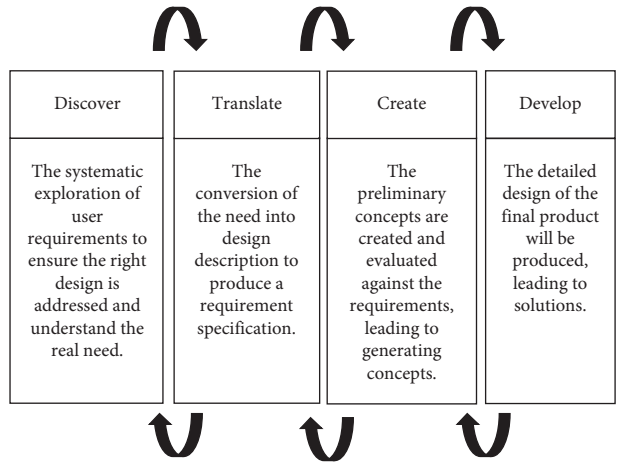

Figure 1: The inclusive design process.

2.5.1. Universal Design. Ronal L. Mace created the concept of universal design. Universal design is defined as the design of a product that everyone can use. The principles of universal design are as follows: [51].

(i) Equitable use
(ii) Flexibility in use
(iii) Simple and intuitive use
(iv) Perceptible information
(v) Tolerance for error
(vi) Low physical effort

Studies on universal design have also focused on interface technology. Several factors support the universal design of an application. Table 5 shows the elements of universal design.

Universal design is important in designing a product to be used by all users, including disabled people. The universal design elements need to be implemented in the user interface design to produce a simple user interface that does not burden children's cognitive ability. This is because the development of cognitive ability varies on different levels.

Universal design is essential in designing a product to use both normal and disabled users. The universal design elements need to be applied in the user interface design to produce a serious user interface design that is simple and does not burden children with cognitive impairment. Thus, it is important that the developer designs for children and children's technology principles when designing serious games. The next design principle for accessibility is the children's technology principle.

2.5.2. The Children's Technology Principle. With increasing exposure to mobile technology, the use of ICT among children has grown. Many interactive applications help children learn, so it is essential to assess their abilities, interests, and developmental stages when designing ICT applications specifically for them.

Table 5: The elements of universal design.

Universal Design elements	Descriptions
Alignment	The alignment of elements in an interface design should be in line with each other
Chunking	A technique where the information is combined into specific pieces (chunks) so that the information is easy to process and remember
Colour	Limit the use of colours to at least five colours depending on the complexity of the design. Do not use colour as the only way to convey information
Consistency	The consistency: the same section is presented similarly
Control	The control level provided to a system suits the abilities and experience of the user
Readability	The readability of certain information is based on word size, contrast, and space
Mapping	The relationship between control over a system and its effects. Good relationships can facilitate the use of a system
Ockham's razor	The interface should be simplified, and any unrelated element needs to be reduced
Performance load	Performance load consists of cognitive load and kinematic load. The cognitive burden can be reduced with minimal design, while kinematic load involves the burden of physical activity by reducing an action or movement

Children constitute a significant user group for ICT applications, and their needs must be considered. They use these applications for both educational and entertainment purposes and possess varying levels of experience and skills. Interface design requirements for children differ significantly from those for adults, as children need interfaces that align with their cognitive, physical, and social development [52]. Table 6 lists the important aspects to consider when designing interfaces for children [52, 53].

It is important to have a design that fulfils children's needs. The children's design elements must be applied in the user interface design to produce a concise game interface and compatible with their cognitive and physical capabilities. Indirectly, the usability of serious games can be improved.

3. Materials and Methods

There are two main activities in the design phase: serious game design and expert validation. The serious game design includes accessibility design and game design.

3.1. Serious Game Design Activities. The design phase includes implementing the conceptual model in the storyboard (low-fidelity prototype), where the storyboard is used as a reference to produce a prototype (high fidelity). The low-fidelity prototype is chosen for evaluation since low-fidelity prototypes are easy to create, modify, and facilitate rapid iteration. It helps identify fundamental flaws or usability issues early in the process. The accessibility elements are applied in the design of the game interface. Game design and the pedagogy component of the game were also designed and implemented into the low-fidelity prototypes. Game design involves game elements such as storyline, challenges, rewards, fantasy, and rules, whereas the pedagogy involves learning objectives, theory, and contents. In addition, expert validation was conducted to confirm the implementation of the accessibility design model in serious games for low-vision children into the low-fidelity prototypes.

3.2. Experts' Validation. Expert validation was conducted on the prototype using heuristic evaluation to assess its usability. The purpose of the examination is to validate the serious game accessibility design model.

The evaluation involved six experts from the game area, human-computer interaction, and special education. Game design experts have extensive experience in the field of game design. Their insights were crucial in evaluating the game mechanics and overall gaming experience aspects of the prototype. HCI specialists bring expertise in user interface and interaction design. They helped ensure that the user interface elements were intuitive, responsive, and conducive to a positive user experience, especially for low-vision children. Special education experts were included because they possess valuable knowledge about the specific needs and challenges faced by low-vision children, allowing them to assess the game's appropriateness for educational purposes. Feedback from the expert evaluation was used to refine the prototype. The low-fidelity prototype will be used as a guide in developing serious games for low-vision children. Table 7 shows the list of experts involved in the evaluation.

3.2.1. Instruments. The instruments used for this evaluation were a low-fidelity prototype and a checklist. The researcher constructed a heuristic evaluation checklist based on the literature review, consisting of three sections: interface design, game, and learning. A list of heuristic principles [54] and heuristic evaluation for user interface [55] were adopted for the interface section in the checklist. Heuristic evaluation for games by [56, 57] and heuristic for learning [58] were adopted for the checklist.

3.2.2. Hardware and Software. The hardware used for this evaluation was a tablet, while the software used was Microsoft PowerPoint to develop the low-fidelity prototype.

3.2.3. Evaluation Process. The experts were invited to participate in the evaluation, and the researcher set a date for the evaluation. During the evaluation, the researcher explained the evaluation purposes to the experts. The researcher demonstrated the low-fidelity prototype to the experts. Next, the checklist was given to the experts. The experts tested the low-fidelity prototype and filled in the checklist. In this evaluation, the experts' role is a regular player. The experts need to follow the instructions and answer every question

Table 6: The children's technology principle.

Children's development aspects	Children's design elements	Descriptions
Cognitive	Visual design	(i) The icon used should represent an easily recognisable, interactive, and not complex visual (ii) The icon should be large so that children can click it easily (iii) Use graphic metaphors. For example, using an interface that looks like a children's storybook. Children will also sense the object as if they are in the real world
	Text	(i) Reduce text usage due to different levels of children's literacy (ii) Use simple instructions that are suitable for the children's age
	Interaction styles	(i) Provide immediate feedback. Children are usually impatient and need immediate feedback to show that every action impacts (ii) The interface should provide scaffolding and guidance to assist children in completing their tasks (iii) Use audio and animation with specific functionality (iv) The interface should display the system status and facilitate children's navigation (v) Use direct manipulation where each input device has a direct effect on the screen
	Menu	(i) Menus should be used easily, and there should be no submenus
Physical (motor skills)	Indicators	(i) Interaction for the mouse should be easier. For example, a one-click interface is easier than using a two-click (ii) Touch screen is appropriate for children (iii) The dragging movement must be done by clicking on the object to attach it to the pointer and then clicking again and releasing it to the desired location (iv) The interface should not cause children to hold the mouse button for a long duration

Table 7: Experts' information.

Expert list	Experts information
E1	(i) Lecturer at Universiti Kebangsaan Malaysia (software technology management centre) (ii) Specialises in digital games, graphics, and computer-aided design
E2	(i) Lecturer at Universiti Kebangsaan Malaysia (artificial intelligence technology research centre) (ii) Specialises in game, 3D, and database fields
E3	(i) Lecturer at the University of technology MARA (ii) Specialises in gamification, digital games, and multimedia
E4	(i) Lecturer at the University of technology MARA (ii) Specialises in human-computer interaction and user experience (UX)
E5	(i) Deputy dean of FSTM students, Islamic University college Malaysia (ii) Specialises in multimedia
E6	(i) Lecturer at faculty of education, Universiti Kebangsaan Malaysia (ii) Specialises in special education

provided in the checklist with a 2-option rating scale such as yes or no. When the answer is yes, the expert agrees that the features represent good usability while no represents the opposite. When the experts completed the evaluation, the researcher analysed the data.

The experts' answers were quantified using usability percentage [59]. Yes is weighted with 1 point. No is weighted with 0 points. The values were added to obtain the final value, translated to a percentage value (usability percentage). Thus, the usability percentage enabled the comparison between the design elements. The experts provided suggestions to improve the design.

In summary, the design phase of this research encompasses two key activities such as serious game design and expert validation. Serious game design involves creating a low-fidelity prototype of the game based on the conceptual model and implementing accessibility and game design elements, including storyline, challenges, rewards, and rules, as well as the pedagogical components such as learning objectives and educational content. Expert validation is then conducted to assess the usability and adherence to the serious game accessibility design model. The process involves serious game design and expert validation, with a focus on including experts from diverse backgrounds and utilizing

a comprehensive heuristic evaluation checklist. The feedback gathered and usability percentages obtained will serve as guides for further refining the low-fidelity prototype, ultimately contributing to the development of serious games tailored to the needs of low-vision children. The next section discusses the specific findings and recommendations resulting from this expert evaluation.

4. Results

The serious game accessibility design model was developed during the design phase. The accessibility model of a serious game for low-vision children consists of three components: accessibility for low-vision children, game design, and pedagogy.

4.1. Proposed Serious Game Accessibility Design Model. In the accessibility for low-vision children component, universal design and children's technology design principles were used to design serious games. Several accessibility elements include multimedia, language, object movement, and screen design (menu, button, and navigation). The multimedia elements include audio, graphics, text, and animation. For the language element, low-vision children should easily understand the language used. The movement of objects in the game includes speed and direction.

The game design consists of two main components: the user interface and game elements. The game elements include game contexts and gameplay design.

The game contexts consist of the game environment, including game fantasy, goal, and storyline. The gameplay design consists of challenges, rewards, and rules. The game accessibility elements are adapted to the low-vision children's requirements and implemented into the serious game design as follows:

4.1.1. Screen Design (Buttons, Menus, and Navigation). The user interface design includes screen design and navigation. The screen design consists of layouts, menus, and buttons. The menu size and buttons should be bigger. The colour of the menu or button should be bright and has a high contrast between the background colours to facilitate the navigation of low-vision children. The interface designs should be simple to reduce the cognitive burden on the children and flexible to accommodate the needs of low-vision children. To ease the navigation of low-vision children, the menu layout and buttons should be simple. The menu and buttons should also include background audio for easy navigation. The accessibility elements are implemented in the serious game design as follows.

4.1.2. Multimedia. Multimedia is important when designing a game. The accessibility to the game can be improved through the adaptation of multimedia elements in the game context and gameplay. Several multimedia elements are implemented into the game context and gameplay as follows.

4.1.3. Graphic. The game context, such as game environment and storyline, involves a lot of graphic elements. Therefore, the graphic design must be suitable for visually impaired people. The game environment involves the fantasy element. The game environment should use bright colours for graphics. Besides that, the contrast between the background colour and graphics should be high and adjusted based on players' preferences. The graphics design in the game environment should also be minimal to focus on the game's important contents. For gameplay, the game challenge should be balanced with the children's visual ability. Thus, the size of the target object in games should be bigger. The important graphics in-game challenges should also use bold lines.

4.1.4. Texts. The game context requires the storyline with texts visible to low-vision children. In games, the size of the text should be larger. The colour contrast between the text and background must be high, and the type of text used is serif. Important text content needs to be highlighted so that users can access important information in the game. As for the game mechanism, the rewards in the game activities should be designed with bold-type texts.

4.1.5. Audio. Audio also plays an important role in the design of game contexts, such as storyline and goals. The game storyline includes a voice-over so that low-vision children understand the storyline clearly. Besides, the game goals are the core concept to design a game because the gaming experience is based on the goals. The game goals should be clear and specific to have greater persistence and enhance performance when playing a game. The game instructions are also included with a voice-over so that low-vision children understand the game goals clearly. In addition, a positive audio sound can tell whether a task was successful. Thus, low-vision children will be notified whether they achieve the game goals.

Besides, the gameplay requires audio to balance the game challenge and the children's visual ability. The target object in the game challenge should be included with the background sound to make it easier for children to locate the target objects in the game.

4.1.6. Animation. Animation is one of the important elements in game design. For the game context, the animation design for the storyline should be simple. The main characters in the game design should use a bright colour, and the characters are introduced at the beginning of the game so that children will understand the storyline. The gameplay requires animation that assists low-vision children in completing the challenge. Some animations help children complete math tasks successfully and hint for the next action. The game rewards are designed with animations to notify children of their rewards.

4.1.7. Instruments' Language. Language is an important element of accessibility when playing a game to enable children to play better. Therefore, the language used should

be easy to understand. For the game context, such as storyline and goals, the Malay language was chosen to enable children to understand the game's storyline and goals.

4.1.8. Object's Movement. When designing a game for low-vision children, the object's movement in the game storyline and challenges can be adjusted based on the children's preference. The object's movement should not be too fast so that the children can play well.

4.1.9. Interactivity. Interactivity refers to how low-vision children interact with the game. Low-vision children's interaction with the game is mediated by gameplay. The game mechanism is important to achieve game goals. The process of achieving the goals is accompanied by game challenges. The challenge requires low-vision children's abilities, associated with the game mechanism. Mechanisms such as tasks and rewards encourage challenges and motivate children to achieve goals. Therefore, the design of interactivity for the game challenge must be adjusted based on the children's abilities. For example, based on the children's design principle, drag and drop can be used to mediate the interaction between children and the game.

The game rules are important to define what children should do while playing. Low-vision children communicate with the game interface and act via related game rules. When they play the game, they will comply with the rules and control them based on the rules. The game rules are processed in the background and not accessible to the children. Thus, the game rules should be simple so that children can follow the game rules easily.

The pedagogical component consists of learning objectives, theories, and learning content. The learning objectives should be parallel with the game objectives. The learning theory used is constructivism. Lastly, the learning content should be suitable for low-vision children's ability. Figure 2 shows the conceptual model of accessibility in serious games for low-vision children.

4.2. Implementation of Accessibility Design in the Low-Fidelity Prototype. The accessibility conceptual model of serious games for low-vision children was implemented in the low-fidelity prototype. The purpose of the model's implementation is to improve the usability of the game. The serious game designed for this study is a math game. This game is about a rabbit named Bunny who tries to save his friends that are kidnapped by a tiger. Bunny has to complete the math tasks provided for each level to save his friends. Table 8 shows the example of how the accessibility elements are implemented in the game prototype.

Examples of the interface design are shown in Figure 3.

4.3. Heuristic Evaluation Results. A total of 6 experts had completed the heuristic evaluation to assess the accessibility, game, and learning components. Based on the evaluation of the accessibility component, the highest value of usability percentage was object's movement (100%), followed by multimedia (89%), and interactivity (87%). The object's movement was the most satisfying aspect, which means that the object's movement was relatively good. The experts were satisfied with the multimedia and interactivity aspects of the game. The lowest value of usability percentage was screen design and language (76%). However, the screen design and language were still acceptable. Table 9 shows the summary of the experts' responses for the accessibility of the game based on the heuristic principle:

Heuristic evaluation was also conducted on the game component. The highest value of usability percentage was a challenge (98%), followed by a game reward (90%). Challenge was the most satisfying aspect because the game challenge was quite good. The experts were also satisfied with the game's reward. The goal and fantasy elements have the same value with the usability percentage (87%), where both aspects were acceptable. The lowest value for usability percentage was storyline (80%). Table 10 shows the summary of experts' responses on game heuristics.

For the learning aspect, the highest value of usability percentage was learning objectives (100%). The learning objectives were the most satisfying aspect. The value of usability percentage was the same for the learning theory and learning contents, which was 87%. The experts were satisfied with the game's learning theory and the learning contents. Table 11 shows the summary of experts' responses on pedagogy heuristics.

The evaluation provided significant responses regarding the usability of the serious game design model. The mean value of all evaluations was 88%, indicating a good usability level. However, certain aspects of the prototype need to be improved based on the feedback from experts to improve the serious game design. Table 12 shows the summary of the usability percentage for heuristic evaluation and the experts' comments to improve the serious game designs.

5. Discussion

The results from the proposed model contribute to previous research in several ways. This study was comprehensive, including users with disabilities such as low vision. The accessibility component ensures that the model can be used by low-vision children, thus supporting the accessibility of serious games for them. Previous research results on web accessibility models presented accessibility elements such as content (text, graphics, and animation), navigation, and user interface (buttons and menus). However, these web accessibility elements cannot be fully applied to games due to their complex graphic elements, and there are also challenges that need to be addressed in order to design accessible games. Accessibility requires specific adaptations such as alternative controls, visual and auditory cues, captioning, or options to control difficulty levels or game speed. Moreover, game accessibility may require different considerations for different types of games. Most accessibility studies provide little guidance on how to implement accessibility components in serious games because they do not take into consideration game design, thus hindering the learning process.

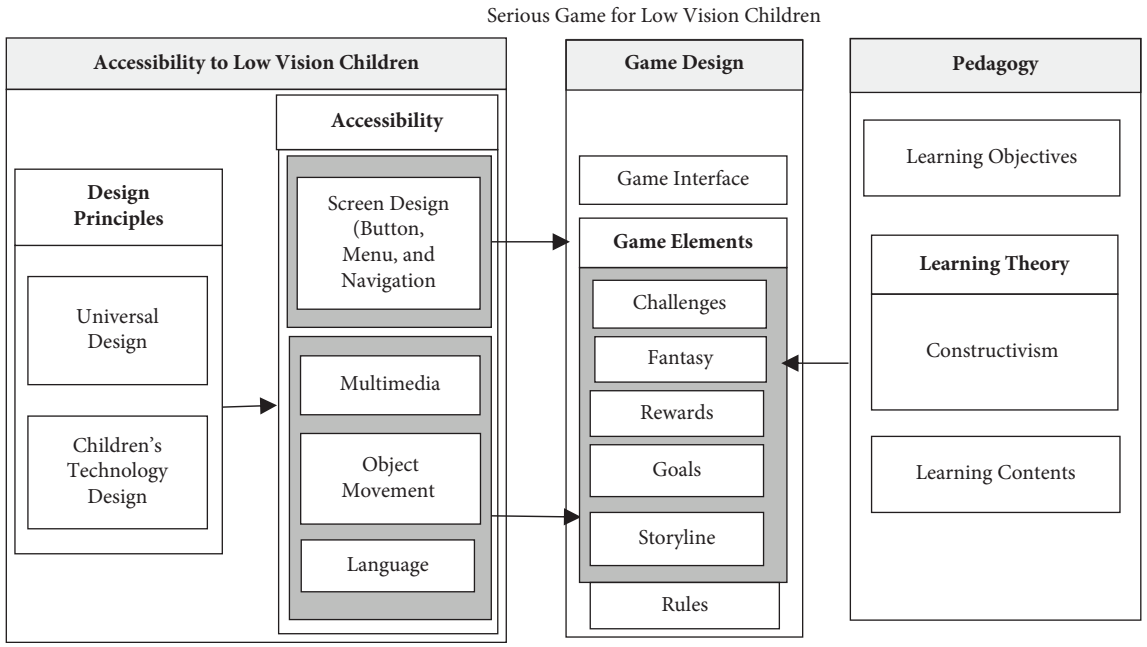

Figure 2: The conceptual model of accessibility in serious games for low vision.

Table 8: Implementation of accessibility elements in the prototype.

Accessibility elements	Descriptions
Screen design (buttons, menus, and navigation)	Simple interface design. Examples of the screen design are shown in Figures 3 and 4 (1) The size of the buttons and menus is big (2) A bright colour is used for the menu or button and contrast the background colours. The colour can be adjusted (3) The menu and buttons are included with background audio to navigate the game easily
Multimedia	*Graphic* The graphics are designed as shown in Figure 4 (4) The game environment uses bright colours for graphics (5) The size of characters and target objects in the game is big (6) The colour is high contrast and brightness (7) The colour can be adjusted, as shown in Figure 5 *Texts* The texts used are shown in Figure 4 (8) The size of the texts is large (9) The type of text used is serif (10) Important text content needs to be highlighted to access important information in the game *Audio* (11) Audio is used for storyline, character, task description, indicator, and dialogue (12) The target object in the game challenge should be included with a background sound to assist children in locating target objects in the game, as shown in Figure 6 *Animations* (13) Animations are implemented to assist low-vision children in playing the game. Figure 7 shows the example of animation used in the game (14) The animations are hints for the next action
Object speed	(15) The object's movement is slow, adjustable, and in one direction (16) The object's speed can be adjusted based on users' preferences, as shown in Figure 4
Language	(17) Children should easily understand the language (18) The Malay language is used for the game, as shown in Figure 3
Interactivity	(19) Drag and drop are used as the mechanism for interaction between children and the game

Figure 3: Front interface.

Figure 4: A serious game's storyline.

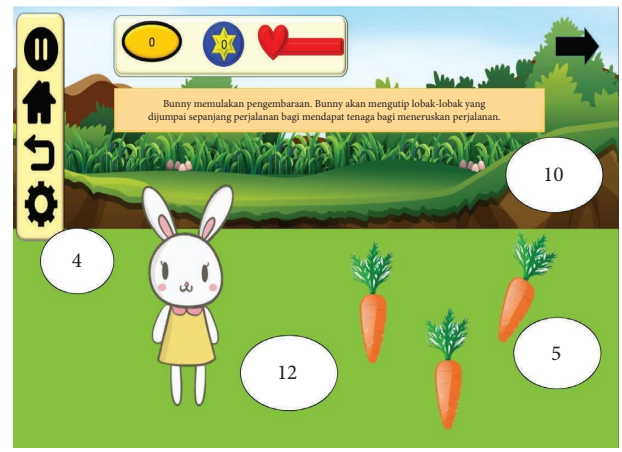

Figure 6: A serious game's task.

Figure 5: A serious game's setting.

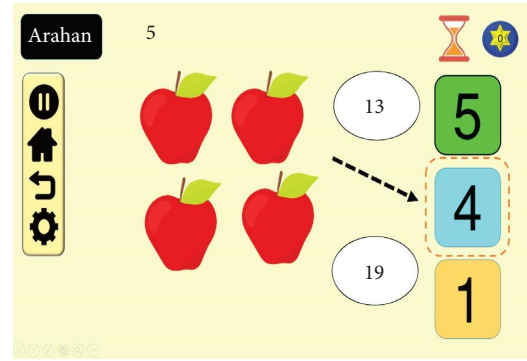

Figure 7: Mathematical task.

Furthermore, most previous serious game models consist of game and pedagogy components. The use of accessibility components has demonstrated the effectiveness of serious game models. However, most serious games focus on normal players, making accessibility components important for low-vision children to ensure that games are inclusive for all players, regardless of their abilities, and facilitate the learning process.

Therefore, to address the accessibility problems and improve game design to make games more effective for learning, we propose a model that combines accessibility and pedagogy with games. This model aims at establishing a conceptual structure that can be used by game designers for efficient game development or by educational practitioners when designing serious games for low-vision children.

Table 9: Summary of responses from experts for accessibility.

Heuristic principles	Experts' responses
Visibility of system status	The experts stated that the game informed users on what was going on using proper multimedia feedback. The game provided multimedia feedback for users' actions because the title on the screen describes the contents and game status. Users can understand the multimedia feedback easily
Consistency and standard	The experts agreed that the multimedia presentation was consistent. The texts, graphics, animation, and audio were consistent throughout the game
Visibility and easy access to all information	The experts agreed that users could see the information in the game because the screen elements can be adjusted based on users' preferences. Users can access the game content easily
Sufficient combination of multimedia elements	The experts were satisfied with the multimedia presentation in the game because the multimedia elements were suitable for certain purposes. The multimedia element used in the game conveyed information to users
Match between the system and the real world	The experts agreed that appropriate icons for the screen design were used and commonly seen. The menu was arranged logically and users interacting with the screen design without difficulties Experts also found that the language used was normal using acceptable words
User controlling and navigation	The experts agreed with the screen design, and the game provided well navigation. Users can move to another screen effectively. The screen design provided a way for users to leave the game directly. Users can also access the setting button based on their preferences. For interactivity, the experts can interact with the game easily. Thus, they can control the game well
Recognition rather than recall	The experts found that users did not need to remember unimportant things to proceed. Users also did not need to remember information from the previous to solve the task
Aesthetic and minimalist design	The experts agreed that the game contains relevant information to minimise screen design elements. They found that the screen design was simple and understandable

Table 10: Summary of responses from experts for game design.

Game heuristics	Experts' responses
Challenges	The experts agreed that the challenges provided a positive experience since the challenges and strategies are balance. The challenge in the game did not disappoint users and changed from easy level to difficult level
Rewards	The rewards were acceptable, and the experts were satisfied with the rewards
Goal	The experts agreed that the game's goal was clear, and the gameplay supported the goal
Fantasy	The experts were also satisfied with the game fantasy because they could control the game world. The game fantasy attracted users to play the game
Storyline	The experts found that the storyline supported the gameplay. The storyline was easy to understand, and the experts were interested in the storyline. The background story and the game were consistent

Table 11: Summary of responses from experts for pedagogy.

Pedagogy heuristics	Experts' responses
Learning objectives	The experts were satisfied with the learning objectives because they were clear. They also found that the learning activities were interesting, and the game assisted users in learning
Learning theory	The experts agreed that the learning activities were interesting. The game can support self-learning and learning medium through activities
Learning contents	The game contents were acceptable. The contents were clear, simple, and easy to understand. Thus, players will be able to understand the learning goals

Table 12: Summary of usability percentage and improvement comments.

Components of serious game model	Elements	Usability percentage (%)	Comments
Accessibility	Multimedia	89	(i) Improve the text size for the name of the game (ii) Provide animations in the menu section so that users will choose the menu better (iii) Minimise the graphic presentation (iv) Provide background audio for the target objects in the game. For example, there is a sound when the rabbit collects the carrot, which helps users recognise the exact location of the carrots
	Language	76	—
	Screen design	76	Provide a save button in the game task
	Object's movement	100	—
	Interactivity	87	—
Game	Goal	87	Users can see their progress in the game
	Rewards	90	Provide interesting rewards to the rabbit
	Challenges	98	The answer for the game should be differentiated, whether correct or wrong, with audio or visual feedback
	Storyline	80	Provide an introduction to the characters in the game
	Fantasy	87	—
Learning	Learning objective	100	—
	Learning theory	87	—
	Contents	87	(i) The topic and subtopic should be presented in the learning contents (ii) The number of mathematical tasks should be increased, and the task design should be improved

6. Conclusion

There are three key components of the game-based accessibility model regarding the serious game accessibility of low-vision children: accessibility components, game design components, and pedagogical components. The conceptual model is implemented into a low-fidelity serious game prototype for low-vision children. Based on the experts' evaluation, they agreed on implementing the proposed conceptual model into the prototype. The prototype will be refined based on the experts' comments. Therefore, the study presented a comprehensive model for serious game accessibility tailored to low-vision children, encompassing accessibility, game design, and pedagogical components. The successful agreement among experts on implementing this model into a low-fidelity prototype marks an important milestone in addressing the specific needs of this underserved user group. In the broader field of game design for low-vision children, this research can have implications.

The design of serious games is a complicated process that involves a range of challenges. The game's design must strike a balance between entertainment and educational elements because if the game is too focused on learning, it may become boring and fail to achieve its intended outcomes. Accessibility elements must also be integrated carefully into the game design to ensure that the game is accessible to all users, including low-vision children who need to understand the game's storyline easily. This finding is relevant not only for low-vision children but for game designers, aiming to create inclusive and engaging experiences for diverse audiences. By emphasizing the equilibrium between learning and fun, this research contributes to a broader understanding of how to design games that are both accessible and enjoyable for all.

Future studies should explore how this accessibility design model can be improved for disabled users, such as those who are hearing impaired. Expanding the model's applicability to a wider range of disabilities would make it even more impactful and relevant in the field of educational game design. In addition, accessibility design can be enhanced with technologies such as artificial intelligence (AI) and augmented reality (AR). AI can be used to provide adaptive gameplay experiences tailored to individual needs, while AR can create immersive and interactive learning environments.

Evaluating serious games is crucial in determining their effectiveness and impact, and further studies could be conducted using standardized evaluation and assessment methodologies for serious games. Future studies can focus on creating and refining these evaluation tools, enabling researchers and educators to consistently measure the impact and educational outcomes of such games.

The limitation of this research is that the sample size was relatively small. These limitations should be taken into account in future research. Researchers can consider expanding the study to a larger and more diverse group of participants, including low-vision children from different age groups and backgrounds.

Data Availability

The data used to support this study are available at https://doi.org/10.1109/ICEEI47359.2019.8988791 and https://doi.org/10.14569/IJACSA.2020.0110528 from the earlier study and are cited at relevant places within the text as reference.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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