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Design and Prototype Development of Augmented Reality in Reading Learning for Autism

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Abstract: (1) Background: Augmented reality is no less popular than virtual reality. This technology has begun to be used in education fields, one of which is special education. Merging the real and virtual worlds is the advantage of augmented reality. However, it needs special attention in making software for children with special needs, such as children with autism. This paper presents an application prototype by paying attention to the characteristics of autistic individuals according to the Autism Guide, that has existed in previous studies. (2) Method: The method used in the development of this prototype is the Linear Sequential Model. Application development is made using Unity3D, Vuforia, and Adobe Illustrator by considering accessibility and other conveniences for developers. (3) Results: The prototype was developed with reference to the Autism Guide, then validated by media experts and autistic experts with the results of the assessment obtaining a score of 87.3/100 which is in the "Very Good" category and is suitable for use. (4) Conclusions: The development of a prototype that refers to the characteristics of children with autism needs to be considered so that what will be conveyed can be easily accepted.

Keywords: e-learning; augmented reality; autism; gamification

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1. Introduction

Augmented reality (AR) allows users to see and combine virtual objects with the real environment, creating interactions between the real world and these virtual objects [1,2]. In simpler terms, AR is defined as the merging of the virtual world and the real world [3,4]. This technology works based on image detection and the image used is a marker [5]. AR is feature-based, in which real and computer-generated information is combined in the physical world, interactive in real-time, and displays virtual objects intrinsically aligned with real-world orientations [2,6,7]. The use of AR in learning significantly affects learning outcomes because most AR provides factual and contextual knowledge that can support learning that begins with students [8]. In addition, AR can help educators make the limited learning time more effective [9].

AR has begun to use in improving the academic skills of children with autism [10], one of which is reading skills [8]. Most individuals with autism lack reading comprehension [11,12], but not infrequently; they also have difficulty identifying letters and words, and others cannot recognize letters at all [13–15].

Various previous studies have discussed using AR to improve reading skills. Research conducted by McMahon, Cihak, Wright, and Bell [16] used marker-based AR to improve mastery of science vocabulary in autism children. The AR vocabulary intervention positively impacted students' mastery of science vocabulary terms through a combination of real-world and digital content. Meanwhile, Howorth, Rooks-Ellis, Flanagan, and Ok [17], uses marker-based AR to increase phonic awareness, reading fluency, and reading comprehension for autism children. The results of his research are that students remember more letters and words after being involved with AR. Kolomoiets and A. Kassim [6] use marker-based AR to teach reading using the global reading method. AR makes students interact with the artificial world through mobile devices, which is more accessible and predictable for future child development.

The visual way of thinking in autistic children supports all the positive impacts of using AR [18]. This virtual object can make it easier for children with autism to represent realistic images and stimulate children's cognitive processes so that information exchange and processing will occur [6]. AR can also attract attention and increase the involvement of children with autism in the presented material [19].

Planning teaching programs for students with autism is complex because these students have significant differences in learning styles, communication, and social skills development and often have challenging behaviors. Currently, personalized interventions for autistic students are mainly used for behavioral therapy of autistic students assisted by machine learning [20,21]; therefore, it is used to improve social communication [22]. In testing the feasibility of software that implements personalized interventions, it is carried out in various ways, such as internal system testing by calculating system accuracy [20,23], and testing directly on students with autism to determine the influence and involvement of students in a personalized learning process [21].

In previous research, most of the use of AR in improving reading only focuses on one-size-fits-all. Heterogeneity in autistic reading skills should be the focus of educators in providing teaching. In addition, in testing the feasibility, previous research rarely involved experts. Experienced experts can provide views on the feasibility of a program. Therefore, the general objective of this research is how to develop AR based on personalized learning in beginning reading, especially word, syllable, and letter recognition. The teaching materials provided are adjusted to the student's initial reading abilities, which are grouped into three (able to read, less able to read, and unable to read). The research questions are as follows:

RQ1. What is the process of developing personalized learning-based AR prototypes for children with autism to learn to read?
RQ2. What is the feasibility of the prototype that has been developed?

This paper is organized into five sections, including Section 2, discussing previous research; Section 3, presenting the methodology; and Section 4, providing the results. The last section is the conclusion and future research.

2. Previous Work

AR for children with autism in previous studies was used to assist in improving communication skills [24,25]. This is because the conspicuous limitations in children with autism are communication deficits and social skills. However, over time, practitioners and parents began to be aware of the academic skills of their children. In the last seven years, AR has begun to be used to help improve the academic skills of children with autism. Kellems, et al. [26] used AR to enhance mathematics skills with significant improvement results in maintaining the learned skills. In addition, McMahon, Cihak, Wright, and Bell [16], used AR to increase science vocabulary knowledge, proven by all students that show improvement in their skills to define and label science terms. In line with research by Kolomoiets and A.Kassim [17], used AR to teach reading skills with a global reading method. Howorth, Rooks-Ellis, Flanagan, and Ok [17], used AR as an instructional support in the form of video to teach reading. Meanwhile, Antão, et al. [2] combined AR with motion control to learn alphabets and numbers. The result of this combination not only improves the knowledge but also gives more considerable motivation and an exciting experience for the students who use it.

3. Methods

The software development model used in this research is Linear Sequential Model by Pressman [27]. The reason to use this model is that it has systematic steps, and each activity is detailed so that its development process is well understood. Development flow can be seen in Figure 1.

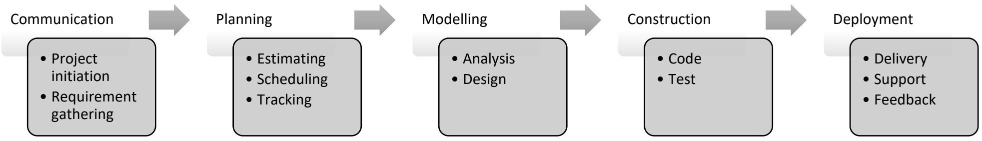

Figure 1. Linear Sequential Model.

A. Communication

In the communication step, the developer team members communicate with the teachers to gain data about the problem in the school (Extraordinary School). Then, a literature study is conducted to obtain the research support information by collecting data or supporting theory through books, journals, and other resources related to the research. The obtained data will help define the feature and software functionality that will be created.

The results of the findings at the communication stage are that the education and teaching of autistic children are generally carried out based on the following principles [28].

1. Structured. Education and teaching for autistic children apply structured principles, meaning that in learning, the learning materials given to children start from the most accessible teaching materials and can be carried out by children. After this ability is mastered, it is then upgraded to teaching materials at the level above it.
2. Patterned. Activities of autistic children are usually formed from patterned and scheduled routines, both at school and at home. Therefore, education must be conditioned or accustomed to an orderly pattern. Autistic children whose cognitive abilities have developed can be trained using a schedule adapted to their environment's circumstances and conditions so that children can accept changes from routines to be more flexible.
3. Programmable. The educational material program must be carried out in stages and based on the child's ability so that the target of the first program will become the basis for the target of the second program and so on and make evaluation easier.
4. Be consistent. Implementation of education and behavior therapy for children with autism; consistent principles are necessary. If the child behaves positively and gives a positive response to a stimulus, the supervising teacher must quickly give a positive response.
5. Continuous. Education and teaching for autistic children are not much different from normal children. The principle of continuous education and teaching is also necessary. Continuity in education is not only at school but also followed up for activities at home and the environment around children.

B. Planning

In this step, the time planning in application development is made by considering the software complexity that will be created. The time required for software development is nine weeks.

In the first week, team members communicated to plan software development. A preliminary study was conducted in the second week to determine user requirements. In the third week, a timeline was started for prototype development, such as making use cases, flowcharts, storyboards, and materials. Week four saw the creation of 2D objects, interfaces, and markers. After that, the augmented reality coding process was carried out for three weeks. Black box testing, bug fixes, and feature additions were carried out in week 8. In the last week, media experts carried out validation; after that, improvements were made for further development.

C. Modelling

The researcher uses an object-oriented model, and UML notation called use case diagram in the software modeling. Use case diagram is an activity description that works following the needs. The use case diagram also describes the interaction between the user and the software that will be built to discover what functions are available.

According to Figure 2, the Select group is a feature where the user can choose a group 1 (high), 2 (moderate), and 3 (low) based on his reading skills. Furthermore, the user can scan markers from the given book. The outputs of the scan marker result are 3D objects, text, and audio. Click 3D objects is used if the user wants to repeat the audio from the appeared 3D object. Last, the user is given practices to emphasize their skills.

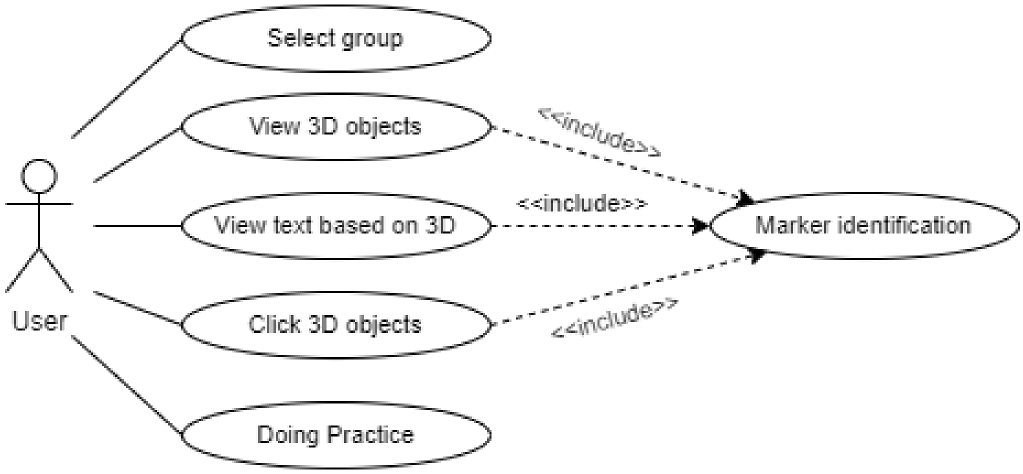

Figure 2. Use case diagram of learning applications for autistic children.

The user target in this application use is individuals with autism, so the user interface follows the Autism Guide: a usability guideline to design software solutions for users with autism spectrum disorder from Aguiar, Galy, Godde, Trémaud, and Tardif (2020).

The developer team, modeling the data flow (Data flow diagram (DFD)) of the application to be developed. First, the context diagram (Figure 3) describes a system scope. In this context diagram, there is an AR process for autism implementation, and the user is its entity.

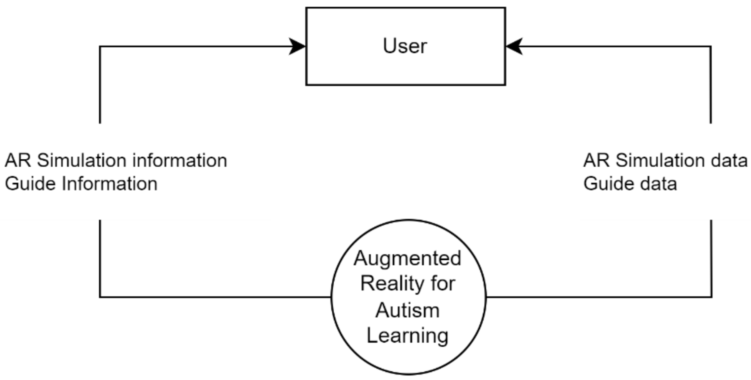

Figure 3. Context diagram.

Next, this context diagram is divided into smaller subs (Figure 4). The user will click the menu to start the AR, then the system will show the AR camera. As well as the guideline menu, the user can click the guideline if he wants to view the application guidelines, and the system shows the guidelines in the form of a picture. Last, if the user wants to log out from the application, he can log out through the log-out button, and the system will confirm whether the user is sure they want to log out or not.

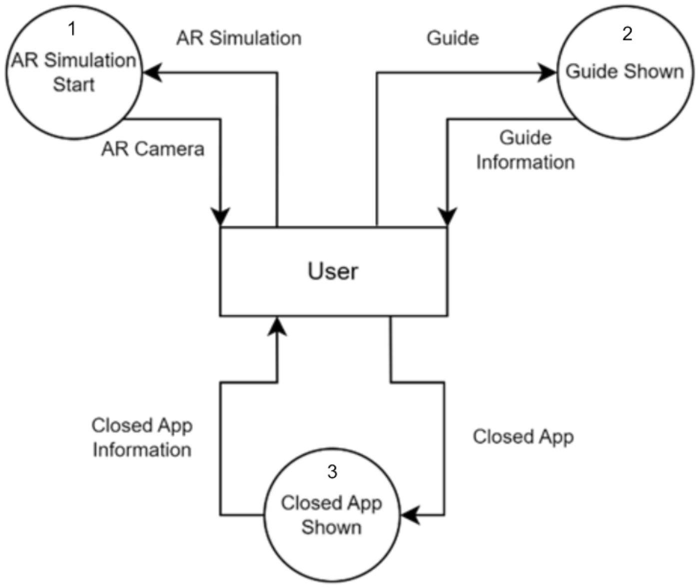

Figure 4. Level 1 data flow diagram.

Lastly, the advanced level from the previous level, where the process will be explained in more detail (Figure 5). The developer results in a marker which is then inputted into the Vuforia. The marker collection is stored in Vuforia's AR Marker database. When the user detects the marker using the AR camera, it will conduct a checking process in the AR marker database. If the marker exists in the database, the system will show the 3D object and other information related to the created marker.

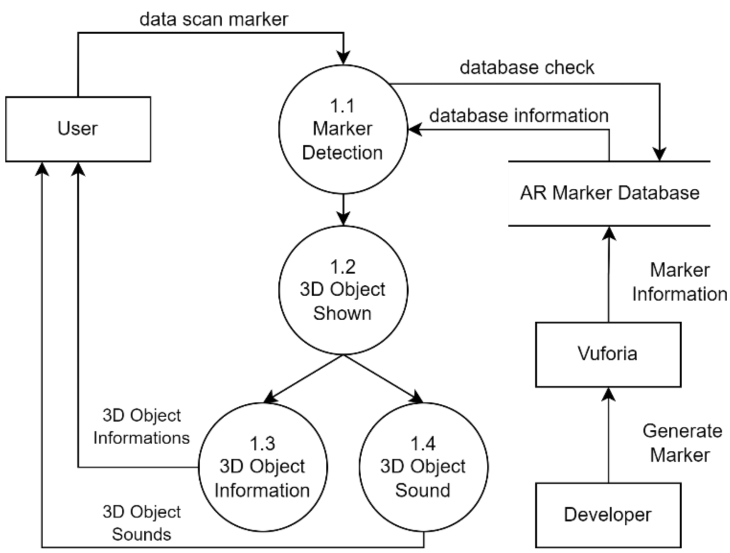

Figure 5. Level 2 data flow diagram.

In general, the model flow in this application can be seen in Figure 6. The group selected the first time using the application is stored in the unity database. Then, the content displayed for each group varies according to their children's abilities. Personalized learning, here, is not only related to the content displayed, but students can choose which material to learn (vocabulary or letter material). So, students can explore the material they are studying.

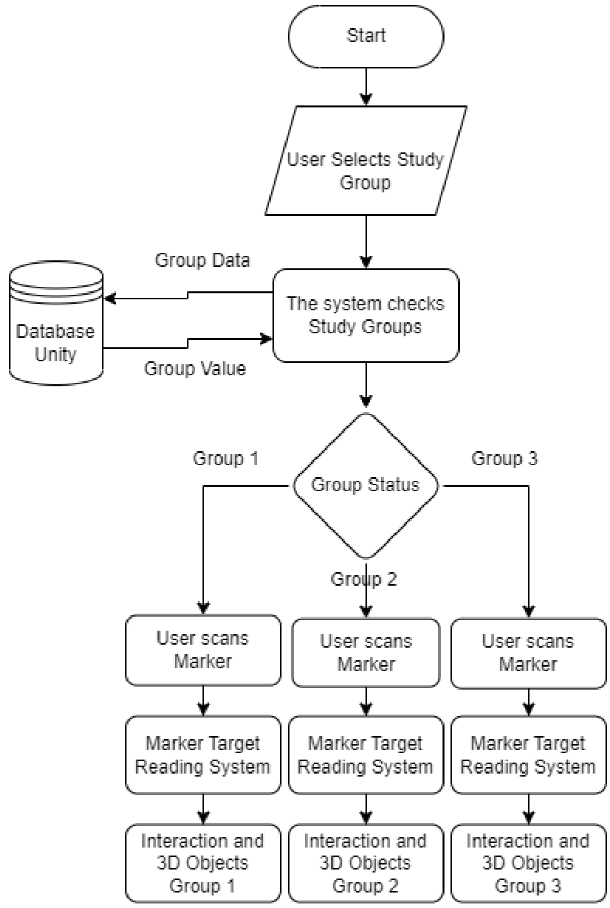

Figure 6. Feedback page.

D. Construction

After all the software development needs are obtained, we conduct the technology selection planning. Unity Game Engine, especially Unity3D (2021.3.5f1 version), is selected as the platform for developing the AR prototype. The fundamental reason is that Unity has high accessibility and offers various software development kits (SDK) to quickly compile the created projects to become a mobile application (Android). The AR procedure is scanning a marker to show the arranged 3D model. The marker illustration is made using Adobe Illustrator as the vector graphic design software that the designer quickly explores.

Moreover, Vuforia as the developer kit (SDK) eases the developer in making AR-based applications. Vuforia is selected because its API uses native support to be built in android or iOS. Vuforia tries to detect the marker by comparing the picture captured by the AR camera with the markers database used in this application. The simple setup and convenient development process become the advantages of Vuforia. In addition, Blender 3D is selected as the platform in the 3D model that emerges in the AR marker. Blender has quite complete features and low requirements, it only needs the support of OpenGL, and the application is based on open source.

After the initial prototype is created, the researcher conducts testing using the black box. Black box testing is conducted to determine whether the input and output are following the existing features. Later, the maker detection trial, which implements single target detection, is conducted, where the system will detect only one marker. The tests conducted were a distance test of 50 cm (Figure 7) and a tilt angle of 30° (Figure 8) to see the sensitivity of the marker when scanned from different distances and tilt angles.

Figure 7. Trial for 50cm distance.

Figure 8. Trial for tilt angles 30°.

E. Deployment

After coding and black-box testing, the application is sent to media experts to be tested for compliance with predetermined criteria. This is done to determine the feasibility, improvement, and evaluation of the application that has been made. The feedback obtained will be used for further application development so that it can be tested on users with autism.

Two students with autism were involved as participants in using the AR application for reading using a personalized learning model. Before the trial, the assessment was carried out using the Early Grade Reading Assessment (EGRA) instrument. This instrument includes assessing the ability to read words, syllables, and letters. The research was conducted in 12 sessions. Baseline-1 (A-1), an assessment before the AR application intervention is given, is carried out in three sessions. Then, Intervention (B), which is the condition of students using the AR application, was carried out in six sessions. Finally, Baseline-2 (A-2) is an assessment after three intervention sessions.

4. Results and Discussion

The results of this study are prototypes of AR applications for autistic children in learning to read with personalized learning. A collection of markers consisting of illustrated images, is made into a book. The book is made into two books based on the material, in order to make it easier for students to choose the material they want to learn.

The learning process created is adapted to the learning principles of autistic students, which are described in the Communication subsection. This personalized learning model can be programmed based on students' abilities by providing primary material that can be used to improve sentence reading skills. The learning method used is the SAS reading method. This method was chosen because it has structured steps in learning to read. The patterns used to start with words, broken down into syllables and then letters. In the development of knowledge, the system's feedback follows the students' responses, as shown in Figure 17. This learning can occur continuously so students can use it for advanced reading. The results of the learning design applied to AR applications can be seen in Table 1.

Table 1. Learning activities with AR applications and personalized learning models.

Syntax	Learning Activities	Learning Activities in AR Media
Delivering Objectives and preparing Giving Feedback	Teacher: 1. Prepare students to take part in lessons physically and psychologically by providing motivation 2. Convey the learning objectives and outline of the initial reading material 3. Convey how to use the media 4. Showing the video as a step-in apperception	In AR media, videos are shown as steps in Apperception. The video contains chants in recognition of the alphabet A–Z.
Learners Organizing	Teacher: 1. Give students the opportunity to choose initial reading material that they have not mastered 2. Provide material suggestions in accordance with the results of the reading skills assessment if students cannot choose material Learners: 1. Communicating interest and desire in learning to read 2. Determine the initial reading material to be studied	In AR media, students are directed to choose groups according to the results of the preliminary reading assessment. After that, students can choose the material in the FunReado book that they will study according to their interests. In the book, there are 15 words that can be learned by students.
Information Access	Teacher: 1. Guiding students to access information about initial reading material on the media 2. Give students the opportunity to ask for help Learners: 1. Access information about initial reading materials on the media 2. Ask for help if there are difficulties in the learning process	In this syntax, the teacher guides students in scanning markers on books as material to be studied by students. The reading method used is the SAS method so there is a button to change the stages of the SAS method on AR media. If students are able to use AR media, the teacher gives students the freedom to explore the material they will learn and provides space for students to ask questions.
Develop knowledge	Teacher: 1. Helping students to do exercises on the media as a form of knowledge development 2. Helping students to validate the knowledge they have acquired Learners: 1. Do the exercises that have been provided by the teacher 2. Paying attention to the teacher in validating the knowledge he has acquired	In this syntax, students are given practice questions in the form of drag and drop. In the first exercise, students are instructed to compose words from syllables. The second exercise, students are instructed to show the letters according to what is ordered.
Student Choices and Votes	Teacher: 1. Provide feedback if students can do the exercises correctly 2. Give encouragement to try again if students have not got knowledge correctly according to orders Learners: 1. Get feedback from the teacher on the activities he is doing	In this syntax, giving feedback is done based on the answers to practice questions. This feedback is complemented by a sound corresponding to the positive feedback or encouragement to try again.

Application prototypes that are ready to be tested are built into Android with tablet-specific settings. Because this application is not yet available on the PlayStore, users download the. apk file on the Google Drive that has been provided and can immediately install it. Figure 9 displays the splash screen of an application that the researcher called FunReado—an application for learning to read at the beginning for autistic children.

Figure 9. FunReado Splash Screen.

Before using this application, users first make an assessment in reading the guide. Then, in the initial appearance of the application, the user is directed to select groups according to their abilities with the display as shown in Figure 10. Group 1 is defined as a child who has high ability, group 2 is defined as a child with moderate ability, and group 3 is defined as a low group. Any content provided based on children's abilities.

Figure 10. Group selection page.

After selecting a group, the user will be directed to open the AR camera and scan the title of the material on the first page of the book. As seen in Figure 10, 3D objects appear after being scanned with additional voice overs to explain the purpose and description of the material to be taught.

The material taught in this application begins with the introduction of word variations of vowels (V) and consonants (K) using the SAS (Synthetic–Structural Analytic) method. Display can be seen in Figure 11. Group 1 was given words with the *KVKKVK* pattern, group 2 was given words with the *KVKVK* pattern, finally, group 3 was given words with the *KVKV* pattern. The selection of these word variation patterns takes into account the ease of pronunciation and the simplicity of the word sequence. The "recognize" button can be clicked which will then be directed to the SAS method format.

The SAS method is an initial reading learning method that begins with the presentation of complete sentences, broken down into words to become syllables and letters that stand alone and recombined them starting from letters into syllables, words, and complete sentences [29]. With this SAS method, early reading learning can present sentence structures extracted from students' language experiences.

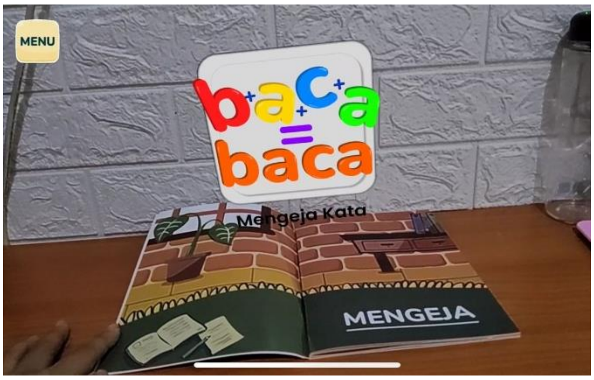

Figure 11. Title page.

Exercise is given in order to develop the user's knowledge of reading material. Word recognition exercises using Drag and drop forms. This allows the user to arrange words according to what is ordered. Display can be seen in Figures 12 and 13. After successfully completing the exercise, the system will issue positive feedback (Figure 17) to validate knowledge of children with autism.

Figure 12. 3D objects for teaching spelling words.

Figure 13. User interface for practice spelling words.

Other material provided is regarding the introduction of letters which can be seen in Figure 14 and objects that contain the first letter of the selected letter as shown in Figure 15. The "Benda" button is used to display an object that represents the selected letter, and when clicking the "Letter" button, this will display the uppercase and lowercase letters that have been selected.

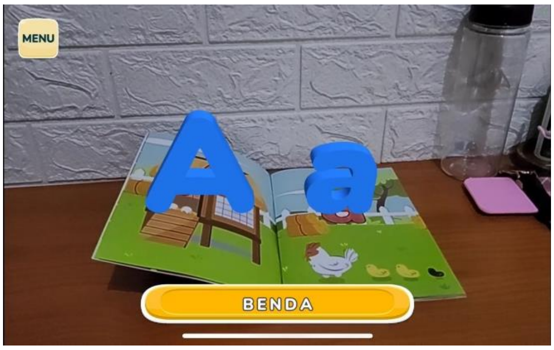

Figure 14. User interface for teaching letter recognition.

Figure 15. 3D objects for teaching recognize letters.

Practice questions on letter recognition material are in the form of multiple choice, which can be seen in Figure 16. The user will be given an order to show letters from a group of letters that exist. If it is correct, the system will give positive feedback (Figure 17) and vice versa if it is wrong; the system will provide feedback that motivates the user to try the question again.

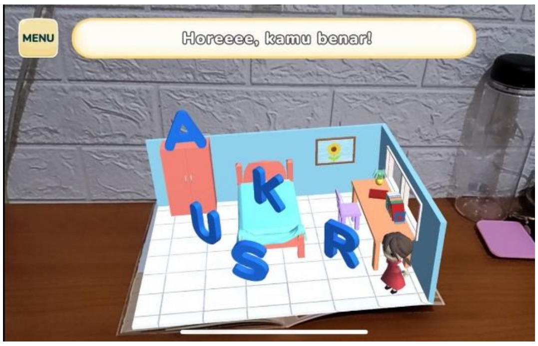

Figure 16. User interface for practice of letter recognition.

Figure 17. Feedback page.

Black-Box Testing

After the prototype was completed, the researcher tested it using a black-box. At this stage, the black-box testing method is used to find out every function, feature, input, and output in the application to test if it is as expected or not. The results of the black-box testing can be seen in Table 2.

Table 2. Black-box testing.

Test Item	Expected Results	Real Results	Test Results
Group options within the application	Options can be clicked and redirected to the page according to the selected group	Each group option is clickable and already corresponds to the page it goes to	appropriate
Enter the name in the application	Name input can work	Each user can input a name	appropriate
All buttons inside the application	All buttons function according to their function	Each button can be clicked and functions according to its function	appropriate
Audio narrator within the application	Audio narrator speaks according to the content being displayed	The narrator's speech is in accordance with the content displayed	appropriate
Augmented reality feature in the application	The 3D object appears after scanning the marker	Every 3D object already appears after scanning the marker	appropriate
Drag and drop feature within the application	Features can pick up and move objects when tapped	Exercises that use this feature, the user can pick up and move objects when tapped	appropriate
Multiple choice feature in the application	Features can select objects when tapped	Exercises that use this feature, the user can select objects by tapping	appropriate

Expert Judgement

Expert judgment is carried out after black-box testing. This is to test the feasibility of the prototype by considering the characteristics and ways of learning of autistic users. Two media experts (curriculum development lecturer), two autistic experts (special education lecturer), and one linguist (Indonesian literature lecturer) were selected for the prototyping test because they had sufficient competency regarding instructional media and language.

The test instrument used refers to Multimedia Mania 2004—Jury Rubric. The instrument was chosen because it was completed and has certain aspects that ensure the assessment is carried out thoroughly. The aspects assessed are mechanisms, multimedia elements, information structures, documentation, and content quality, with the results shown in Table 3. The ideal score has been determined by the instrument.

Aspects of the mechanism include technical criteria, navigation, spelling, and grammar. The average rating is 83.1%, which means that the developed prototype has been fully completed by running without any errors in appearance, music or video. The buttons used function well and are easy to operate. It is necessary to add a warning if the student does not scan the image within a certain time limit. However, there are some parts that need more attention in the use of spelling and grammar. Explanation of the material at the beginning of learning is not really necessary, remembering that children with autism need simple instructions and direct delivery which is to the point.

Aspects of multimedia elements include interface design criteria and the use of enhancements. The average rating is 85%. This assessment illustrates that this prototype is very effective in conveying messages and learning objectives, and pays close attention to interface design with the characteristics of users with autism. The use of images, audio, video, and 3D objects is effective enough to enrich the learning experience. However, it must be ensured that the content provided will be appropriately conveyed so that students are not distracted while studying. Then, some pictures are unrealistic, considering that children with autism cannot think abstractly.

Table 3. Multimedia Mania 2004 scores.

Aspect	Criteria	Ideal Score	Score	Total Score	Presentation (%)
Mechanical	Technical Navigation Spelling and Grammar Completion	16	3.6 3.4 3.1 3.2	13.3	83.1
Multimedia Elements	Screen Design Use of Enhancements	8	3.2 3.6	6.8	85.0
Information Structure	Organization Branching	16	6.8 6.2	13	81.3
Documentation	Citing Resources Permissions Obtained for Resources	8	3.3 3.4	6.5	83.8
Quality of Content	Originality Curriculum Alignment Evidence That Objectives Were Met	36	11.4 9.9 11.7	33	87.7
	Depth and Breadth of Project Content Subject Knowledge	16	6.4 7	13.4	

Aspects of the information structure including preparation and branching obtain an average rating of 81.3%. In this prototype, the learning flow sequence is considered clear and to the point. In addition, the prototype that has been developed contains several scenario options that are easy to manage and suit the characteristics of autistic users.

Aspects of documentation include source citations and permission to use sources. The average rating for this aspect is 83.8%. The majority of the assets in the prototype, including text, graphics, audio and video, already have permission to use them.

Aspects of content quality include originality, curriculum alignment, goal alignment with media content, media depth and breadth, material in the media. The average rating for this aspect is 87.7%. The value indicates that the prototype demonstrates authenticity by going beyond previous discoveries and offering new insights. The content is related to KI/KD and supports the expected learning objectives. The material provided can be improved so students can explore more of the words around them. Then, teaching reading with this introduction can be carried out with simple, meaningful sentences so that the material presented is not too abstract for autistic students.

Limited Test Result

The research was conducted on two autistic students. The results showed that Student A was quite capable of pronouncing letters and showing letters without assistance but could not distinguish letters similar in shape, such as m and n or p and q, and there were still pronunciation errors in some words. Meanwhile, Student B could distinguish between letters but still had difficulty pronouncing several words. The results showed increased student learning outcomes in reading words and syllables from the initial baseline to the final baseline. Supported by research conducted by Shemshack and Spector [30], this personalized learning model is suitable for children with special needs, ensuring that schools accommodate the needs of students with different needs, interests, and individual goals. The research results of Basham, Hall, Jr., and Stahl [31] also support this finding that personalized learning provides tremendous growth for students with special needs. In addition, the results of this study align with the findings of Rastegar-moghadam and Ziarati [32] that the implementation of personalized learning is more effective with the use of technology to facilitate the organization of learning with a large number of students.

However, there was no significant increase in the material to recognize letters because elementary school teaching starts with recognizing letters.

5. Conclusions

The results of this study are prototypes of AR applications for children with autism in learning to read. The application made is able to provide an alternative in teaching reading skills, especially in spelling words and recognizing letters to make it more attractive to students. The development process is based on a systematic and detailed Linear Sequential Model at each stage. In developing the AR application prototype, the development team tried to pay attention to the profile of individuals with autism in accordance with the Autism Guide so that this application has user-friendly characteristics. The overall assessment of media experts and autistic experts resulted in a score of 87.3% in the "Very Good" category and shows feasibility for use.

The assessment from the media experts and autistic experts showed positive results on the AR prototype for autism students. This technology makes it possible to implement for autism students with the considerations that have been applied in designing the prototype. Suggestions from media experts and autistic experts, such as adding practice questions and simplifying instructions, will be adopted for further development in implementation for students.

Further development can add simple sentence reading material to make it more meaningful, then, combine learning reading skills with other skills such as communication, writing, or arithmetic. In addition, learning activities can be developed with more variety so that students do not become bored quickly.

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