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Android-Based AR Game for Teaching Division to Students with Mild Intellectual Disabilities

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ABSTRACT

This study aims to develop innovative learning media in the form of Android-based educational games with Augmented Reality (AR) technology to help students with intellectual disabilities (mild mental retardation) in public high schools in the DKI Jakarta area understand the basic concepts of division in mathematics. The limitations of conventional learning media and the lack of teacher knowledge in digital technology development are the background of this study. The approach used is Research and Development (R&D) with the Multimedia Development Life Cycle (MDLC) method, which includes the stages of conceptualisation, design, material collection, creation, testing, and distribution. The developed application was validated by media experts, material experts, as well as teachers and students through questionnaires, showing positive responses to the material, design, and language aspects. A total of 56.5% strongly agreed that the application improved their understanding of division, and 60.9% strongly appreciated the design features. The language used in the application was perceived as easy to understand, reflected in 96.7% positive responses. Moreover, the application encouraged active participation (100%), increased learning interest (100%), and contributed positively to classroom activities (95.3%). The test results concluded that this application is effective in attracting students' interest and improving their understanding of the concept of division, and can be an innovative solution in inclusive education based on the principles of Gender Equity and Social Inclusion (GESI). This learning media is expected to expand access, improve the quality of learning, and support equal education rights for children with mild intellectual disabilities.

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INTRODUCTION

The Indonesian education system, including public secondary schools, accommodates students with intellectual disabilities in accordance with national regulations such as Law Number 20 of 2003 on the National Education System and Permendiknas No. 70 of 2009 on Inclusive Education. Children with mild intellectual disabilities categorized as students with special needs typically have an IQ between 51 and 36 [1], experience limitations in cognitive abilities and social skills [2], and often face challenges in communication, attention, memory, and daily functioning, requiring substantial social support [3]. Providing an appropriate learning

environment is therefore essential to ensure their quality of life and uphold their right to equitable education, which requires collaboration between government, schools, and society [4]-[5].

Public senior secondary schools have increasingly implemented inclusive practices that allow students with special needs to learn alongside their peers [6]. However, despite having equal rights to education, students with mild intellectual disabilities still lack access to suitable learning aids that address their cognitive characteristics and learning challenges. A humanistic approach that integrates human rights principles and gender equality is needed to support students with special needs [7]. The Gender Equity and Social Inclusion (GESI) framework reinforces the importance of equality across gender, disability, socioeconomic background, ethnicity, and educational access. Incorporating GESI principles into learning management ensures that students with intellectual disabilities are not separated or treated differently, helping schools cultivate respect, diversity, and social inclusion.

In practice, the limited availability of innovative learning media in public senior high schools particularly in DKI Jakarta has hindered students with mild intellectual disabilities from understanding mathematical concepts such as division. Learning activities still rely heavily on textbooks, while teachers often lack the skills to design digital learning media aligned with current technological developments. Many educators are unfamiliar with Android-based instructional methods, including Augmented Reality (AR), due to limited technological competence, resulting in less effective learning support for students with intellectual disabilities.

This study aims to address the lack of innovative learning media for students with mild intellectual disabilities in public senior high schools in DKI Jakarta by developing an Android-based educational game that incorporates Augmented Reality. The media is expected to enhance students' interest and enthusiasm, while also reducing barriers related to access, technological limitations, and learning gaps. Additionally, the AR-based learning application is intended to assist teachers in creating more engaging and effective learning experiences, particularly in understanding division and multiplication in the digital era. The Android-based AR system used in this study is designed to be appealing, effective, and accessible anytime and anywhere, making it a valid and relevant tool to improve educational quality and support equal learning opportunities for students with mild intellectual disabilities.

METHOD

This research is a research and development (R&D) study conducted using a GESI perspective. The study involved the development of a learning media application for teaching basic division concepts to students with mild intellectual disabilities enrolled in a public high school in DKI Jakarta during the 2023–2024 academic year. A total of 20 students, 2 mathematics teachers, and 2 experts (comprising media experts and subject-matter experts) participated in the study. The product was developed using the Multimedia Development Life Cycle (MDLC) method to produce an augmented reality–based learning medium [8]. The study was conducted at a public high school in DKI Jakarta Province [9]. Participants were selected based on inclusion criteria, namely students diagnosed with mild intellectual disabilities, in stable health conditions, and actively receiving instruction from mathematics teachers at the selected school. The product testing phase involved evaluations by media experts, subject-matter experts, and practising teachers, including form tutors.

To ensure instrument quality, the questionnaires underwent expert validation. Expert assessment scores were summarized in structured tables, and a validity index was calculated to confirm the appropriateness of the items. The development of the questionnaire followed a four-

point Likert scale consisting of the following response categories: Very Poor (VP), Poor (P), Adequate (A), Good (G), and Very Good (VG). Scoring guidelines and interpretation procedures were established to support consistent data coding. Ethical procedures were observed throughout the research. The study obtained ethical clearance and written informed consent was collected from teachers and parents/guardians of participating students. All participants were informed of the study's purpose and voluntarily agreed to participate. Data were collected using validated questionnaires and semi-structured interviews. Responses from students and mathematics teachers were analysed descriptively to evaluate the feasibility and acceptance of the developed product [9]. A flowchart summarizing the overall research steps was also prepared to illustrate the sequence of activities from development to evaluation in figure 1.

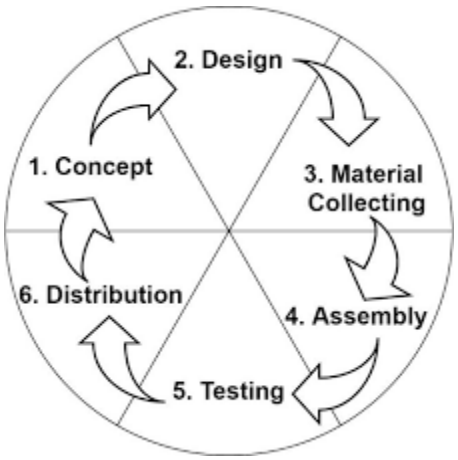


Figure 1. MDLC method

The research process is illustrated in Figure 1. First, the problem is identified. Next, a review of the research is conducted through relevant journals and studies. Second, the MDLC method is used, which is carried out in six stages. The MDLC method is applied in each phase, including conceptualisation, design, component collection, creation, testing, and distribution of the application.

RESULTS AND DISCUSSION

Application Development Stages

a) Conceptualisation

Everything was considered regarding the conceptualisation of the system user's objectives and the evaluation of system requirements. The purpose of this application is to provide students with mild intellectual disabilities at public high schools in the 2023–2024 academic year with an understanding of the basic concepts of division through *augmented reality-based* learning. The results of the conceptualisation process, which is the first stage, were used to create a preliminary design for the "Learning Division" game. *Storyboards* are an important component in media development. *Storyboards* can be used as a tool at the beginning of the design process. Graphic configurations such as images and a series of illustrations displayed periodically for the purpose of displaying a collection of interactive media, such as animation files or web interactivity, are called *storyboards. The storyboard* display of the "Learning Division" game is designed to teach children with intellectual disabilities the concept of division along with an understanding of the concept of multiplication and can be seen below.

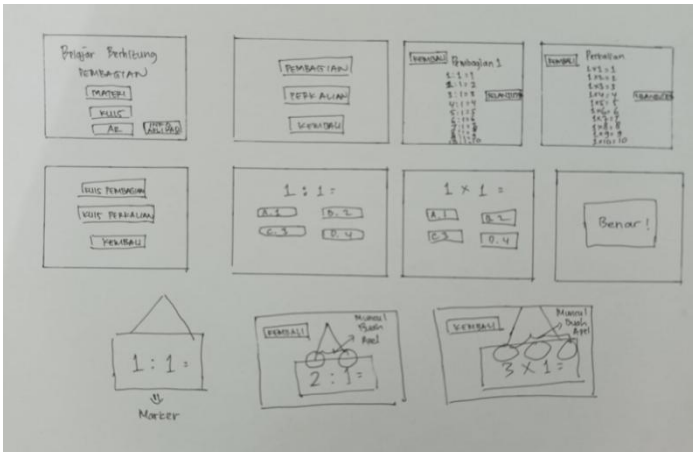


Figure 2. Application Concept

Based on figure 2 the application offers content that includes information about division, multiplication, quiz questions, and information about the application. To display 3D objects, the *smartphone* camera captures predetermined markers. In the material information section, which contains material on division and multiplication, you will find explanations of the basic concepts of division and multiplication, as well as instructions on how to use the application. In the quiz section, there are ten questions on the concept of multiplication and ten questions on the concept of division. For each question answered by students with mild intellectual disabilities, the correct answer will appear if the student answers correctly, and the incorrect answer will appear if the student with intellectual disabilities gives the wrong answer. This application offers content that looks like an apple, which can be used to provide an understanding of the basic concepts of division.

b) Design

At this stage, context diagrams and system *flowcharts* are part of the system design application development process. Context diagrams are the result of two stages of the system design process. System flowcharts are visual representations of a process or workflow. Both linear and non-linear flowcharts can explain the steps of a process systematically. They typically use standard symbols to indicate the activities, decisions, and data flows involved in a process. *Flowcharts* help analysts group problems and find potential solutions. However, context diagrams, which show how the system being built interacts with related external entities, are one type of diagram used in system analysis. Context diagrams provide an overview of the system and its scope.

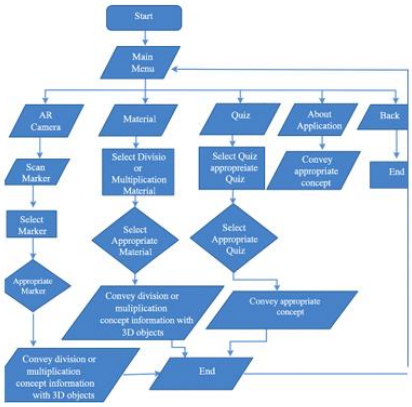


Figure 3. System *Flowchart*

Figure 3 shows the general workflow of the application; the main menu will appear in it. The main menu displays various options, including the AR camera button menu, material and quiz information, application information, and exit. The AR camera application allows the camera to perform marker detection by displaying 3D objects. The application information menu displays information about the application designer's data. Figure 3 above explains how the application system works.After installing the application, users can request data responses from the application. These responses consist of information about 3D objects, *markers*, and application instructions. Using Canva *tools*, design lines. Lines are graphic design components that can be used to indicate specific design elements or mark them. Select photo elements from *the toolbar* to create markers in Canva, adjust the size of the photo and text, and then save and download the design. *The markers* are added to the database provided by *Vuforia Developer* as *image targets* after being successfully saved. To enable developers to create AR applications, *Qualcomm* provides *Vuforia* as an SDK.



Figure 4. Marker Creation

Figure 4 above shows the process of creating markers and using Canva as an online graphic design tool to create various types of visual content. *Blender tools* are used to create 3D objects. The creation of 3D objects is done at the 3D object creation stage. After the 3D object model is created in *Blender,* the colouring or texturing process is carried out to give it the desired colour. The purpose of creating this 3D object is to demonstrate the concepts of division and multiplication.

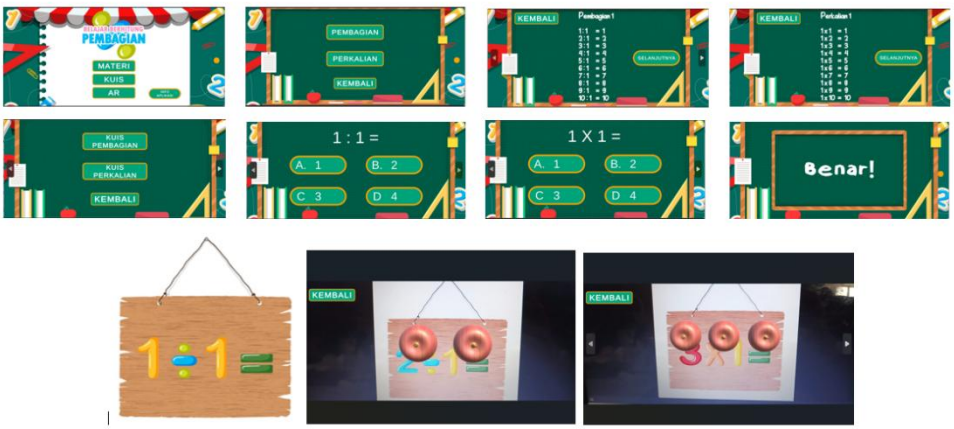


Figure 5. Game Design

Figure 5 based on the results of the conceptualisation stage, which served as a reference in the game development, the "Learning Division" game design was created to meet the needs of students with mild intellectual disabilities. The choice of media and materials was also tailored to

the analysis requirements during the conceptualisation and *storyboard* development stages. The game design can be viewed here.

c) Component Collection (Material Collecting)

Components were collected in an effort to build an *Augmented Reality* application related to the concept of division that can be understood by students with disabilities (mild intellectual disability). The component collection process began with research on the basic concepts of division that can be understood by students with disabilities (mild intellectual disability) by adding the concept of multiplication so that there is a connection to reinforce the basic material in arithmetic. In the information search research stage, the internet was used as a source of information. The aim was to gain a better understanding of the basic concepts that students with disabilities (mild intellectual disability) must have when learning the basic concepts of division in mathematics. In addition, data was collected on the appropriate three-dimensional object shapes so that they could be used as objects that could appear when the *Augmented Reality* application was used. The 3D modelling technology known as Blender was used to accomplish this.

d) Assembly

At this stage, the creation of the application using Unity 3D began after the necessary components had been designed. Users can display 3D objects using *markers* that have been identified in *augmented reality* (AR). *Markers* can be recognised by importing and adjusting marker objects in Unity 3D.

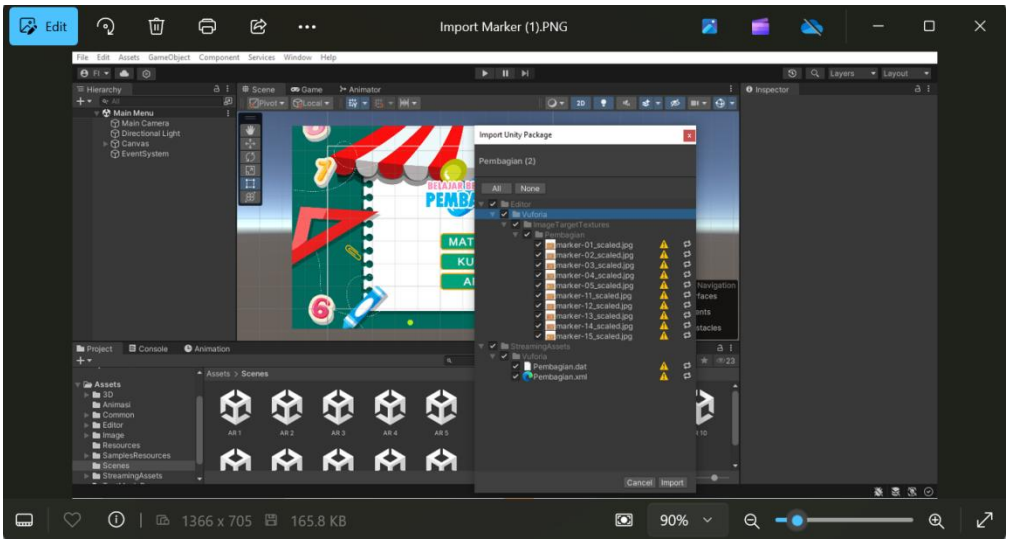


Figure 6. Importing Markers in Unity 3D

Figure 6 shows the process of importing marker packages into Unity 3D during the development of an Augmented Reality (AR) application. At this stage, marker files such as Marker_01_scaled.jpg to Marker_15_scaled.jpg are imported into the Unity project. These markers function as triggers recognized by the AR camera to display corresponding 3D objects. Additionally, supporting files such as Pembagian.dat and Pembagian.xml are also included to configure and store supplementary learning data. This view indicates that the AR application development has entered the integration phase, where visual components and logical functions are combined within the Unity 3D Editor before proceeding to testing and implementation stages.

e) Testing

This application was tested on a POCO M3 smartphone with a 124.2.2 GHz processor, 6GB RAM, Android version 11, and 128GB storage. During the testing phase, black-box testing was used. Software developers can use the *Black-Box testing* technique, which emphasises the functional requirements of the software, to design a series of application conditions that will teach each functional program.

Table 1. Application Testing Using Black Box Testing

Code	Test Case	Expected Output	Actual Output	Test Case
1	AR Camera Feature on Main Menu	The smartphone camera is activated by the system, a 3D object appears and is displayed for 5 seconds.	The camera is successfully activated by the system and can detect the marker, displaying the 3D object for 3 seconds.	AR Camera Feature on Main Menu
2	Material Feature	The system displays the division and multiplication materials separately.	The system successfully displays the division and multiplication materials.	Material Feature
3	Quiz Feature	The system displays a quiz consisting of ten questions for each concept of division and multiplication.	The system successfully displays a quiz consisting of ten questions for each concept of division and multiplication.	Quiz Feature
4	Next Feature	The system displays the continuation of the explanation for both division and multiplication materials.	The system successfully displays the continuation of the explanation for both division and multiplication materials.	Next Feature
5	Back Feature	The system returns to the previous feature.	The system successfully returns to the previous feature.	Back Feature
6	Application Info Feature	The system displays the application developer information.	The system successfully displays the application developer information.	Application Info Feature

The application has been tested with six test cases, and all features functioned properly, as shown in Table 1. All AR camera features, materials, quizzes, application information, further explanations with the next button, and the back button worked well. In test case number one, the system was slightly faster than expected in displaying three-dimensional objects in three seconds.

f) Distribution

After the testing process was completed, the application was sent to public high schools in DKI Jakarta, which were used as samples. At the distribution stage, questionnaires were given to students with mild intellectual disabilities at public high schools in DKI Jakarta for the 2023-2024 academic year and mathematics teachers to determine how effective the use of educational innovations was for children with intellectual disabilities in the classroom.

Table 2. Student Response Questionnaire Results

No	Statement	(SD)	(D)	(N)	(A)	(SA)
1	This application helps students improve their understanding of the basic concept of division.	-	-	-	43.5%	56.5%
2	Students are very pleased with the media design and enjoy learning using this application.	-	-	-	60.9%	39.1%
3	The language used is easy for students to understand.	-	-	3.3%	45.5%	51.2%
4	The application helps students participate more actively in learning.	-	-	-	46.5%	53.5%
5	Students enjoy learning using this application.	-	-	-	48.8%	51.2%
6	Students are very interested in using this application as a learning medium.	-	-	-	56.5%	43.5%
7	This application has a significant positive impact on learning activities.	-	-	4.7%	57.2%	38.1%
8	Information about the basic concept of division is expanded through this application.	-	-	2.4%	46.5%	51.1%
9	The application provides interactive learning resources.	-	-	-	52.2%	47.8%
10	The application offers innovation in learning.	-	-	-	47.8%	52.2%

Based on table 2 the respondents' feedback to the ten statements, it can be concluded that the application received highly positive evaluations from students. All respondents expressed agreement (A) or strong agreement (SA), with the majority leaning toward strong agreement across most items. A total of 56.5% of students strongly agreed that the application helps them understand the basic concept of division, while 60.9% strongly enjoyed the media design. The language used was also considered easy to understand, with 96.7% positive responses. Furthermore, the application successfully encouraged students' active participation (100%), increased learning interest (100%), and had a significant positive impact on learning activities,

with 95.3% agreeing or strongly agreeing. Therefore, it can be concluded that this application is not only effective in improving students' understanding of division concepts but also serves as an innovative, interactive, and engaging modern learning medium.

Discussion of Development Results and Research Findings

The findings of this study demonstrate that students with mild intellectual disabilities in public high schools across DKI Jakarta responded positively to the use of an Android-based augmented reality (AR) educational game designed to enhance their understanding of basic division concepts [10]-[14]. The development of this application followed the Multimedia Development Life Cycle (MDLC) model, ensuring that each stage from design to implementation was systematically carried out to meet the learning needs of students with special educational challenges [15]-[18]. The use of AR technology made abstract mathematical concepts more concrete and visually engaging, thus helping students grasp the principles of division in a more interactive and accessible way. This indicates that integrating AR into learning media can bridge cognitive gaps often faced by students with intellectual disabilities.

Furthermore, the results from user testing show that the application is easy to use, visually attractive, and effective in maintaining student engagement during learning activities. Both teachers and students expressed positive feedback regarding the interface, interactivity, and learning outcomes achieved through the AR application. The combination of visual support, interactive features, and game-based learning elements creates a stimulating environment that enhances motivation and participation [19]-[21]. These findings suggest that such applications can serve as an innovative and inclusive learning solution, particularly for students who struggle with conventional learning methods in mathematics.

In addition, this study highlights the potential of educational games as effective tools for mathematics instruction among students with special needs. The application not only improves conceptual understanding but also transforms the learning experience into one that is enjoyable and meaningful [22]-[25]. It is recommended that future research explores the integration of AR-based educational games in other mathematical topics or academic subjects, and extends their application to diverse groups of learners with different disabilities. Moreover, continuous refinement of design features and adaptive learning algorithms could further enhance personalization and long-term learning outcomes for students with intellectual disabilities.

Limitations and Future Research

This study has several limitations that need to be considered when interpreting the findings. First, the scope of participants was limited to students with mild intellectual disabilities in one school setting, which may not represent the broader population of learners with similar characteristics. As a result, the generalizability of the findings remains restricted. Second, the intervention period was relatively short, making it difficult to evaluate long-term learning retention or the sustained impact of the AR application. The evaluation design also has methodological constraints. The learning outcome assessment used a simple pre–post structure, and although improvements were observed, the results should be interpreted cautiously due to the limited scale of the data. The questionnaires and expert validation sheets used in this study were assessed by a small number of evaluators, which may influence the strength of the instrument reliability.

Future research should aim to address these limitations. Studies involving multiple schools or more diverse learning environments would strengthen external validity. Longer-term evaluations are needed to understand how AR-based learning tools influence conceptual understanding, engagement, and independence over time. Future versions of the application could integrate adaptive difficulty levels, voice-guided instructions, or automated error analytics

to enhance accessibility and instructional effectiveness. Methodologically, upcoming research may employ more comprehensive data collection techniques, combine qualitative and quantitative approaches, or incorporate additional assessment tools such as observational rubrics or performance-based tasks. Expanding the learning content beyond basic division could also provide insights into the broader potential of AR applications for supporting students with various learning needs. Overall, while the present study demonstrates promising indications regarding the use of AR as a learning aid, further refinement and more robust research designs are required to strengthen the evidence and improve the application's instructional value.

CONCLUSIONS

The results of this study indicate that students with mild intellectual disabilities in public high schools in DKI Jakarta during the 2023/2024 academic year showed interest and reported improved comprehension of basic division concepts when using the Android-based augmented reality (AR) educational game. Developed using the MDLC approach, the application functioned as a supplementary learning aid to support the introduction of division concepts. The evaluation results suggest that the application is generally perceived as attractive and easy to operate by both teachers and students. However, these findings should be interpreted cautiously due to several limitations, including the relatively small sample size, the descriptive nature of the evaluation, and the use of a single device type during testing.

Despite these limitations, the positive user responses indicate that AR-based educational media may offer a promising alternative within mathematics instruction for students with mild intellectual disabilities. Future development could incorporate adaptive difficulty levels, voice-guided instructions, and automated error-analysis features to better tailor the learning experience to individual needs. Further studies could also explore broader subject areas, include larger and more diverse participant groups, and examine how AR-based games can be integrated with other instructional methods to enhance learning variability and support students with different types of disabilities.

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