

Analysis and Development of an Educational Game for Early Childhood Numeracy Learning through a Curriculum-Based and Functional Evaluation Approach

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Abstract

Digital transformation in education has become a crucial necessity in the era of globalization, especially in Early Childhood Education. Generation Alpha tends to comprehend information more easily through digital media, which requires educators to be creative in delivering learning materials using technology. Video games as educational media have been proven to enhance children's learning motivation and create a joyful learning atmosphere. However, uncontrolled use of digital devices raises concerns regarding excessive screen time. To address this challenge, this study aims to design and develop a curriculum-based educational numeracy game for Early Childhood Education that can be collectively played in class using a projector and directly supervised by teachers. The method employed is Research and Development using the ADDIE model (Analysis, Design, Development, Implementation, Evaluation). The research process includes curriculum analysis, numeracy content design, interactive game scenario development, and functional testing using black box testing. Test results show that all core features of the application function as designed, with 100% validation. The educational game consists of three levels featuring various numeracy activities, pattern and shape recognition, tailored for Kindergarten levels A and B. This study demonstrates that pedagogically designed educational games integrated with technology can serve as an engaging, interactive, and developmentally appropriate solution for early childhood numeracy learning.

Keywords: Early Childhood Education, Numeracy, Learning Innovation, ADDIE, Construct 3

I. INTRODUCTION

Education plays a crucial role in navigating the era of globalization. Quality education produces a generation with noble character and competitive excellence in this challenging era. In the context of globalization, integrating education with technology is no longer a mere option but a necessity. This integration is applicable not only at higher levels of education but also at the early childhood stage.

Generation Alpha tends to absorb information more effectively through digital media [1], [2]. This phenomenon requires teachers to be more creative in delivering learning materials by implementing digital technology. Such conditions present an opportunity for research that integrates technology into education. Innovations in teaching methods through technology may take the form of videos, animations, or video games. This aligns with the study by Haura (2022),

which found that the majority of early childhood learners today use gadgets primarily for watching content and playing video games [3].

Learning media in the form of video games has been proven effective in increasing student motivation and creating a joyful learning environment [4]. Prior research has developed educational video games both for school subjects like mathematics and for introducing cultural content not typically covered in formal education [5], [6]. Nevertheless, concerns arise regarding excessive screen time, which may lead to negative impacts [7], [8]. Therefore, this study proposes the development of a video game designed for classroom use through a projector and supervised directly by teachers.

By integrating video games into education, this study aims to develop an application that functions as a learning medium for early childhood education in the classroom environment.



This is in accordance with the Regulation of the Minister of Primary and Secondary Education No. 13 of 2025 concerning the Early Childhood Education curriculum, which implements meaningful play as part of the curriculum. The use of appropriate technology, which is in line with the characteristics of early childhood today, can create a more engaging and practical learning experience, helping children feel comfortable and focused during the learning process [9].

The main objective of this study is to address educational challenges for early childhood by designing engaging educational video games. It is hoped that video games can increase students' interest and enthusiasm in learning, especially in mathematics and numeracy. The research method used is Research and Development (R&D), adopting the ADDIE model (Analysis, Design, Development, Implementation, Evaluation). This model was chosen because the ADDIE model's systematic approach is very suitable for the development of educational media [10].

Through the integration of video games into education, this research aims to develop an application that serves as a classroom learning medium for early childhood students. The use of technology that aligns with the characteristics of today's young learners fosters a more engaging and effective learning environment, enabling children to feel more comfortable and focused during the learning process. Therefore, this study, titled "Analysis and Development of an Educational Game for Early Childhood Numeracy Learning through Curriculum-Based and Functional Evaluation Approaches", is expected to offer a solution to existing challenges and contribute lasting benefits for both present and future educational needs.

II. RESEARCH METHOD

This study was conducted using the Research and Development (R&D) method, adopting the ADDIE model, which includes five stages: Analysis, Design, Development, Implementation, and Evaluation. The ADDIE model was chosen for its systematic structure, making it suitable for developing educational media [11].

As explained in Robert Maribe Branch's book *Instructional Design: The ADDIE Approach*, the ADDIE model is generally applied to develop performance-based learning systems [12]. The research process begins with an analysis stage, followed by design, development, implementation, and ends with evaluation.

A. Data Collection Methods, Research Instruments, and Testing Methods

The primary data collection method in this study was observation, based on the characteristics of early childhood learners (ages 3–6), who, according to Jean Piaget's theory (1980), have not yet reached full intellectual maturity [13], [14]. The observation stage used structured observation sheets with a Guttman scale as the research instrument, filled in by classroom teachers. The Guttman scale was employed to systematically and gradually assess early childhood learners'

understanding and achievement in numeracy, allowing for evaluation of consistency in responses based on difficulty level [15]. Data collection was conducted in two phases: before and after implementation.

The testing method employed in this study is black box testing. This testing approach examines both the system's functional suitability and its non-functional aspects, particularly the impact resulting from the system's implementation [16].

B. Research Stages

The research stages encompass a workflow outlining each step undertaken in the study. The detailed stages are as follows in Figure 1:

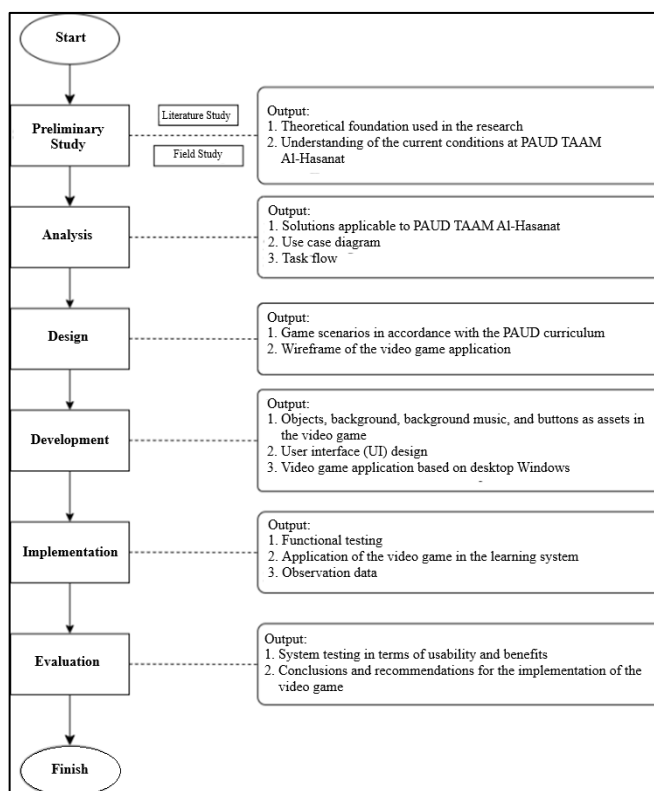


Figure 1. Research Stages

1. Preliminary Study

This stage was aimed at understanding the needs of early childhood learners in numeracy learning. It involved an in-depth review of the Early Childhood Education (ECE) curriculum and discussions with teachers to determine relevant materials to be included in the game. The outcome of this phase was a clear depiction of the educational content to be developed.

2. Analysis

During this stage, the ECE curriculum was analyzed to identify learning materials aligned with the curriculum. System requirements, such as use case diagrams and task flows, were also developed. Numeracy content was categorized into two levels: for Kindergarten A and

Kindergarten B. Topics included number recognition, counting, symbols, and patterns.

3. Design

This stage involved designing the game scenarios based on the previously analyzed ECE learning objectives. Once the scenarios were completed, wireframes were created to form the basis of the game’s user interface.

4. Development

During the development stage, assets were created and processed according to the requirements of the previously designed video game scenarios. These assets comprised essential components for game development, including objects, characters, background media, buttons, user interface (UI) designs, background music, and sound effects.

The asset creation process was carried out using a graphic editing software, Adobe Illustrator. Once completed, all assets were assembled into the game’s user interface using the Construct 3 game engine.

5. Implementation

At this stage, the game was tested internally by the development team. The objective was to ensure that the game flow operated in accordance with the design, although it had not yet been tested directly with children. This implementation phase focused primarily on preliminary technical testing prior to proceeding to subsequent stages.

6. Evaluation

The evaluation stage was conducted to assess whether all core features functioned properly or if any required refinement. This testing focused solely on functional aspects, for example, whether buttons were clickable, audio played correctly, and the game flow ran smoothly without interruptions. If any issues were identified, the development team would address them before proceeding to the next phase of development.

III. RESULT AND DISCUSSION

This section will provide a detailed explanation of the research process leading to the creation of a product in the form of a numeracy video game application.

A. Analysis

In the initial analysis phase, the research focused on studying and understanding the early childhood education (ECE) curriculum related to basic numeracy learning. This process involved identifying the learning materials taught to young children, particularly those concerning number recognition, counting, and simple number concepts. The outcomes of this phase served as the foundation for designing the game content to ensure it aligns with the learning needs of ECE students and remains consistent with the established curriculum. Based on this identification, several key considerations for effective early childhood numeracy instruction were identified, including the following:

1. Ensure that learning encourages children's curiosity.

2. Align the learning activities with the child’s age, developmental stage, interests, and individual needs.
3. Provide holistic and integrative stimulation.
4. Offer challenges, guidance, and support during learning through meaningful conversations and interactions with each child.
5. Use authentic assessment (assessments conducted simultaneously with the learning process).
6. Utilize the environment and technology as learning resources.
- In the initial analysis stage, the research was focused on studying and understanding the early childhood education (ECE) curriculum related to basic numeracy learning. This process involved identifying the specific materials taught to young children, particularly those concerning number recognition, counting, and pattern concepts. The results of this stage served as the foundation for designing game content that aligns with the learning needs of ECE students while remaining consistent with the curriculum. During this stage, the intended learning outcomes outlined in the ECE curriculum were also identified as shown in Table 1.

Table 1. Learning Outcomes for Kindergarten A and B	
Kindergarten A	Kindergarten B
Recognizing and Using Numbers - Identifying numbers from 1 to 10 through everyday activities. - Counting objects in simple quantities (for example, counting the number of toys or commonly encountered items).	Advancement in Number Usage Skills - While in the earlier stage (Kindergarten A), children are introduced to numbers up to 10, in this phase, they are expected to recognize numbers up to 20. - Children are expected to count fluently up to 10 and accurately match quantities with the corresponding numbers. - At this stage, children are also introduced to simple comparative concepts such as greater than (>) and less than (<).
Understanding Basic Concepts of Addition and Subtraction Using objects from the child’s surroundings to help illustrate simple addition and subtraction concepts, such as increasing or decreasing the number of toys (example, dolls).	Advancement in Understanding Basic Mathematical Operations In this phase, children are expected to solve simple problems involving addition and subtraction to deepen their understanding of fundamental arithmetic operations.
Recognizing Patterns and Sequences of Objects	Advancement in Pattern and Sequence Recognition At this stage, children are introduced to more complex

Kindergarten A	Kindergarten B
Identifying patterns in objects found in the child's surroundings, such as differences in color, shape, and size, which are then arranged in a specific sequence.	patterns with increasingly diverse criteria. They are then encouraged to independently create patterns using various objects, colors, and shapes.

B. Design

In the design stage, this study focused on developing game scenarios. The scenarios were created based on the early childhood education (ECE) learning outcomes, specifically number recognition, counting, and pattern concepts. The following outlines the scenarios for game levels 1, 2, and 3.

1. Level 1

a. Kindergarten A

- Setting: Bedroom (resting area)
- Learning Outcome: Recognizing and using number (1-5)
- Level Stage (Table 2):

Table 2. Scenario for Game Level 1 Kindergarten A

Chapter Type	Activity Type	Description
Chapter 1	Counting number 1-5	1. Scenario: The player will see a bedroom with various items in quantities from 1 to 5, such as one blanket, two pillows, three dolls, four shirts, and five books.
		2. Mechanism: The child must drag the corresponding number to the object that matches in quantity. For example, the number 3 should be dragged to the group of 3 dolls.
Chapter 2	Matching numbers with objects	1. Scenario: The player will be presented with a number on the screen, and several groups of objects will appear at the bottom.
		2. Mechanism: The child must select the group of objects that corresponds to the given number. For instance, if the number 4 appears, the child should choose the group that contains four books.
Chapter 3	Number sequencing	1. Scenario: Five dolls are arranged randomly in the bedroom. Help the mother organize

Chapter Type	Activity Type	Description
	2.	them from the smallest to the largest.
		Mechanism: The player must drag the dolls labeled with numbers 1 to 5 onto a shelf, arranging them in ascending order.

b. Kindergarten B

- Setting: Bedroom (Resting Area)
- Learning Outcome: Recognizing and using number (1-10)
- Level Stage (Table 3):

Table 3. Scenario for Game Level 1 Kindergarten B

Chapter Type	Activity Type	Description
Chapter 1	Counting objects in the bedroom	1. Scenario: The player enters a bedroom and sees various objects scattered around (e.g., 1 night lamp, two pillows, three dolls, four shirts, and up to 10 toy cars).
		2. Mechanism: The player must drag the correct number to the corresponding group of objects.
Chapter 2	Identifying the missing number	1. Scenario: A child is organizing the bookshelf in their room, but one number is missing from the sequence of 1 to 10..
		2. Mechanism: The child must select the missing number from the available options. For example, if the screen displays 1, 2, __, 4, 5, the child should select number 3.
Chapter 3	Arranging numbers based on the order of objects	1. Scenario: Ten toy cars are racing in the bedroom, each with a number on its roof, but they are out of order.
		2. Mechanism: The child must drag the toy cars with numbers 1–10 into the correct numerical sequence.

2. Level 2

a. Kindergarten A

- Setting: Bathroom (personal hygiene area)

- Learning outcome: Recognizing and using numbers (6-10)
- Level stage (Table 4):

Table 4. Scenario for Game Level 2 Kindergarten A

Chapter Type	Activity Type	Description
Chapter 1	Arranging Numbers According to Bathroom Objects	1. Scenario: Inside the bathroom, there are several items whose quantities are initially unknown.
		2. Mechanism: A number appears in the center of the screen, and beneath it are several groups of bathroom objects (example: 6 toothbrushes, seven shampoo bottles, 8 bars of soap, nine towels, 10 dippers). The child must select the correct group of objects that matches the number shown in the center.
Chapter 2	Matching Numbers with Bathroom Objects	1. Scenario: Bathroom items need to be matched with the number corresponding to their quantity.
		2. Mechanism: Similar to drawing lines in a workbook, the child must connect each number to the appropriate group of bathroom items. Numbers 6, 7, 8, 9, and 10 appear on the left side, while groups of objects with matching quantities are on the right. The child draws a line to match the number with the correct quantity (example, 6 bars of soap are matched to the number 6, and 9 towels to the number 9).
Chapter 3	Finding Hidden Objects	1. Scenario: A child has lost their rubber duck toys while bathing and must find them according to the number that appears.
		2. Mechanics: A circle is displayed in the center of the screen with a child character next to it. Rubber duck toys are scattered around the bathtub, bucket, and bathroom floor.

Chapter Type	Activity Type	Description
		The child must drag the correct number of rubber ducks into the circle based on the number that appears (example, if the number 8 appears, the child must drag eight rubber ducks into the circle).

b. Kindergarten B

- Setting: Bathroom (Personal hygiene area)
- Learning outcome: Recognizing and using numbers (11-20)
- Level stage (Table 5):

Table 5. Scenario for Game Level 2 Kindergarten B

Chapter Type	Activity Type	Description
Chapter 1	Finding Objects that Match the Given Number	1. Scenario: There are soap bubbles floating around the bathroom, each containing a number.
		2. Mechanism: The child must find and select the group of soap bubbles that corresponds to the displayed number. For example, if the number 12 appears, the child must select 12 soap bubbles floating around the bathroom.
Chapter 2	Sequencing Numbers on Objects from Smallest to Largest	1. Scenario: There is a group of rubber duck toys (a parent duck and its ducklings), and the ducklings have numbers on their bodies. They must walk in order from the smallest to the most significant number, following the parent duck.
		2. Mechanism: The child must rearrange the ducklings numbered 11–20 in the bathtub using drag-and-drop so that the rubber ducklings can follow their parent in the correct numerical sequence.
Chapter 3	Sequencing Numbers on Hidden Objects from Smallest to Largest	1. Scenario: Several towels and toothbrushes in the bathroom are labeled with numbers, but all of them are arranged randomly.
		2. Mechanism:

Chapter Type	Activity Type	Description
		The towels and toothbrushes are placed in a disorganized manner on the bathroom shelf. The child must arrange the numbers 11–20 on the towels and toothbrushes in the correct order by dragging them into their proper positions..

3. Level 3

a. Kindergarten A

- Setting: Living room (Family gathering area)
- Learning outcome: Recognizing patterns and sequences of objects
- Level Stage (Table 6):

Table 6. Scenario for Game Level 3 Kindergarten A

Chapter Type	Activity Type	Description
Chapter 1	Arrange Color Patterns in the Living Room	1. Scenario: The child is asked to arrange colored blocks on a bookshelf in the living room according to a given pattern (example red–blue–red–blue).
		2. Mechanism: A reference pattern appears (example ) , and the child must drag and place the colored blocks onto the shelf in the correct sequence according to the pattern.
Chapter 2	Matching Patterns on Pillow	1. Scenario: The child is asked to match the pattern on one sofa pillow with another pillow in the living room that has the same design.
		2. Mechanism: Several pillows with different patterns, such as stripes, dots, and zigzags, are provided. The child selects or drags the pillow that has an identical pattern to make a matching pair.
Chapter 3	Identifying the Missing Pattern	1. Scenario: The child observes a pattern on the living room rug or carpet and is tasked with filling in the missing part.
		2. Mechanism:

Chapter Type	Activity Type	Description
		The carpet pattern is displayed with a missing segment (example:  ____ ). The child selects the correct option from several pattern choices to complete it, either by clicking or using drag-and-drop interaction.

b. Kindergarten B

- Setting: Living room (Family gathering area)
- Learning outcome: Advantage recognition of size and shape of the object
- Level stage (Table 7):

Table 7. Scenario for Game Level 3 Kindergarten B

Chapter Type	Activity Type	Description
Chapter 1	Identifying Basic Shapes	1. Scenario: The child is asked to find 10 objects in the living room that are square-shaped.
		2. Mechanism: The screen displays a view of the living room, along with the instruction: “Select 10 objects that are square-shaped.” The child selects objects such as paintings, clocks, books, and others, up to 10 items with a square shape.
Chapter 2	Matching the missing shapes	1. Scenario: There are five incomplete objects, each missing a part with a specific shape, such as a circle, square, triangle, and others. The child must complete the missing parts.
		2. Mechanism: The child moves the available shape pieces from the side of the screen and places them into the corresponding empty slots based on their matching shapes.
Chapter 3	Correcting transposed forms	1. Scenario: The objects in the living room suddenly change shape. The child must restore each object to its correct shape.
		2. Mechanism: The child will see several objects that are misshapen, for example: a wall clock shaped

Chapter Type	Activity Type	Description
		like a triangle (when it should be a circle), a pillow shaped like a star (when it should be a square), a photo frame shaped like a heart (which should be oval)
		Instructions Appear: “There are incorrect shapes! Help restore the original shape of each object according to the instructions provided. The instructions are located at the bottom of the screen.” The child will swap the shapes by dragging a line to the correct shape on each object.

After the game scenarios were developed, the next step was to design the Use Case Diagram and Task Flow as the foundation for system design. The Use Case Diagram illustrates the relationship between the user and the main features available in the game, such as selecting the type of gameplay, engaging in numeracy challenges, and receiving feedback [17]. Meanwhile, the Task Flow describes the sequence of user activities from the moment the game is launched until gameplay is completed [18].

a. Use case diagram

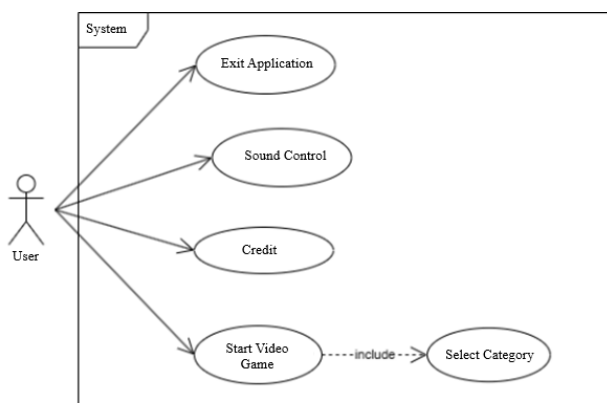


Figure 2. Level 0 Use Case Diagram

Figure 2 presents the level 0 use case diagram, which illustrates how the user interacts with the system. The diagram shows four available options starting the game, controlling the sound, opening the credits menu, and exiting the application. In other words, the level 0 use case provides an overview of the main features accessible within the system.

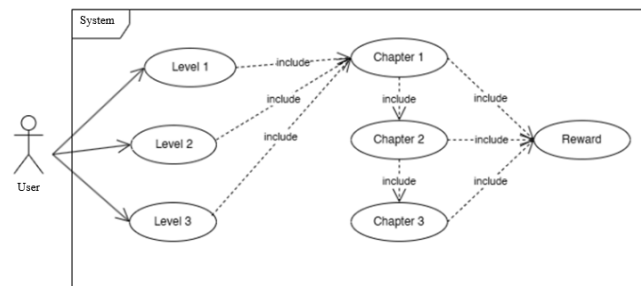


Figure 3. Level 1 Use Case Diagram

Figure 3 provides an overview of the detailed structure within the video game. In this scenario, the user plays the role of the main actor who can access the video game system. The video game system consists of three levels. Each level contains three chapters with varying degrees of difficulty. After completing each chapter, users will receive rewards in the form of motivational messages and congratulations as a form of recognition and motivation. Users can be said to have successfully completed each chapter if they can complete each game.

b. Task flow

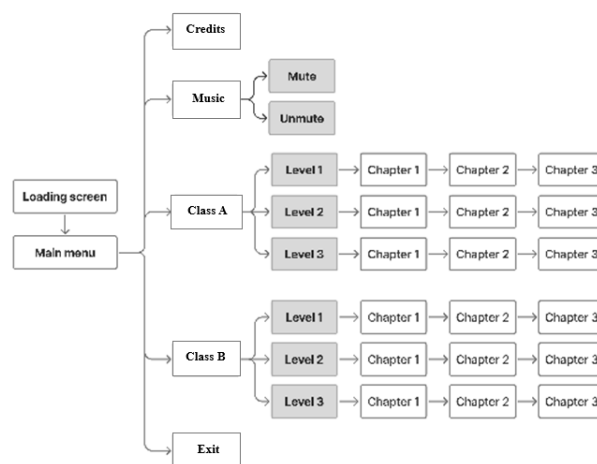


Figure 4. Task Flow Main Features

Figure 4 illustrates the system workflow for the main menu feature. The application begins by displaying a loading screen, indicating that the video game is being initialized. Once loading is complete, the main menu is presented. The main menu includes five features: Credits, which displays the names of individuals involved in the game's development; Music, which allows users to toggle background sound on or off; Class Selection, divided into Class A and Class B categories; and an Exit button to close the application.

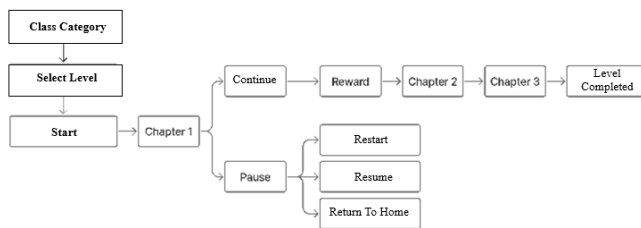


Figure 5. Task Flow Level

Figure 5 presents the task flow diagram for the level system. The flow begins with a class category selection, which is divided into two options: Class A and Class B, corresponding to the ECE levels. This is followed by level selection, starting from Chapter 1 and concluding with Chapter 3. Within each chapter, there is a pause menu that allows the game to be temporarily halted and provides three options: restart the chapter, return to the home screen, or resume the game. As a form of appreciation, rewards are given upon the completion of each chapter and level, serving both as motivation and an indicator of progress.

C. Development

The software utilized in this stage included Adobe Illustrator for vector graphic processing and Construct three as the game development engine. As an initial step, the authors created illustrations to serve as assets, which would later be assembled into a cohesive user interface design for the game.

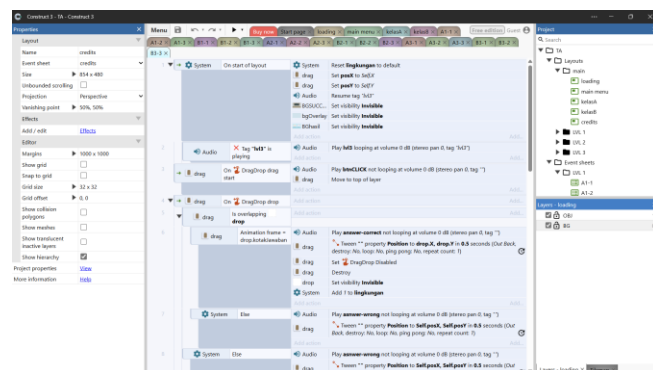


Figure 6. Visual Scripting Screen Display in Construct 3

The created assets were then compiled and arranged to form the video game interface using the Construct 3 game engine. In Construct 3, visual scripting was implemented, as illustrated in Figure 6. This visual script functions similarly to conventional programming code, enabling users to interact with the game in a manner typical of standard video games (Figure 7-11) [19].



Figure 7. Main Menu Display



Figure 8. Class A Menu Display



Figure 9. Class B Menu Display

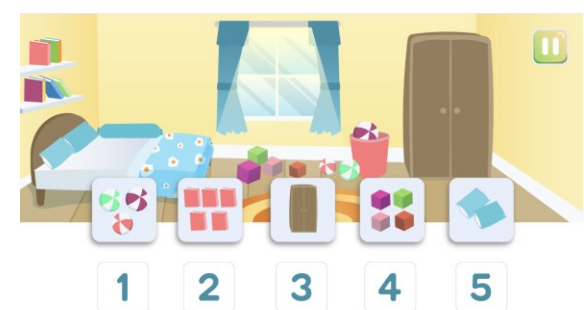


Figure 10. Example of Level 1 Chapter 1 Class A Display



Figure 11. Example of Level 1 Chapter 1 Class B Display

D. Implementation

The implementation phase was carried out after the game development process was completed. At this stage, the game underwent internal testing to ensure that each feature functioned as intended, with particular focus on functional aspects. The testing method employed was black box testing, which was used to evaluate the functionality of the numeracy educational game based on its output, in order to ensure that each feature operated in accordance with early childhood learning requirements as shown in Table 8 [20]. This phase did not involve direct participation from end users; instead, it focused on initial testing conducted by the development team or evaluators to assess whether the game flow, user interactions, and system responses aligned with the previously designed scenarios.

Table 8. Blackbox Testing Result (Use Case Testing)

Scenario	Test Case	Expected Result	Test Result	Result
Main menu	Enter the main menu	Display main menu	The main menu appears.	Valid
Credits	The player presses the credits button.	Display credits page	The credits appear.	Valid
Voice	The player presses the sound button.	Player turns off background music	The music stops playing, and the button icon changes to mute mode.	Valid
Class A category	Enter and try games in category A.	Go to class A home and get rewards for completing each chapter and level	The Class A home page appears, and rewards appear after completing a chapter or level.	Valid
Class B category	Enter and try games in category B.	Go to class B home and get rewards for completing each chapter and level	The Class B home page appears, and rewards appear after completing a chapter or level.	Valid

Pause	The player presses the pause button in the middle of the game.	Display pause overlay	The pause overlay appears.	Valid
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E. Evaluation

The evaluation stage was conducted to determine whether the game functioned in accordance with its intended development objectives. At this stage, functional testing was carried out to verify that all features, such as navigation, game selection, interaction between elements, and system feedback, operated smoothly without technical issues.

Table 8 presents the results of the black box testing (use case testing), which demonstrated 100% validity across all tested features. This indicates that the developed product successfully operated as expected and aligned with the designed business processes.

IV. CONCLUSION

Based on the results of this preliminary research, the researchers successfully created a game scenario, designed an educational video game, and conducted the initial design of a desktop-based numeracy education game. This game is designed to help early childhood children (ECE) recognize numbers, perform simple addition, and identify patterns through an interactive approach tailored to their cognitive development using the EDDIE model. The initial prototype was tested through functional evaluation of the video game, and all core features were confirmed to operate effectively according to the development plan.

For further research, it is recommended to continue development to the testing phase involving end users such as children and teachers in early childhood schools to gather feedback on user experience and usability. In addition, the game can be further developed into a mobile version to increase accessibility on various devices and begin to integrate artificial intelligence-based features to adjust the difficulty level according to each child's individual abilities.

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