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Utilizing Game Development Life Cycle Method to Develop an Educational Game for Basic Mathematics Using Unity 2D Game Engine

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ABSTRACT

The rapid advancement of technology has profoundly impacted various aspects of human life, including education. While technology offers numerous advantages, such as fostering interactive and innovative learning experiences, the shift to online learning during the Covid-19 pandemic has highlighted some challenges, including a decline in students' motivation and engagement, exacerbated by distractions like video games. However, amidst these challenges, Digital Game-Based Learning (DGBL) has emerged as a promising approach to engage students and enhance learning outcomes. This research aims to develop a basic mathematical game using the Unity game engine to enrich children's learning experiences. The educational game seeks to support educators in fostering active engagement among children, specifically in fundamental mathematics. The game is developed utilizing the Game Development Life Cycle (GDLC) methodology.

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1. INTRODUCTION

In this modern era, people worldwide have become highly reliant on technology. The advancement of technology has become a primary driver in various aspects of human life [1]. Technology is a form of expertise or aspect related to knowledge. However, in this current era, technology can be defined as the development of hardware or software based on scientific knowledge, technology also develops based on the needs of humanity [2]. Technology has become a basic necessity for everyone, especially considering its rapid advancement in today's era [3]. This kind of rapid advancement is unavoidable, and its impact spans across numerous fields, including education [4], [5]. This is because the advancement of technology will progress in line with the growth of human knowledge [2]. Every new innovation is created with the aim of positively impacting human life, providing convenience, and introducing new ways to human activities. Technology is highly suitable for learning, because it can be used as a learning medium and it offers numerous advantages, such as fostering more interactive and innovative learning experiences [6]. These advantages can motivate students to be more active in learning, and furthermore, they can create enjoyment in the learning process. The impact of technology on education is vast, including the emergence of media usable as sources of knowledge and the introduction of new teaching methods [4].

Looking back at the Covid-19 pandemic, the policy of online learning during the crisis has led to hindrances in students' mathematical abilities [7]. This occurs due to students' learning fatigue during online classes, resulting in a decline in their motivation to learn. This aligns with research findings indicating that online learning leads to a decrease in students' motivation to learn [8]. If we observe the Covid-19 pandemic and all the digitalization that has occurred, it's evident that many students prefer playing video games over studying. The habit of gaming has shown to impact the education of students [9]. According to the research done by Erlyn Dwi Larasati, Mohammad Kanzunnudin, and Ika Ari Pratiwi, the longer the intensity of students playing video games, the greater the impact on their learning motivation. The learning motivation of children can also be observed from the intensity or duration of their gaming activities [10]. Children who spend a significant amount of time playing video games rather than studying will reduce their study time, leading to procrastination and ultimately making them lazy to learn [11]. Video games also have addictive qualities, as can be observed in the daily lives of childrens who may spend 3 to 5 hours a day playing video games after school [12]. However, it is unfortunate that they rarely engage with games that contain educational elements or content.

In the rapid advancement of technology in the field of education over this past few decades, one notable rising method in teaching and learning is Digital Game-Based Learning (DGBL). This can be observed through research conducted by Nguyen Ngoc Dan, Le Thai Bao Thien Trung, Nguyen Thi Nga, and Tang Minh Dung, indicating that DGBL has been extensively studied by other researchers [13]. Digital Game-Based Learning (DGBL) is a learning approach that utilizes modern gaming technology as a tool or medium for education. The primary goal of DGBL is to leverage the cognitive elements within games to support the learning process of students [14]. DGBL has significant influences on children's learning activities [15]. Based on research conducted by Rifka Toyba Humaida and Suyadi, it has been proven that DGBL demonstrates an impact in enhancing cognitive mastery in early childhood. Educational games can build interest in learning, stimulate imagination, develop technological skills, and support the social needs and skills of learners with diverse abilities. Thus, educational games make a significant contribution to learning activities [16].

Unity is a cross-platform based game engine that is flexible and can be used to create games runnable on various platforms. With support for platforms such as desktop computers, mobile devices (Android and iPhone), Playstation, and Xbox [17]. Unity also features an integrated development environment (IDE) that plays a role in creating various engaging media such as video games. Developed by Unity Technologies, this platform was first introduced in June 2005 at the Apple Inc. Worldwide Developers Conference. Since then, Unity has become one of the most famous and widely used game development platforms worldwide, known for its uniqueness in providing powerful and intuitive tools, making it easier for developers to create and optimize creative and exciting gaming experiences [18]. From that we know, Unity is an excellent game engine, but solely relying on it for game development isn't sufficient; creating visually appealing assets like models or sprites is also crucial.

Due to the aforementioned factors, we have developed an educational game using Unity game engine to enhance children's learning activities. This educational game aims to assist educators in engaging children more actively in learning, particularly in basic mathematics. For asset creation of our game, numerous software options are available. We opt for Adobe Photoshop to create our 2D game assets due to its versatility and familiarity in our workflow. Adobe Photoshop is great for making 2D game sprites due to its extensive array of features tailored for image editing and manipulation. Thus, using Adobe Photoshop to create our educational game assets is a wise choice.

2. METHOD

In this research, the Game Development Life Cycle (GDLC) method will be utilized. In game development, there are design steps required to guide the development process. One commonly used method is the Game Development Life Cycle (GDLC), which consists of six development stages: initiation, pre-production, production, testing, beta, and release [12].

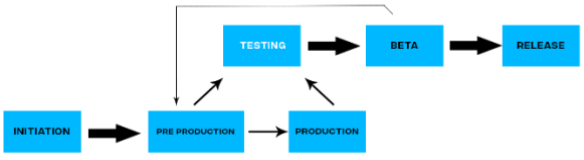

Figure 1. GDLC Diagram

Initiation is the initial stage in game development, involving the creation of a rough concept or idea of the game. This phase entails the early thought process to form the foundational planning of the game to be created. It serves as an important step where ideas are brainstormed, and the overarching vision for the game is established, setting the groundwork for the subsequent stages of development [19]. Pre-production is the next stage after initiation stage in game development that encompasses the creation and refinement of game designs along with the development of game prototypes. During this stage, detailed plans and designs are formulated based on the concepts established during the initiation phase [20]. Next is the production stage, the production stage stands as the cornerstone of the game development process. This stage encompasses the creation of assets and source codes [21]. The testing stage is the stage where testing will be conducted on the game. This stage is useful for identifying bugs and errors that may occur in the game so that they can be promptly fixed, ensuring the smooth operation of the game [22]. Beta stage refers to a phase in the development process where the game is feature-complete but may still contain bugs or other issues and the game is typically released to an external or third-party tester to test the gameplay experience [23], [24]. The release stage marks the final step of the GDLC methodology model. At this stage, the game has reached its concluding phase after a lot of extensive testing and fixing. Then the game would be released to the public at this stage [25].

3. RESULTS AND DISCUSSION

The results of implementing the Game Development Life Cycle (GDLC) method in the creation of our digital education game are outlined as follows:

3.1. Initiation

At this stage, a brief description of the game is created. In this game, the player will control a character that can move freely within the provided map. Within the map, enemies will appear one by one to approach the player's character. When the player is attacked by an enemy, their HP (Health Points) will decrease by 1 point. Enemies will appear in increasing numbers as time passes. In addition to the physical combat elements, this game adds an educational aspect by incorporating basic mathematical questions. These questions are used to attack the existing enemies. Each time a player wants to attack an enemy, they must answer a basic math question with three different answer options. If the player can answer the question correctly, the player's character can successfully attack the enemy, and if the answer is incorrect, it results in a reduction of the player's HP by one point. The player's HP is limited to only five points, providing a higher challenge during the game. Therefore, players need to utilize their basic mathematical knowledge to keep the character alive and collect points by defeating as many enemies as possible, as each defeated enemy will give the player 1 point.

3.2. Pre-production

After knowing the concept of the game in the initiation stage, a flowchart can be formulated to determine the flow of the game. The flowchart of the game can be seen as follows:

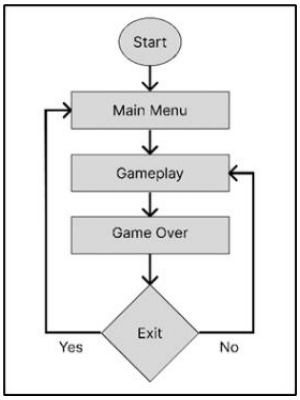

Figure 2. Game Flow Chart

During the pre-production stage, besides designing the gameplay flow as seen in the figure above, there are also initial designs for the scenes that will appear within the game. In this case, three main scenes are formed: the menu page, the gameplay page, and the game over page.

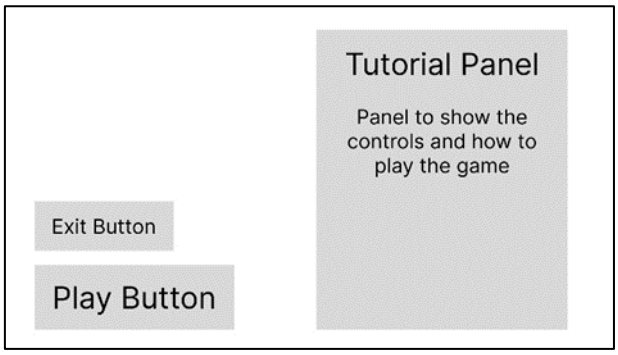

Figure 3. Main Menu Page Design

In Figure 3, there are buttons labeled "play" and "exit." As their names suggest, the "play" button functions to transition the player to the gameplay scene, while the "exit" button serves to close the game. Additionally, a tutorial panel is visible, explaining how to play the game.

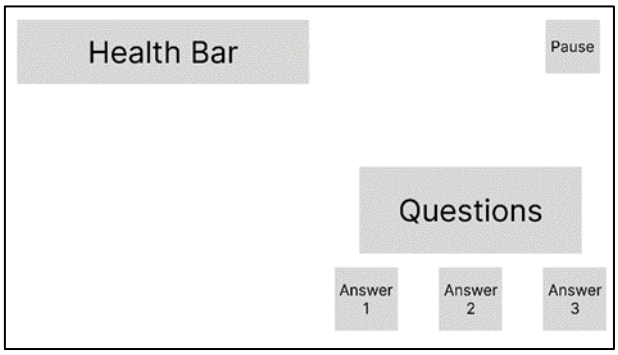

Figure 4. Gameplay Page Design

In the gameplay design layout as seen in Figure 4, firstly, there is a health bar. The health bar serves to display the character's current HP (Health Points). Next, there is the "questions" section, which displays automatically generated mathematical questions along with the answer choices below. Then, there is a "pause" button, which functions to temporarily halt the game.

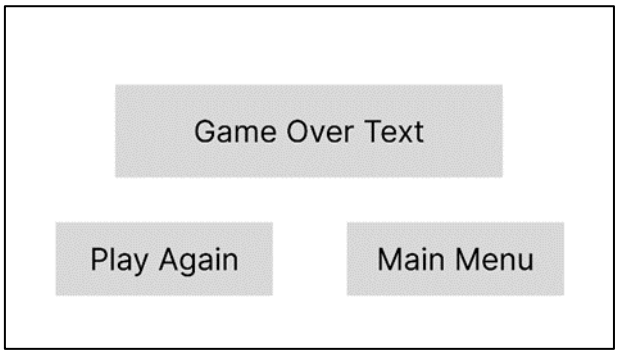

Figure 5. Game Over Page Design

If the player's HP is depleted, they will be redirected to the game over page as seen in Figure 5. On this page, two buttons are visible: the first one is "play again," which functions to return the player to the beginning of the gameplay, and "Main Menu" to redirect the player to the main menu page. There is also a “game over text” above the buttons. The "game over text” will be replaced with a message later indicating that the player has died or failed, such as "you died" or "you've failed."

3.3. Production

In this stage, the creation of the game assets and the game itself takes place. The game’s asset will be crafted using Adobe Photoshop software and the game itself will be created using Unity game engine. Asset

creation includes designing characters and the map that is required for the game. Additionally, the game creation process involves programming and integrating all of the assets together into a cohesive gaming experience.

3.3.1. Assets creation

We opted for 2D pixel art assets for our game due to their nostalgic appeal and ability to evoke retro gaming aesthetics. The main reason we chose this style is because the production of pixel art assets is relatively efficient and is easier to create due to its simplified design process.

Figure 6. Map Design

The map design depicted in Figure 6 is the terrain where the player character can navigate. It serves as the backdrop for the game environment, providing the setting for the gameplay scenario. This design incorporates several objects strategically placed to obstruct the player movement, intensifying the challenge when facing multiple pursuing enemies.

Figure 7. Character Design

For the character sprite as seen in Figure 7, we aimed to create a design that is both simple and endearing, with a touch of cuteness. Despite the character's serious expression, the use of blocky pixels and a minimalist color palette gives the overall design a charming and adorable appearance. This approach strikes a balance between seriousness and cuteness.

Figure 8. Enemy Design

For the enemy sprite, we envisioned a ghostly character capable of spawning anywhere on the map and swiftly advancing towards the player upon spawning. Even though we portrayed the enemy as a ghost, we still retained a cute aesthetic in its design, this is to match the whole vibe of the game.

3.3.2. Game creation

In the game creation process, three key scenes emerge after the initial design phase in preproduction: the main menu scene, where players can see the tutorial on how to play the game before diving into gameplay; the gameplay scene, where the core mechanics and challenges of the game unfold, and finally, the game over scene, marking the end of a session.

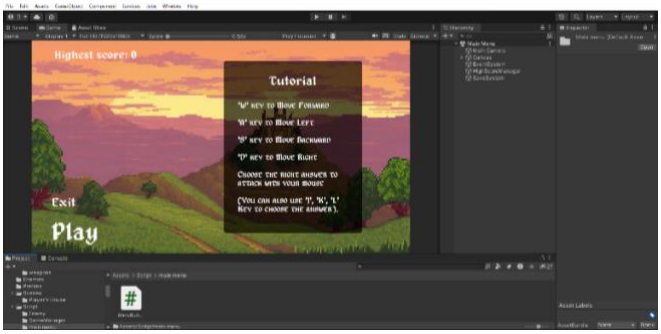

Figure 9. Main Menu Scene

The main menu scene as seen in Figure 9, comprises two buttons outlined in the pre-production design, the "Play" button, facilitating the transition to the gameplay scene upon activation, and the "Exit" button, designed to terminate the application. Alongside these buttons, a tutorial panel is present, providing players with instructions on how to play the game. Positioned in the top-left corner of the screen, is an additional element that displays the player's highest score, offering a visual representation of their progress throughout the gameplay experience.

Figure 10. Gameplay Scene

In the gameplay scene seen in Figure 10, players have the freedom to navigate within the provided map, while enemies spawn randomly throughout the area. Over time, the rate of enemy spawn will increase, adding to the challenge. At the top left corner of the screen, a health indicator prominently displays the player's remaining health. Just below this indicator is the current score, offering players immediate feedback on their performance. Moving to the right side of the screen, a pause button is positioned at the top right, allowing players to temporarily halt the game if needed. At the bottom right corner lies the core gameplay mechanic, a text-based mathematical question accompanied by multiple-choice answers. These questions are randomly generated, serving as triggers for the player's attacks. A correct answer initiates the character's attack sequence, whereas an incorrect one results in a decrease in the player's health. This setup creates a dynamic gameplay experience where players must balance movement, combat, and problem-solving skills to survive and progress.

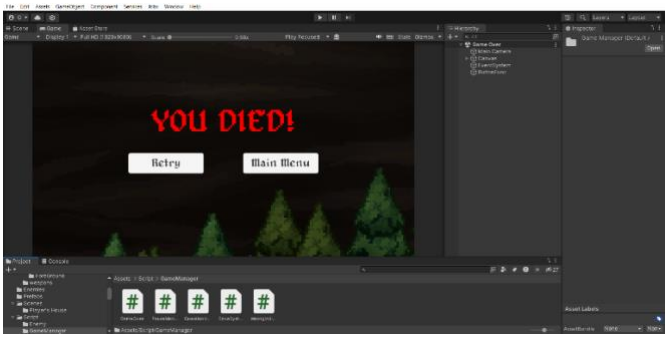

Figure 11. Game Over Scene

Upon the player's demise, they are directed to the Game Over scene, featuring two clickable buttons. The buttons are the "Retry" button and "Main Menu" button. Clicking the "Retry" button redirects the player to the gameplay scene for another attempt, while selecting "Main Menu" returns them to the main menu scene.

```
void GenerateQuestion()
{

    x = Random.Range(1, 10);
    y = Random.Range(1, 10);
    op = GetRandomOperator();


    switch (op)
    {
        case '+':
            correctAnswer = x + y;
            break;
        case '-':
            correctAnswer = x - y;
            break;
        case '*':
            correctAnswer = x * y;
            break;
    }

    questionText.text = $"{x} {op} {y} = ?";

    int[] options = GenerateOptions(correctAnswer);
    for (int i = 0; i < optionButtons.Length; i++)
    {
        optionButtons[i].GetComponentInChildren<Text>().text = options[i].ToString();
    }
}
```

Figure 12. Generate Question Function

In the gameplay scene seen in Figure 10, lies the core gameplay mechanic. The gameplay mechanic involves solving basic mathematical questions to initiate player attacks. The function depicted in Figure 12 generates random questions and their corresponding multiple-choice answers then displaying them into the gameplay scene.

```
char GetRandomOperator()
{
    char[] operators = { '+', '-', '*' };
    return operators[Random.Range(0, operators.Length)];
}
```

Figure 13. Get Random Operator Function

In the function responsible for generating questions seen in Figure 12, there's a call to another function named “GetRandomOperator()”, this function is illustrated in Figure 13. This function serves the purpose of returning a randomly selected mathematical operator, represented as a character or char value.

```
int[] GenerateOptions(int correctAnswer)
{
    int[] options = new int[optionButtons.Length];

    for (int i = 0; i < optionButtons.Length; i++)
    {
        if (i == 0)
        {
            options[i] = correctAnswer;
        }
        else
        {
            int option = correctAnswer;
            while (option == correctAnswer)
            {
                option = Random.Range(correctAnswer - 5, correctAnswer + 6);
            }
            options[i] = option;
        }
    }

    for (int i = 0; i < options.Length; i++)
    {
        int temp = options[i];
        int randomIndex = Random.Range(i, options.Length);
        options[i] = options[randomIndex];
        options[randomIndex] = temp;
    }

    return options;
}
```

Figure 14. Generate Options Function

Within the generate question function seen in Figure 12, there's also another call to a function named "GenerateOptions()", which is responsible for generating the multiple-choice answers and randomizing the correct answer position.

```
public void CheckAnswer(int selectedAnswer)
{
    Debug.Log(selectedAnswer);

    if (selectedAnswer == correctAnswer)
    {
        player.GetComponent<PlayerAttack>().Attack();
        Debug.Log("Correct!");
    }
    else
    {

        wrongInd.StartTransition();

        if (player.GetComponent<Health>() != null)
        {

            player.GetComponent<Health>().Damage(1);
        }

        Debug.Log("Incorrect!");

    }

    // Generate next question
    GenerateQuestion();
}
```

Figure 15. Check Answer Function

In Figure 15, there is a function designed to verify the player's answer. If the player has selected the correct answer, this function initiates the player's attack sequence. However, if the answer is incorrect, it will trigger a display indicating the wrong answer and reduce the player's health by one point. After all of that has happend, this function then calls the "GenerateQuestion()" function once again to generate the next question. This function is invoked whenever any answer button is clicked, with the parameter being the corresponding text displayed on the clicked button.

3.4. Testing and Beta

In this case, testing will be conducted using black box testing. This is done to test the existing functionalities that are in the game. Table 1 shows a summary of the black box test results for the functionalities within the game.

Table 1. Black Box Testing

Test Case	Expected Result	Actual Result
Loading	Opens the game and displays the main menu	Success
Play button	Redirect the player to the gameplay scene	Success
Exit button	Exits the application	Success
Player movement	Move the player with keyboard	Success
Generate question function	Generate a question along with the answer choices	Success
Attack sequence	The player will attack when the correct answer is chosen	Success
Wrong answer	The player's HP decreases if the chosen answer is wrong	Success
Pause button	Pauses the game temporarily until the player presses the resume button	Success
Retry button	Restart the game	Success
Main menu button	Return to the main menu page	Success
Highscore system	Saves the player’s highest score	Success

For beta testing, we retest the functionalities that is in the game on different machines to ensure that these functionalities work well across machines. This process allows us to verify the performance and compatibility of the game across different hardware configurations.

3.5. Release

After undergoing a series of tests with no errors found, the game is then released. This is done by uploading it to Google Drive and subsequently sharing it with potential users. This distribution method allows for easy access and dissemination of the game to a wide audience. Once uploaded, users can access and download the game files from Google Drive to play the game on their machines.

4. CONCLUSION

The integration of technology, particularly digital game-based learning (DGBL), has emerged as a transformative approach to education, especially in enhancing children's learning experiences, such as in basic mathematics. This educational game has been developed to sharpen basic mathematical skills. It was created using the Game Development Life Cycle (GDLC) method, which encompasses stages such as initiation, pre-production, production, testing, beta, and release. The development process of the game begins with the creation of a brief description outlining how the game works. Subsequently, a game flowchart is designed to illustrate the gameplay process. After the creation of the flowchart, three main scenes are identified. Those three main scenes are the Main Menu scene, the Gameplay scene, and the Game Over scene. Once these three main scenes are established, initial designs for each scene are created. The initial design of these three scenes serves as a guideline for proceeding to the actual game creation process. The process starts with the creation of assets, which consist of 2D pixel art assets to be used in the game. Then, all these assets are combined into

one within the Unity game engine. Within the Unity game engine, the functions and features of the game are also coded. The design of the actual scenes in the game also follows the initial design that has been initialized previously. After the production process is completed, functional testing of the game is conducted using black box testing. For beta testing, the game is run on different machines to ensure its performance and compatibility across various hardware configurations. After passing a series of tests, the game is then released via Google Drive, enabling easy access for potential users to download and play on their machines.

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