

Developing a Dyscalculia Identification Game Using The Rapid Game Development (RGD) Model

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Abstract- Dyscalculia, a common learning difficulty impacting arithmetic comprehension, poses challenges across diverse intelligence levels. Often misconstrued as a lack of intelligence or effort in mathematics, dyscalculia's accurate identification remains elusive. This study focuses on developing a 3D digital game incorporating basic arithmetic instruments for dyscalculia identification. Leveraging the Rapid Game Development (RGD) method and Unity Game Engine, the game integrates interactive features to assess arithmetic skills. Through standardized assessments and game participation, children both with and without dyscalculia were evaluated, revealing a significant correlation between the game and standard assessments. This innovative, interactive game holds promise for early dyscalculia detection and intervention, enhancing educators' and professionals' capacity to address this learning difficulty effectively. Future research should validate its efficacy across varied populations and explore its integration into educational settings. In conclusion, this study presents a compelling tool in the form of a 3D digital game utilizing basic arithmetic instruments, fostering timely support and improved outcomes in dyscalculia identification and intervention.

Keywords: Digital Games, Dyscalculia, Learning Difficulty, Rapid Game Development, Unity

Article info: submitted July 7, 2023, revised December 19, 2023, accepted January 8, 2025

1. Introduction

At the elementary level, there are typically three types of learning difficulties that are commonly associated with learning namely dyslexia, dysgraphia, and dyscalculia [1]. Dyslexia, dysgraphia, and dyscalculia are distinct learning difficulties, each with its own unique set of characteristics and challenges. Dyslexia is a learning difficulty that affects the phonological system, such as letter recognition, spelling, and reading [2][3]. Dysgraphia is a learning difficulty that affects the ability to write manually. Dyscalculia, in contrast, is a specific learning disorder that affects mathematical skills in general [4][5].

At present, numerous studies have explored the neuroscientific aspects of learning. However, despite the extensive research, there is still no conclusive evidence explaining precisely how individuals experience learning disorders, particularly dyscalculia [6]. Several studies have employed brain imaging techniques, such as Magnetic Resonance Imaging (MRI), to examine the neural underpinnings of dyscalculia. Nevertheless, these studies have only been able to conclude that dyscalculia, like other types of learning difficulties, may have a genetic component [7]. Based on the findings of numerous studies, it is estimated that around 3-4% of the population experiences learning difficulties [8].

Consequently, addressing the needs of these children has become a top priority for educational institutions worldwide. Learning difficulties need to be addressed early because they affect both the children and parents. In the future, children who have learning difficulties can also experience potential long-term impacts on their mental health, such as performance anxiety, depression, low self-esteem, chronic fatigue, or loss of motivation [9][10].

However, the challenge lies in identifying these children and selecting suitable teaching strategies that accommodate their learning difference [11][12]. Individuals with learning difficulties may require a different approach to teaching that is tailored to their unique learning style [13]. Children with dyslexia may benefit from multisensory instruction that incorporates auditory and kinesthetic learning activities. While children with dyscalculia may benefit from more visual and concrete learning experiences, such as using manipulatives or visual aids, to help them understand abstract mathematical concepts.

Research on dyscalculia often requires interdisciplinary collaboration, drawing insights from various fields such as psychology, education, neuroscience, and computer science. This collaborative approach is crucial because addressing dyscalculia effectively is challenging when relying solely on one discipline [14].

Despite its complexity, this research endeavors to investigate the potential of children with dyscalculia through a visual-oriented approach. Visual learning has a significant impact on children's comprehension and concentration compared to audio or verbal learning [15][16]. Thus, print media and conventional games that rely on gross motor skills are among the tools that can be utilized to identify children with dyscalculia [17]. Visual learning is considered to be an effective tool for children with dyscalculia because it can help them understand mathematical concepts more easily.

Children with dyscalculia usually struggle with abstract ideas, and visual aids can assist in their comprehension [18]. The use of printed media and conventional games that rely on gross motor skills, such as board games or puzzles, may also be beneficial in identifying children with dyscalculia [19]. These tools may reveal common indicators of dyscalculia such as spatial awareness, or problem-solving.

The objective of this study is to create a digital game that can detect the inclination of children towards dyscalculia. The game was developed using the Unity Game Engine and employs the Find and Configure typology [20]. The game's testing was conducted at a school in Bandung while keeping the student's location and names confidential to preserve the reputation of all parties involved.

The game aims to provide an engaging and interactive learning experience for children with dyscalculia. Unlike traditional

assessment methods, that may cause anxiety or frustration for children, a game-based approach can be less intimidating and more enjoyable. This approach could potentially result in more accurate and comprehensive identification of dyscalculia in children.

2. Methods

In this study, the Rapid Game Development (RGD) method was employed to develop a digital game aimed at identifying children with dyscalculia. The RGD method was first introduced in a previous author's research [21]. RGD was chosen because this method is deemed suitable for developing a game prototype in this research. The main issue in this study is the lengthy process of formulating questions and assessment formulas for dyscalculia detection, which takes a long time. Hence, the time and budget required to create the game prototype using conventional Game Development Life Cycle (GDLC) would not suffice.

The main characteristic of RGD lies in its rapid game development using generic and purchased assets. Additionally, this method would function optimally if implemented with a game framework, thus shortening the game production time as it does not entail building all game mechanics from scratch. As shown in Figure 1, RGD comprises three main phases: Pre-Production, Production, and Product Launch. Each phase includes one or more activities with implementation considerations.

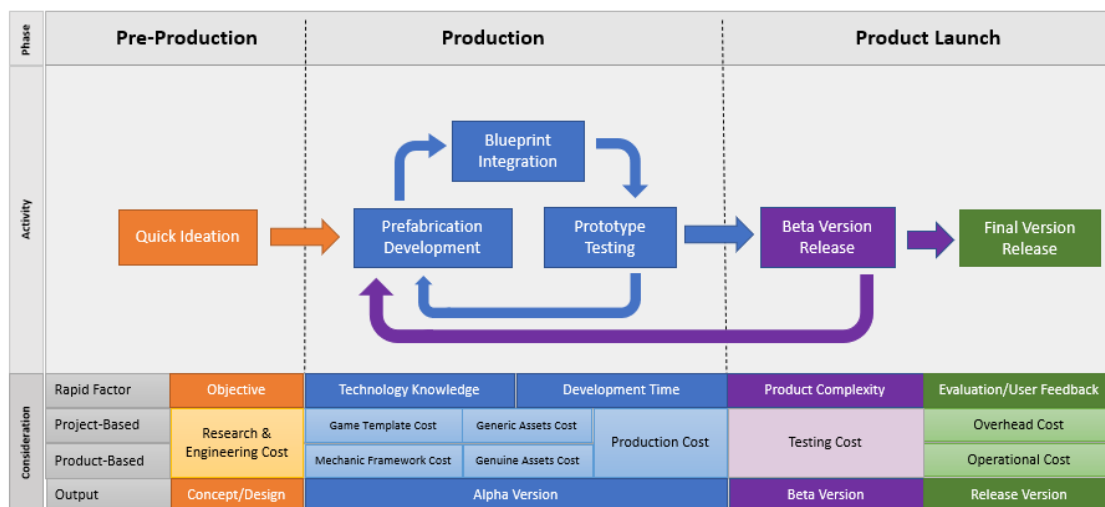


Figure 1. Rapid Game Development Model

1. Pre-Production

The main activity in the Pre-Production phase of RGD is Quick Ideation. This activity involves brainstorming game development ideas by conducting a literature review on dyscalculia identification, examining existing educational game titles, determining the basic game typology and mechanics, and designing the game based on semiotic theory. The primary output of this stage is a design architecture that outlines how the game will be

developed. This includes identifying the logic and mechanic engine that will be used, determining the character and game typology, and outlining how the game's output will be processed. By establishing a clear design architecture, the subsequent stages of the RGD method can proceed more efficiently and effectively, resulting in a game that is better suited to the needs of children with dyscalculia. The design resulting from the Quick Ideation activity presented in Figure 2.

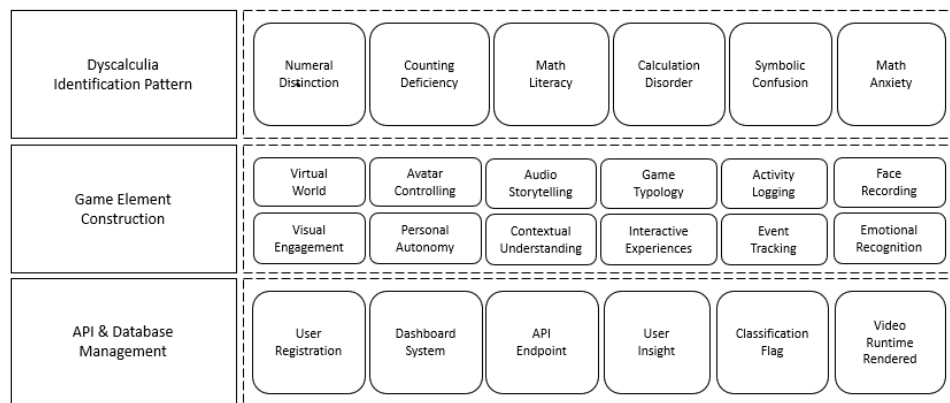


Figure 2. Dyscalculia game architecture concept

The dyscalculia game architecture concept consists of three layers, each with a unique function. The first layer is focused on identifying dyscalculia based on criteria such as numeral distinction, counting deficiency, math literacy, calculation disorder, symbolic confusion, and math anxiety. These patterns are used to identify potential dyscalculia in students and inform the construction of game elements that can help address these issues.

The second layer of the game architecture focuses on game element construction. This layer includes visual elements such as virtual 3D worlds, avatar that can be controlled by the player and various Non-Playable Character (NPC). Additionally, there are audio storytelling that used to provide contextual understanding and help students better comprehend math concepts. The game is constructed using various game typologies to provide interactive engagement, including quizzes and drag-and-drop mechanics. The game world can provide a rich visual environment, with a variety of objects, textures, and sounds that can help players improve their spatial and visual skills. The game will record player activity including their answers and facial reactions when facing math questions. By analyzing this data, it can provide insights into the areas where players struggle the most and identify patterns that may indicate dyscalculia.

The last layer of the architectures is an API and database management system. This layer will provide the function to record all player activity to a database. The game is developed using server and client architecture, with the website and database running on the server side while the game runs on the client side. Both the

client and server sides will communicate with each other via API endpoint, allowing for seamless data exchange between the game and the database.

The dyscalculia game architecture concept is designed to provide an engaging and effective way to identify and address math learning difficulties in students. By combining dyscalculia identification patterns, game elements, API and database management, the game is able to provide a comprehensive assessment of a student's math skills while also providing an immersive and enjoyable experience. The immersive and enjoyable experience motivates students to actively engage with mathematical concepts, fostering a positive attitude towards learning and building confidence in their abilities.

2. Production

The Production phase of the RGD method comprises three activities: Prefabrication Development, Blueprint Integration, and Prototype Testing. In the Prefabrication Development activity, a collection of prefabs is built for use in the game. These prefabs are pre-built game objects that can be easily modified as per the game's requirements. In this game, commercial 3D characters and city assets are utilized for speed up the game development process. The collection of game objects (prefabs) that have been quickly modified according to the game's requirements and are ready to be used in the game is shown in Figure 3.



Figure 3. Preview of character assets and city

The Zetcil Framework, which is another previous work of the author, is utilized to create the game [22]. This framework includes several features and functions that speed up game development.

Some key features in Zetcil Framework are core template for character locomotion and animation, a reskin user interface system, and all-in-one game to database integration. Figure 4 shows

the transformation of the main menu UI in the game. By utilizing the features and functions, the game development process can be streamlined and effective in identifying children with dyscalculia.



Figure 4. Main Menu Transformation using Zetcil Framework

In the Blueprint Integration activity, the prefabs developed in the previous stage are combined to create a complete scene. The game comprises eight levels, each with a similar gameplay flow where players help family members find scattered items throughout the city. For instance, in one of the levels, the player

needs to help a mother find vegetables by locating NPCs who sell the required items and solving arithmetic games to fulfill the mission. Figure 5 shows an example of the objective description and a visual representation of the city that players can explore to find the items needed by the mother.



Figure 5. Example of game mission

The Prototype Testing activity is a crucial part of the Production Phase, as it aims to produce a functional Alpha version of the game that can be played in its entirety. This stage involves testing the game to ensure that it is ready for release, with

dyscalculia instruments translated into visual form, and each player's answer recorded on the website, regardless of whether it is correct or incorrect. Figure 6 provides an example of a dyscalculia instrument translated into a visual format.

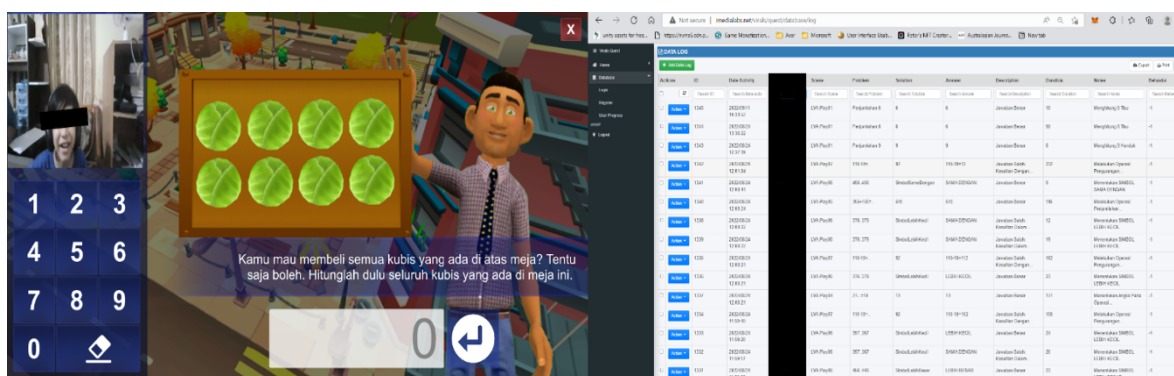


Figure 6. Example of recording player answer data

To classify potential dyscalculia difficulties, the game is connected to a website that provides API endpoints for each action taken within the game. The system can detect every student's answer in the game and classify potential dyscalculia

types based on their answers. For instance, if a student's answer to a question is 9 when the correct answer is 6, the system will flag this in a database as a potential dyscalculia difficulty with reading "similar-pattern-numbers". If a student has difficulty

remembering the "carry-over" method in double-digit addition questions, this will also be flagged as a potential difficulty.

By recording every player's answer and analyzing the data, the game aims to identify potential learning difficulties and provide effective interventions to improve students' mathematical abilities. Ultimately, the game's integration with a website and database provides a comprehensive tool for identifying and addressing dyscalculia in children. In addition to recording each player's answer, the game also has the capability to record the child's face while playing. This data can be used to perform facial recognition analysis to detect emotional patterns that the child may exhibit when solving mathematical problems. However, even the game has the capability to record the child's face the analysis of video data is beyond the scope of this research. The primary objective of this study is to develop a digital game using the RGD model for dyscalculia identification. While the recorded video data has the potential to provide insights into the child's emotional

response to mathematical concepts, the analysis of this data will require a separate research effort.

3. Product Launch

The Product Launch phase for the dyscalculia game includes two main activities namely the beta version release and the final version release. For the scope of this research, the phase will only include the beta version release. The beta version of the game contains two main characters, Ali and Gita, and includes eight levels. Each level has three to four quests that the player needs to complete. Each level also has a different story, different objects to collect or count, and a different mechanic adopted based on the 10 game typologies[20]. Some levels will require the player to choose answers in a quiz format, while others will require players to use a drag-and-drop system to solve problems. Figure 7 illustrates the different variants of game mechanics that are employed in the dyscalculia game.



Figure 7. Game mechanic variation

The beta version is an important testing phase for the game, allowing it to be tested by third-party testers to gain feedback and insights. This feedback will then be used to make necessary improvements and adjustments to the game before the final version is released. By focusing on the beta version release, the dyscalculia game can be refined and improved to ensure that it is accessible, engaging, and effective for the target audience of students, parents, and educators.

3. Result and Discussion

The pilot testing was conducted privately with three elementary school children. The anticipated conditions involved the identification of dyscalculia-related patterns. These include numeral distinction, such as difficulties distinguishing between numerals like 6 and 9; Symbolic Confusion, which entails challenges in determining symbols such as greater than and less than signs; and Calculation Disorder, which involves struggles with addition of two numbers or more.

The initial assumption is characteristics of children with dyscalculia learning difficulties can be predicted using scores. Thus, the primary focus of data acquisition was to ascertain the distribution of scores during gameplay. The expectation was that

children scoring above 50% would not exhibit tendencies towards dyscalculia. From the results of beta testing, a significant number of children yielded noteworthy scores. These scores were subsequently assigned the label "Dyscalculia Potential Rate". However, the pilot testing did not yield the expected results as no signs of dyscalculia were detected.

Given the time constraints of the study, the research proceeded to beta testing regardless. Testing was conducted on 20 second-grade students, evenly distributed by gender. Each participant was afforded the liberty to engage with the game for 15-30 minutes without constraints on the quantity or sequence of levels played. The results of the game testing is summarized in Table 1.

It is show that students played an average of between 1-6 levels out of the 8 levels provided. Each student play with around 3-4 missions. The trial also revealed a significant imbalance in the ability of students to answer arithmetic questions. Some students able to complete up to 22 questions while others could only complete 2 questions.

The data obtained revealed inconsistencies in dyscalculia pattern identification. Out of the 20 students tested, 5 had correct rates below 50%, suggesting a propensity towards dyscalculia. However, upon closer examination, only 3 of these students exhibited distinct dyscalculia patterns, such as symbol confusion

and numeral distinction issues. The remaining 2 students likely made calculation errors without demonstrating clear dyscalculia patterns. Interestingly, some students scoring above 70% showed potential dyscalculia for one pattern. Meanwhile, those scoring around 30% exhibited difficulty in mathematical calculations but did not display the expected dyscalculia patterns. Apart from these

5 students, 4 others with correct rates exceeding 70% made numerous errors unrelated to dyscalculia patterns as we labeled with “Trial Answer Miscalculation”. It is possible that these students simply misread, answered hastily, or had issues with the game mechanics. These results are not a definitive diagnosis of dyscalculia, and further observation may be necessary.

Table 1. Recapitulation of beta testing results

No	Gender	Number of Levels Played	Number Questions Answered	Correct Answer	Trial Answer Miscalculation	Answer Similar to Instrument	Dyscalculia Potential Rate	Suspected Dyscalculia Factor	Tendency to Dyscalculia Scale
1	P	3	7	5	10	0	71,43%	-	1
2	L	6	20	18	2	0	90,00%	-	1
3	P	5	8	5	2	1	62,50%	< & >	2
4	L	6	24	19	4	0	79,17%	-	1
5	L	2	4	4	9	0	100,00%	-	1
6	L	3	4	1	3	1	25,00%	17 & 71	5
7	P	6	24	22	12	0	91,67%	-	1
8	P	6	19	19	4	1	100,00%	5 & 6	2
9	P	3	11	9	17	0	81,82%	-	1
10	L	4	15	15	0	0	100,00%	-	1
11	L	1	3	1	7	0	33,33%	-	5
12	P	3	10	9	5	0	90,00%	-	1
13	P	4	12	9	7	1	75,00%	< & >	2
14	P	2	3	2	1	0	66,67%	-	2
15	L	3	6	5	4	0	83,33%	-	1
16	P	3	8	7	7	0	87,50%	-	1
17	L	4	14	11	13	1	78,57%	< & >	2
18	P	1	3	3	3	0	100,00%	-	1
19	L	4	15	10	20	4	66,67%	< & >, 6 & 9	3
20	L	6	23	20	8	0	86,96%	-	1

To facilitate the labeling process, the research team devised a 1-5 Likert scale to indicate the likelihood of dyscalculia based on combination of “Answer Similar to Instrument” and “Dyscalculia Potential Rate”. The decision to employ the Likert scale stemmed from the spectrum-based scale commonly utilized in assessing dyslexia severity. The common dyslexia spectrum usually comprises three scales: Mild, Moderate, and Severe. The researchers argued that utilizing the Likert scale would suffice to assign labels to potential dyscalculia. Table 2 illustrates the Likert scale developed for this purpose.

Likert scales are commonly used in research to measure people's attitudes, opinions, or perceptions towards a specific topic. They have also been used to assess the potential presence of dyscalculia in individuals [23]-[25]. The scale ranges from 1, indicating no signs of dyscalculia, to 5, indicating a strong tendency towards dyscalculia.

The scale is determined by the total number of correctly answered questions. A score of 1 is assigned when the correct rate exceeds 70% and there are no signs of a dyscalculia pattern. A score of 2 is given if the correct rate falls between 70% and 60%,

or if there is a mild indication of a dyscalculia pattern, indicating a low likelihood of dyscalculia. A score of 3 indicates a correct rate between 60% and 50%, or moderate signs of a dyscalculia pattern, suggesting a moderate likelihood of dyscalculia. Finally, a score of 4-5 is indicative of a correct rate below 50% or frequent occurrences of a dyscalculia pattern, signaling a strong likelihood of dyscalculia.

Despite the use of the Likert scale to assess the likelihood of dyscalculia, it is important to note that dyscalculia identification is a complex and challenging tasks. To ensure the higher accuracy of the identification, we also recorded the player activity, specifically focusing on their answers that showed dyscalculia patterns, even if their overall score was above 70%.

This approach enables us to give label to students who may have a low likelihood of dyscalculia based on their overall score but still exhibit specific patterns that suggest potential math learning difficulties. By analyzing both the overall score and specific patterns, we can gain a more comprehensive understanding of the student's abilities and challenges in math, and inform targeted interventions to address their individual needs.

Table 2. Tendency of dyscalculia scale

Scale	Indicator	Label
1	>= 70% Correct Answer	No signs of dyscalculia
2	>= 60% and < 70% Correct Answer	Low likelihood of dyscalculia
3	>= 50% and < 60% Correct Answer	Moderate likelihood of dyscalculia
4	>= 40% and < 50% Correct Answer	Strong likelihood of dyscalculia
5	< 40% Correct Answer	Very strong likelihood of dyscalculia

Overall, these results provide valuable insights into the potential of the dyscalculia game to identify potential dyscalculia in students. However, the limitations of the game as a diagnostic tool should be recognized, and the results should be considered in the context of other information, such as formal diagnostic assessments and classroom observations [26]-[29]. Additionally, other factors such as children's computer literacy, and nervousness, should be taken into account when interpreting the data obtained.

4. Conclusion

The dyscalculia game developed has the potential to identify the dyscalculia tendencies of students through a unique approach that combines game mechanics and learning. However, because this is the first attempt, there are many considerations on how to interpret the results obtained from the testing.

During game development, challenges may arise in aligning game mechanics with dyscalculia assessment goals, particularly in ensuring accuracy in reflecting the diverse symptoms and difficulties associated with dyscalculia, while also maintaining engagement and accessibility. The overall game development becomes complex in formulating dyscalculia assessment questions into various game mechanics for each question.

Different game mechanics require their own efforts to develop, adding to the complexity. To address these challenges in future iterations, one solution could involve creating a library of independent game mechanics that can serve as templates. This approach would streamline the process of integrating dyscalculia assessment questions into diverse game formats, potentially reducing development time and effort.

Integration of the dyscalculia game into the classroom environment can provide additional benefits for teachers in understanding the individual characteristics of their students more deeply. However, it's important to recognize that errors may occur in the data collected, potentially stemming from factors such as a student's lack of computer literacy, typographical errors, or nervousness during gameplay. Therefore, educators should approach the interpretation of game data with a critical eye, supplementing it with other forms of assessment and observation to ensure a comprehensive understanding of each student's mathematical abilities and learning needs.

Identifying dyscalculia is a highly complex research theme that necessitates interdisciplinary collaboration between educators, game developers, and healthcare professionals. The research findings indicate that attempting to detect the potential for dyscalculia in children through a single assessment is insufficient. This limitation arises from the crucial insights from observing their day-to-day mathematical engagement within the classroom environment. Consequently, it becomes apparent that interactive games, while valuable, cannot operate in isolation; rather, they necessitate seamless integration with conventional classroom teaching and learning practices.

While the dyscalculia game provides a promising tool for identifying potential dyscalculia in students, this game is not a replacement for a formal diagnostic assessment by a qualified healthcare professional. The game only provides an initial indication of potential math learning difficulties and to inform targeted interventions to address these issues. The complexity of dyscalculia detection underscores the necessity for ongoing interdisciplinary research efforts. These efforts could explore

innovative approaches to gathering data from various sources, including classroom interactions, game-based assessments, and clinical evaluations.

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