Bulletin of Electrical Engineering and Informatics
Vol. 14, No. 4, August 2025, pp. 3015~3028
ISSN: 2302-9285, DOI: 10.11591/eei.v14i4.8765

Screening capabilities for the 3D dyscalculia identification game framework

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Article Info

Article history:

Received May 30, 2024
Revised Jun 24, 2025
Accepted Jul 5, 2025

Keywords:

3D-dyscalculia identification game framework
Dyscalculia
Dyscalculia screening
Petri net
Serious game framework

ABSTRACT

Dyscalculia, a learning difficulty in mathematics, remains a concealed challenge affecting individuals of average intelligence or remarkable creativity. This inconspicuous disability often leads teacher to misinterpret students as lacking intellect. Regrettably, this condition can prompt students to disengage from routine activities, resulting in diminished performance and self-confidence. To address this issue, our research introduces a serious game framework, namely the "3D-dyscalculia identification game framework" (3D-DIG framework), integrating a screening feature aimed at detecting mathematical shortcomings in students. This paper focuses on detailing the screening feature, wherein a Petri net structure orchestrates its functionality within the 3D game environment. Specifically, our study highlights how this feature assesses and captures potential student deficiencies during work on game challenges. Employing game engine, and web server technologies, the dyscalculia screening feature captures students' responses, enabling an evaluation of their mathematical proficiency. Analysis of student data affirms that the screening feature's in identifying potential mathematics-related deficiencies. Moreover, the 3D game incorporates a distinctive element: it notifies teachers when a student surpasses a 60-second threshold while solving a problem, facilitating timely interventions. By offering actionable insights, the framework empowers teacher to identify student with the mathematics' deficiency and support the student with the appropriate intervention.

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1. INTRODUCTION

Dyscalculia is a learning difficulty that can occur in students with normal or high intelligence specifically affecting their ability to understand and work with mathematics [1]-[4]. Students with dyscalculia may struggle to distinguish numbers and face challenges in mastering basic mathematical concepts such as addition, subtraction, multiplication, division, and the use of mathematical symbols [5]-[7]. While these

students may not experience difficulties with daily tasks, they often face significant challenges when dealing with mathematics. This can lead teachers to mistakenly perceive the student as reluctant, lazy, or not smart when the student is unable to complete math exercises or tests [1]. This misperception can negatively impact the student's confidence, as they may worry about others' views of their math abilities. Dyscalculia, being a hidden disability, is often difficult to identify [8]-[11]. Table 1 provides information on learning difficulties, namely dyscalculia, in several cities in Indonesia where the number of identified dyscalculia children is not as many as the number of students observed. Table 1 ([12]-[15]) shows that the data for children with dyscalculia are mixed with children with other learning difficulties such as dyslexia and dysgraphia. The prevalence table shows that dyscalculia needs attention to be identified early, so that teachers can provide appropriate interventions.

Table 1. Prevalence data of students with learning difficulties

Ref.	Places	Sample	Prevalence (%)	The number of students
[12]	Semarang	659	18	123 (dysgraphia, dyslexia, and dyscalculia)
[13]	Surabaya	510	20.16	101 (dysgraphia, dyslexia, and dyscalculia)
[14]	Sekolah Dasar Puteraco and Sekolah Dasar Yayasan Beribu, Bandung	40	27.5	11 (dyscalculia)
[15]	Sekolah Dasar Puteraco, Bandung	21	38	8 (dyscalculia)

In this study the identification of potential student with dyscalculia through the assessment process. The identification through assessment plays a crucial role in gathering relevant information about students' math abilities, and the data collected helps in making informed decisions about their deficiency [16]. The term “assessment” will be referred to as “identification,” with the identification results based on students' misconception in subject addition, subtraction, division, and math symbol, while the assessment used to determine appropriate interventions for addressing their deficiencies. Table 2 shows the existing approaches to identify the student learning difficulty in dyscalculia. Table 2 describe the approaching method to identify students with potential dyscalculia, including web-based tools, written exams, and desktop applications. However, the use of games as a medium for this purpose is uncommon, with most existing efforts being directed towards identifying dyslexia rather than dyscalculia.

Table 2. The existing approaches to identify student learning difficulty

Ref.	Existing approaches			
	Application	Paper based test	Computer-based	Game
[17]	P	P	P	P(dyslexia)
[18]				P (dyslexia)
[19]		P		
[20]		P	P	
[21]	P			
[22]	P			
[23]*				P

*The number race game is emphasizing for remediation dyscalculia student

The authors in [24], [25] developed a serious game framework called 3D-dyscalculia identification game framework (3D-DIG framework) aimed at serious gaming. Serious gaming is a game that provides a sense of enjoyment and assessment experience for the player, so that the player will gain an information about the player deficiency or aspect that must improve after playing the 3D game (the 3D game as a framework’s medium to identify student with dyscalculia) [26], [27]. So that the player does not feel like being tested when working on the challenge/problem.

The 3D-DIG framework aims to identify the potential student with difficulty learning mathematics (dyscalculia) which is enhanced from the expanded design play experience (DPE) framework [28]-[30]. The 3D-DIG framework [30] contains six layers: assessment, storytelling, game-play, screening, user experience, and technology. The framework is shown in Figure 1.

In this study, the researchers discuss the screening layer marked with a red dash box (depicted in Figure 1). The screening layer is utilized the Petri net that represent the concurrent system. By incorporating concurrency, Petri nets capture the ability of two or multiple events concurrently, leading to game developers to implement into game programming [31]-[33]. The Petri net is used to describe a concurrent scenario/parallel mechanism that represents parallel activity with multiple tokens running in multiple places simultaneously whereas the parallel mechanism cannot provide by flowchart diagram [34]. Such as the screening feature turned on video recording, game records activities (when the student is solving math

problems as the game challenge) and connection to the web database server simultaneously [35], [36]. This feature stores information of the student screen activities that allow the teacher to examine the, later. It also records data on the student answers that are informative and useful for dyscalculia screening [10], [37], [38].

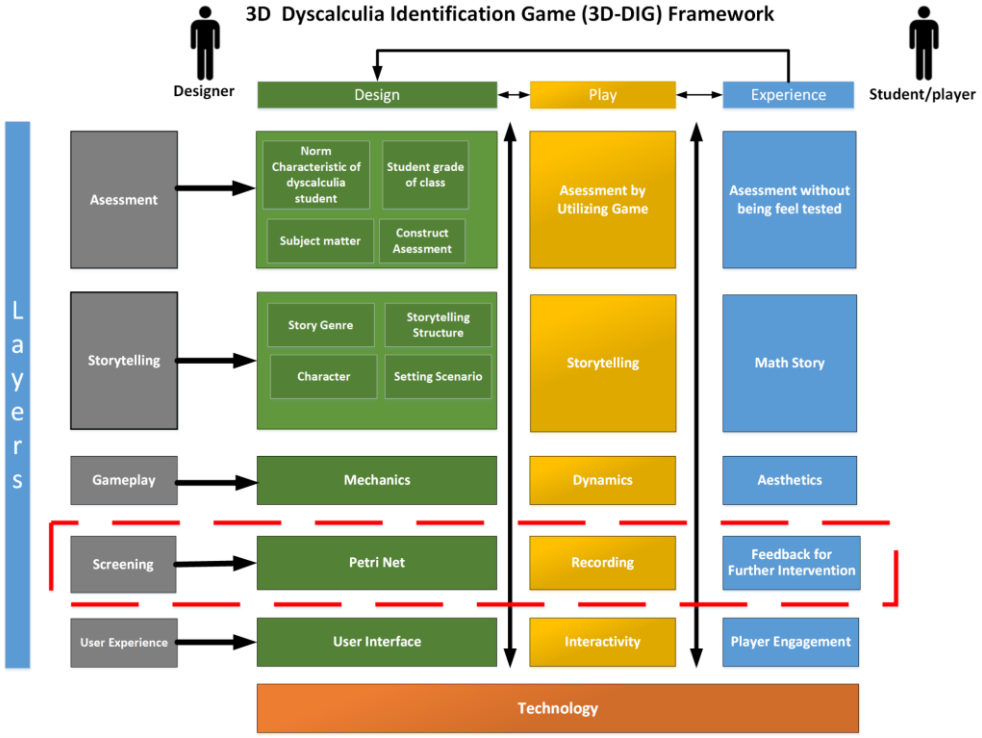

Figure 1. The 3D-DIG framework

While the use of Petri nets in educational modelling is not entirely new, prior research has primarily focused on modelling learning processes, evaluating course structures, or supporting inclusive education environments. For instance, Petri nets [39], [40], have been employed to simulate student learning behaviors in e-learning systems to model the flow of e-learning course content and to support formal modelling of IT requirements in inclusive education. Other studies have explored the use of Petri nets to identify potential learning difficulties in virtual learning contexts [41]. However, to the best of our knowledge, no existing study has integrated Petri net models within a 3D game-based framework specifically aimed at screening for dyscalculia. Therefore, our proposed 3D-dyscalculia identification framework represents a novel contribution by leveraging Petri net [42] structures not only for process modelling but also as a real-time screening mechanism embedded in an interactive game environment.

The data recorded by the screening feature can be analyzed by the teacher for identifying whether a student has a deficiency in learning mathematics (dyscalculia) or not. The screening feature provides information such as the following:

a. The student's answer.
b. The student's face video that is recorded while the student is working on the game challenge.
c. The duration of the student spent working on the question? Is it less than 60 seconds or more than 60 seconds?
d. The screening tool informs the teacher of the number of times students attempt to answer questions. Is it in one attempt to immediately provide an answer or more than two attempts to obtain an answer?

To enhance the understanding and handled of dyscalculia among students, the development of the 3D-DIG framework offers an innovative solution through a game approach. By utilizing advanced monitoring features, this framework not only identifies difficulties in learning mathematics but also provides valuable data for teachers to formulate appropriate interventions. The framework is designed to automatically record student's response and report student's deficiency in near real time, enable teacher access through the web-dashboard. Through early identification and suitable interventions, the teacher can help students with dyscalculia with the proper intervention. Therefore, it is crucial for all stakeholders, including teachers, parents, and policymakers, to pay attention to the signs of dyscalculia and provide the necessary support, ensuring that every student has a fair opportunity to succeed in mathematics education.

2. RESEARCH METHOD

This section is divided into two key parts: i) a comprehensive overview of the general methodology employed throughout the study and ii) a detailed explanation of the specific methodology applied within screening layer of the framework.

2.1. General method

In this study, the researchers implemented a structured three-phase methodology to guide the research process. The process was divided into three distinct phases: the analysis phase, the design and development phase, and the evaluation phase. Each phase was crucial in ensuring a comprehensive and systematic approach to the study. Figure 2 depicts the research methodology that utilized in this study.

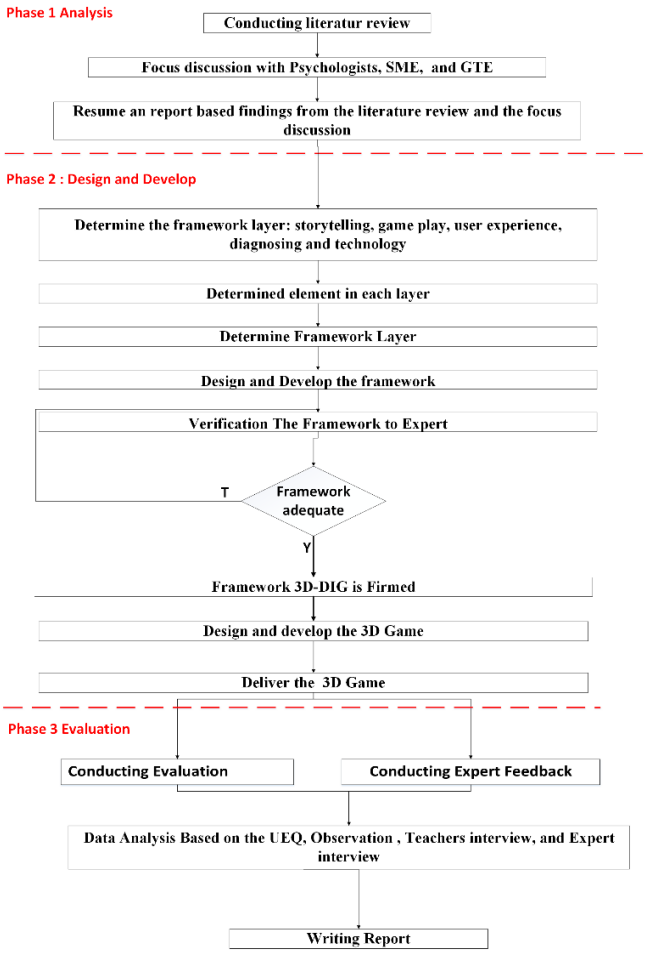

Figure 2. General methodology

The study follows a three-phase methodology:

- Analytic phase: involves a literature review, focused discussions, and compiling findings into a report that informs the next phase.
- Design and development phase: includes determining framework layers (assessment, storytelling, gameplay, user experience, diagnosis, and technology), defining each layer's elements, developing the framework, and validating it through expert review.
- Evaluation phase: data is collected using both qualitative methods (focused discussions, observations with experts) and quantitative methods user experience questionnaire (UEQ). Observations are made during gameplay, and the data is analysed to evaluate the game prototype's ability to identify dyscalculic students. Key elements for data collection include selecting respondents, ensuring suitable test locations, observing student behaviours, and using standardized questionnaires like the UEQ.

This structured approach integrates analysis, design, and evaluation to assess the game's impact on educational outcomes for dyscalculia.

2.2. Method for developing dyscalculia screening feature

Previous research [35], [36] employed a staged identification approach beginning with interviews to gather preliminary insights, followed by the development of assessment questions tailored to specific criteria and written tests to evaluate participants' abilities. Results from these stages were analyzed to draw conclusions, with recent adaptations incorporating applications and desktop tools to enhance assessment processes. Building upon this foundation, the present study integrates a digital framework emphasizing interactivity and engagement. Beyond presenting evaluation results, it provides detailed insights into students' potential weaknesses, aligned with age-appropriate norms. These enhancements are seamlessly incorporated into the 3D-DIG framework's screening feature, offering a more comprehensive analysis, as elaborated in subsequent sections [37]. The methodology underpinning this screening feature is shown in Figure 3, illustrating the interconnection between the screening and assessment layers. The screening layer is constructed based on the norm characteristics established in the assessment layer while integrating elements from the storytelling and gameplay layers. This alignment ensures coherence across the framework, with the assessment layer serving as the foundational basis for the development of other layers, thereby reinforcing the robustness of the 3D-DIG framework. In this paper, the researcher focuses on the development of screening features. Figure 3 shows the steps used in the methodology to develop the screening feature.

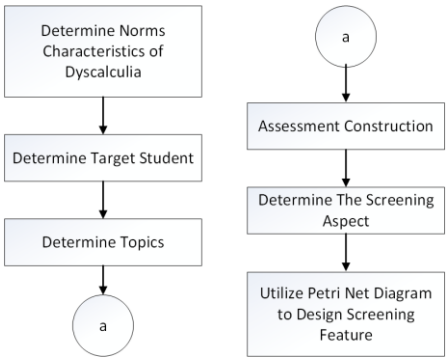

Figure 3. Methodology used to develop the dyscalculia screening features

The explanation of each step is as follow:

- Determine the norm characteristics*:* this study identifies norm characteristics as a key indicator for students with dyscalculia. These characteristics are derived from an extensive review of the literature and prior research. Once established, they will serve as a basis for identifying the target students. The identified norm characteristics, as presented in Table 3, are used to develop the assessment framework in this study.

Table 3. The key indicators of dyscalculia students

No.	Key indicators
1	Has difficulty distinguishing numbers such as 6 and 9, 3 and 8.
2	Having difficulty solving problems with greater than (>), less than (<) and equal (=) operators.
3	Basic operations.
4	Face a problem in subtraction operations such pattern 0-a, where a >0.
5	Forget to bring forward numbers after doing subtraction.
6	Having difficulty adding numbers in column pattern with storing method.
7	Still using fingers to count instead of using more advanced strategies (like mental Mathematics).
8	Doing adding or subtraction (in column pattern) numbers with the direction from left to right.
9	Problems with placing values.

- Determine the target student: based on the appropriateness of the selected norm characteristics, the target age group for this study was identified as grade 2 elementary school students. Student at grade 2 has adequate knowledge about number, mathematical basic operation. Due under Covid-19 that remain happen, the teacher school limited to eight students can be tested with 4 student male and 4 student female. Whereas the student is selected by the teacher based on the norm characteristics and teacher's view (after discussion with the author).
- Determine the topics: the selection of topics for assessment development is grounded in the identified norm characteristics, the target student group, the core material, the topic's alignment with the game's complexity, and consultations with teacher and psychologists. Considering these factors, the topics

chosen for assessment are counting object, addition, subtraction, and symbol identification (>, <, =). Based on the assessment topics that determined—namely counting objects, addition, subtraction, and symbol identification—the game design adopts a level structure that aligns with students' assessment for identifying student deficiency. The initial levels focus on fundamental skills such as counting objects and performing addition with unit numbers. As players advance, the tasks gradually introduce addition and subtraction involving tens, followed by symbol identification tasks using relational symbols (>, <, =). The highest levels are designed to challenge players with operations involving numbers up to the hundreds.

- Assessment construction*:* the assessment targets second-grade primary school students, focusing on addition, subtraction, and the symbols for less than, greater than, and equal to. The design of the number differentiation assessment is based on three key factors: i) norm characteristics, ii) reference materials, and iii) findings from preliminary research. Table 4 presents sample assessments for number differentiation. These factors were used to develop dyscalculia assessments within the 3D game framework across various domains/topics.

Table 4. Sample assessments

Subject	Indicator
Distinguishing numbers	Counting 6 objects (distinguishing numbers 6 and 9)
Distinguishing numbers	Counting 9 objects (distinguishing numbers 6 and 9)

- Determine the screening aspect: this study utilizes technology to monitor student activities during game-based assessments, enabling teacher to review performance remotely without requiring physical presence. This flexibility supports subsequent interventions through detailed performance reviews. The monitoring system incorporates five methods for data collection: i) recording students' responses, ii) tracking the number of attempts, iii) measuring time spent per question, iv) capturing screen activity, and v) recording facial expressions via a webcam [38]-[40]. These features are integrated into the 3D game framework to aid in identifying potential dyscalculia among students [30].
- Utilize Petri net diagram: the Petri net diagram in Figure 4 illustrates the process by which players select game challenges related to number differentiation. In this scenario, two options are provided for the game challenges:
  a. Scenario 1: the player is tasked with locating a non-playing character (NPC) holding nine towels. Once found, the player must count the towels and select the correct answer based on the count. The possible answer choices include 9, 6, or other numbers.
  b. Scenario 2: the player is required to locate an NPC holding six packs of tissues. After identifying the NPC, the player must count the packs and select the correct answer that matches the count. The answer options may include 6, 9, or other numbers.

In the game implementation, players are restricted to selecting only one scenario. When players choose scenario one, they will interact with the NPC carrying towels, thereby preventing access to the game challenge in scenario two. Figure 4 is a Petri net diagram showing this parallel mechanism such as turn on the camera, student activity work on problem at the same time, and when the player chooses one scenario it will disable the other (whereas a flowchart is unlikely to provide a parallel mechanism) [40]. Furthermore, record the student's response, and student's video at the same time also.

The red tokens in the diagram represent the player's choice journey through the selected scenarios and illustrate how the screening process is performed and recorded. The screening system leverages a Petri net model is represent and track student interactions during a cognitive task-based assessment. In this petri diagram, places denote different stages of interaction (e.g., initiating tasks, counting items, and providing responses), while transitions represent events or decisions (e.g., triggering a webcam and mentioning a number). Arcs define the flow between stages and tokens capture the progress of each user through the system. As students perform tasks—such as retrieving and counting items—the system records webcam footage, monitors verbal responses, and logs correctness of answers into a database. Miscounts or number misrecognitions are flagged and categorized, enabling the system to provide feedback and support early detection of numerical cognition issues like dyscalculia. The Petri net diagram in Figure 4, mathematically, is represented as:

$$PN=(P,T,F,W,M_0)$$

where:

- P is a finite set of places
  Refer to Figure 4
  $P=\{p_0, p_1, \ldots, p_{16}\}$

p_0: objective begin
p_1: meet with brother
p_2: webcam on (brother)

– T is a finite set of transitions
Refer to Figure 4
T= {t_0, t_1, …, t_9}
t_0: father needs towel or tissue
t_1: ask brother to get 9 towels
t_2: ask uncle to get 6 tissues

– F ⊆ (P × T) ∪ (T × P) is the set of arcs
Refer to Figure 4
W: F → $\mathbb{N}^+$ is a weight function
Refer to Figure 4
All arcs (F) and weights (W) have weight 1 unless otherwise specified:
W(f)=1; ∀f ∈ F

– M_0: P → ℕ is the initial marking
Refer to Figure 4
$M_0(p)=\begin{cases} 1 \; if \; p = p_0 \\ 0 \; otherwise \end{cases}$
Transition t_3 is enabled if and only if:
$M(p_3) \geq 1 \wedge M(p_2) \geq 1$
and its firing results in:

$$\begin{cases} M(p_3) := M(p_3) - 1 \\ M(p_2) := M(p_2) - 1 \\ M(p_5) := M(p_5) + 1 \; (if \; correct \; answer \; is \; 9) \\ M(p_6) := M(p_6) + 1 \; (if \; correct \; answer \; is \; 6) \\ M(p_7) := M(p_7) + 1 \; (otherwise) \end{cases}$$

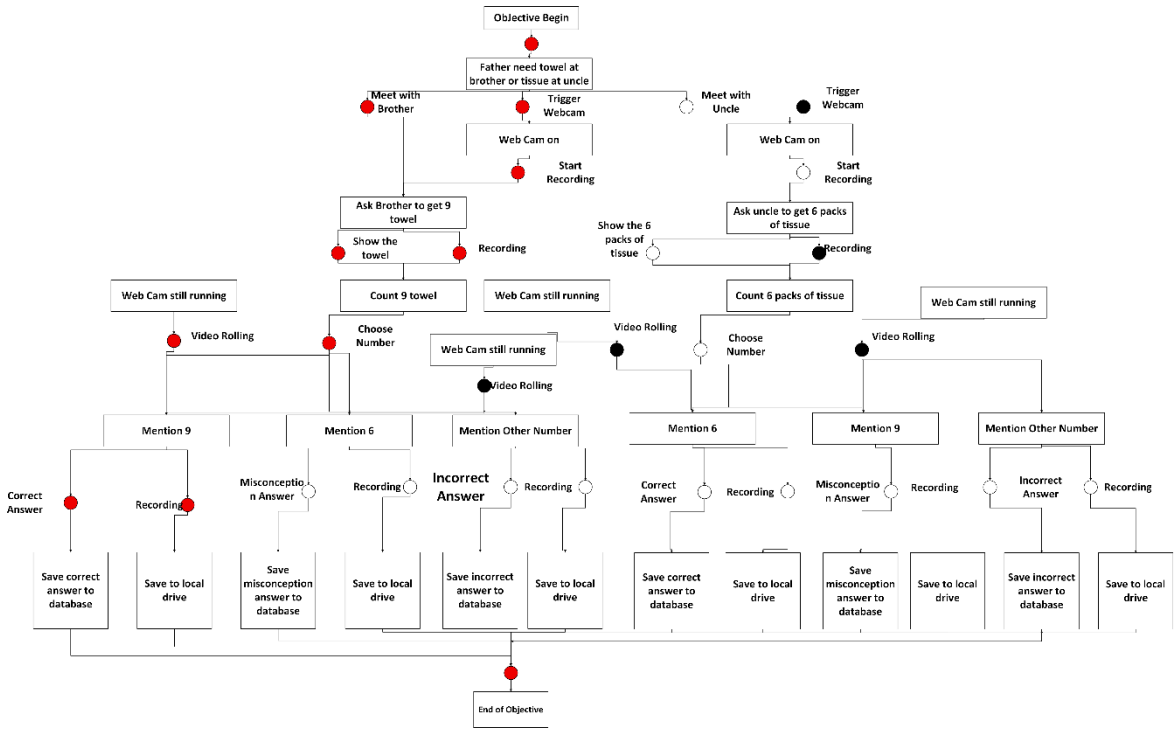

Figure 4. Petri net showing distinguishing numbers 6 and 9 with scenario 1 is chosen

3. RESULTS AND DISCUSSION

This section explains the results of the research based on two monitoring features that were implemented in the 3D game prototype. The monitoring features include the student answers' records, and the

student's face video and screen activity capture. Both features store the appropriate data when the students are playing the 3D game.

The monitoring feature has three purposes: record the student activities (while working on game challenges) and record the student's answer. The video automatically turned on when the student accessed the game challenge. While the student is working on the game challenge, the video recording feature records the student face video and student's screen activities, and the recording feature will automatically save the video recording and the answer into the database.

3.1. The student data record

Eight students participated in the data collection, which was conducted during the Covid-19 pandemic. They were subjected to game testing, and the test resulted with 80 cases of data stored in the database. In this paper, we presented data from three students only, namely student-1, student-2, and student-3. Student-1's data is captured when the student was playing the 3D game on distinguishing numbers. The game play scenario can be visualized using the Petri net diagram in Figure 4. The other data presented here are from student-2 and student-3 that were playing on addition and subtraction topics.

The following three subsections discuss the data captured while the students were working on the game challenges. Subsubsection 3.1.1 discusses the results obtained after student-1 has played distinguishing numbers. Subsubsection 3.1.2 discusses the results obtained after student-2 and student-3 have played addition and subtraction topics. These cases demonstrate other sample cases that were captured by the monitoring feature to identify the student's difficulty in addition and subtraction topics.

3.1.1. Distinguishing numbers

Table 5 highlights student-1's responses, supplemented by an "Elaboration" column added after collaborative analysis with teacher. The data indicates that while student-1 demonstrates proficiency in counting objects, they struggle to distinguish between the numbers 6 and 9, an ability typically expected of children aged 8 to 10. In contrast, the student performed accurately on tasks involving other numbers such as 4, 17, and 8. Upon learning about this difficulty, the class teacher expressed intent to conduct further assessments to address the issue in number recognition.

Table 5. Data of student-1 after playing the game on distinguishing numbers

Indicator	Answer	Description	Time	Elaboration
Distinguish number 6 and 9	9	The solution is 6	9	The player chooses 9 for the solution. The player does not have a problem counting objects among a collection of objects. The student may have difficulty distinguishing number 6 and 9.
Counting an object (4 balloon)	4	The solution is 4	20	Player does not have a problem counting an object.
Counting an object (8 cabbage)	8	The solution is 8	34	Player does not have a problem counting an object.

Moreover, the time required to solve each problem can offer valuable insights for the teacher. Suppose a student solves the problem, but it takes longer than 60 seconds (with the 60-second threshold established through discussions with psychologists, subject matter experts (SMEs), and the class teacher). In that case, the student may also require attention and intervention. The 60-seconds threshold is also discussed with the game technology experts to confirm the opinion sight from the gameplay side.

Table 5 highlights the importance of targeted assessments in identifying specific areas of difficulty for students with dyscalculia. While student-1 shows competence in counting objects, the struggle to differentiate between the numbers 6 and 9 underscores the need for customized interventions. At age 8, students should be able to differentiate between the numbers 6 and 9, according to the child development [43]. The contrasting performance in object counting tasks further emphasizes the necessity of a comprehensive understanding of each student's unique challenges to develop intervention strategies.

3.1.2. Addition and subtraction of numbers

Table 6 presents another data record captured during the screening, following the addition and subtraction topics completed by student-2. The math problems used as game challenges were based on case studies focused on addition, particularly emphasizing number placement and carrying techniques. A similar approach was applied to subtraction tasks, incorporating borrowing techniques and number placement. The last column (elaboration) was added by the researcher after analyzing the data in collaboration with the class teacher. This data aids the teacher in diagnosing the student's difficulties in mathematics, particularly in the addition process using carrying techniques and the subtraction process involving borrowing.

Table 6. Student-2 recorded data after completing addition and subtraction challenges

Question	Answer	Description	Time	Elaboration
Problem 355 155 ___ + 510	4011	There is a problem with the storage method on the addition operation with column pattern	34	The player encounters challenges in appropriately storing numbers within place values such as units, tens, and hundreds. This difficulty is compounded by the student's tendency to perform calculations from left to right, leading to incorrect answers such as 4011.
Problem 64–48=15	25	Misconception	135	The student has done the right to use borrowing techniques. However, s/he forgot to move numbers after subtraction. That is why the student wrote down 25 as the result, instead of 15.

Based on the results in Table 6, taking questions for the case of the saving technique (addition operation) and the borrowing technique (subtraction operation) can identify student deficiencies in mathematical operations involving these two techniques. This student's result provides information for teachers to determine appropriate interventions to overcome these deficiencies.

Table 7 shows another data record captured by the 3D game record's feature after the addition and subtraction topics done by student-3. The game challenge involves addition operation with saving technique and the subtraction operation with the borrowing technique. The game challenge problem is determined through discussion with the SME and refer to textbook reference. The last column (elaboration) in Table 7 is added by the author after analyzing the data together with the teacher.

Table 7. Student-3 recorded data after completing addition and subtraction challenges

Question	Answer	Description	Time	Elaboration
Problem 355 155 ___ + 510	510	Correct answer	428	The database shows that the student has tried five times to get the correct answer.
Problem 223 198 ___ + 421	421	Correct answer	32	This player does not have a problem solving the addition operation in hundreds of numbers.
Problem 63–48=15	25	Misconception	135	The student has done the right to use borrowing techniques. However, s/he forgot to move numbers after subtraction. That's why the student wrote down 25 as the answer. (The correct answer is 15).
Problem 63–48=15	15	Correct answer	32	At the second attempt, the student managed to get the right answer.

As shown in Table 7, student 3 demonstrates the ability to solve mathematical problems but faces challenges with addition operations involving zero, indicating a need for clarification on its role in mathematics. Despite attempting these problems five times during the assessment, the student's repeated efforts underscore their determination to understand the concept. This highlights the necessity for targeted instructional support and tailored strategies to reinforce their understanding of zero in addition, ultimately improving their overall mathematical proficiency.

The teacher, as a SME, emphasized the value of the 3D game as a medium within the framework, helps pinpoint students' specific challenges in mathematics, providing teacher with crucial insights. With this understanding, teachers can develop personalized interventions that enhance students' mathematical skills and confidence (the teacher's statement, as a SME, also applies to subsection 3.1.1).

3.1.3. The expert feedback

The diagram of thematic analysis is depicted in Figure 5, This diagram maps seven main themes along with subthemes and the focus of the role of expert actors in the design and evaluation process of a serious game-based dyscalculia identification system. The feedback from the SME, psychologist, game technology expert, and class teacher that obtained from thematic analysis is described in Table 8.

3.1.4. The student feedback

The student feedback shows in Table 9. Table 9 describes the feedback that obtained from the observations through eye-gaze observations during the assessment activities.

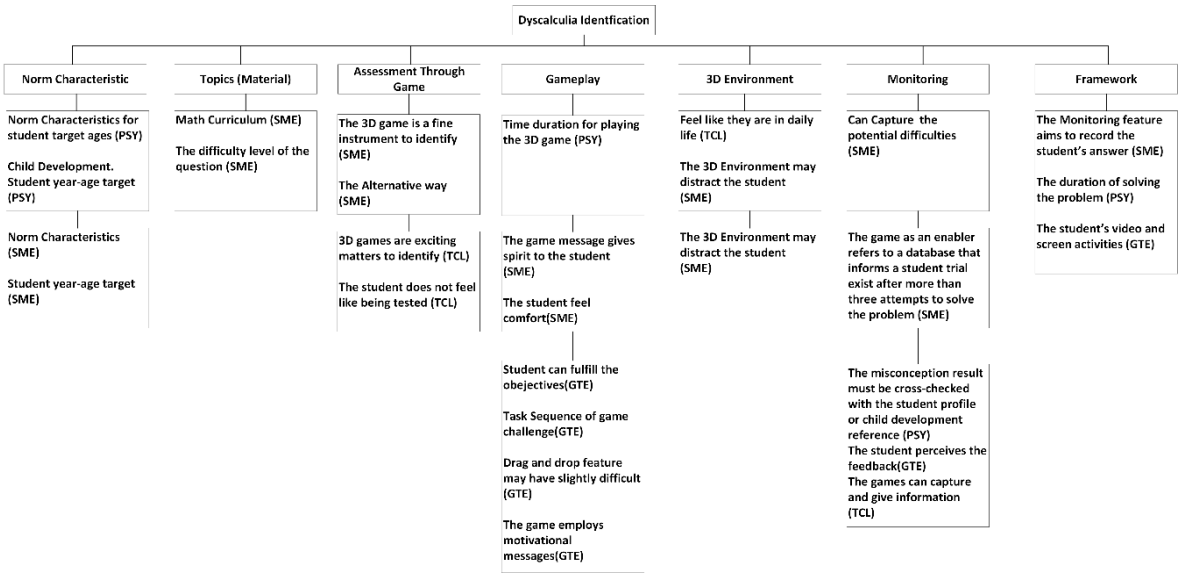

Figure 5. Thematic analysis

Table 8. Expert feedback

Item	Feedback
SME	Can capture the potential difficulties. The game as an enabler refers to a database that informs a student trial exists after more than three attempts to solve the problem.
Psychologist	The misconception result must be cross-checked with the student profile or child development reference.
Game technology expert	The student perceives the feedback, and the teacher has an information about the student deficiency.
Class teacher	– The games can capture and give information. – Teachers reported that the notification feature was beneficial, as it revealed instances where students misread numbers—issues that had previously gone unnoticed during regular teaching and learning activities.

Table 9. Student feedback

Item	Feedback
The game challenge	The student appears focused on her work through the challenge. Even though the student failed at the first attempt while working on the game challenge, the student kept calm and focused on solving the game challenge. The other students also have the same motivation and attitude when faced with a game challenge.
The 3D game environment	When playing the game, some students prefer first to explore the gaming environment rather than jump right into the challenge. However, the students did not have problems returning to the game's objective to start the game challenge.
The game message	In this game, there is no message such as You lose, you are defeated, and you fail. Instead, the game uses positive messages such as Your answer is incorrect, and please try again. During the test session, the game message made the student feel calm and focused on preventing the student from feeling tested.

3.2. Face video and screen capture

The screen capture feature records the student activity when working on the 3D game challenge (the screen capture feature, in this study, is functioned as a companion tool for the teacher). For example, the motion of the mouse, such as doing a drag and drop activity to answer the challenge are recorded in the screen activity video as shown in Figure 6(a). Furthermore, the Figure 6(b) shown the zoom out of the student video when working on the game problem.

In this study, the recording does not provide insights into students' engagement response by utilizing computer vision methods. The video recording serves as a companion tool for the teacher (due to the emphasize is identifying potential student dyscalculia that provide the feedback for the player/user about their deficiency). As illustrated in Figure 6(b), the recordings capture facial expressions influenced by the webcam's position, enriching the understanding of students' learning processes. The student's video is saved

to the local hard drive; these recordings ensure accessibility for future analysis. SMEs highlight that this feature supports tailored interventions, enabling teacher to address students' challenges and enhance their mathematical understanding within a personalized learning environment.

(a) (b)

Figure 6. Recording setup showing; (a) the full screen activity during gameplay and (b) an inset view from the webcam capturing the student's facial expressions and environment while solving the game problem

4. CONCLUSION

The 3D-DIG framework represents a significant advancement in identifying students with mathematical learning difficulties through an engaging, interactive, and non-intrusive approach. By integrating 3D game-based assessments, this framework enables students to undergo screening in a playful environment, reducing the anxiety typically associated with formal evaluations. The use of a subtle screening layer allows for the unobtrusive collection of key data, including students' misconceptions, the time taken to solve problems, the number of attempts made, and additional information such as screen activity and webcam recordings.

This detailed data collection not only helps detect specific errors, such as confusion between similar digits (e.g., 6 and 9 or 3 and 8), but also uncovers difficulties often overlooked in traditional classroom settings. Furthermore, the framework identifies deeper challenges in arithmetic operations, particularly issues related to borrowing in subtraction and carrying in addition. Additionally, the 3D-DIG framework using 3D game media for identification can provide information in a concise form where there are students who are principally problematic with borrowing techniques for subtraction operations and storing techniques for addition operations.

The layered insights provided by the 3D-DIG framework offer valuable input for teacher and psychologists to design targeted and identify the potential student with mathematical deficiency. By presenting results in a concise and structured format, the framework supports timely and personalized educational support. Overall, the implementation of the 3D-DIG framework highlights the potential of interactive digital tools in enhancing early detection and intervention for students with dyscalculia.

ACKNOWLEDGEMENTS

We thank the Ministry of Higher Education Malaysia and Universiti Teknikal Malaysia Melaka for funding this research (Grant No: PJPC/2024/FTMK-C-ACT/SC0019). This research was conducted by Pervasive Computing and Educational Technology Research Group, C-ACT, UTeM in collaboration with researchers at Telkom University. The authors would like to express their gratitude to the Telkom University (Tel-U) for the support that has been given and are grateful to acknowledge the supports given by the Faculty of Information and Communication Technology (FTMK), Universiti Teknikal Malaysia Melaka (UTeM) during the development of this project.

FUNDING INFORMATION

This research is funded by Telkom University and Universiti Teknikal Malaysia Melaka (Grant No: PJPC/2024/FTMK-C-ACT/SC0019).

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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C : **C**onceptualization
M : **M**ethodology
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Va : **Va**lidation
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D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state that no conflict of interest.

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