



The 3D Dyscalculia Assessment Game Framework for Dyscalculia Identification

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Abstract: Dyscalculia is a hidden disability and may happen to ordinary people whether they are normal or highly intelligent students. This makes dyscalculia is challenging to identify. One method to identify dyscalculia students could be through playing games. Games concept could make the students do not feel of being tested when they are doing the test. Developing the game to fulfill the assessment purposes needs a framework that is designed for assessing. Design Play Experience (DPE) is an existing framework that supports the creation of a serious game or game-based learning. The framework contains several layers, such as learning, storytelling, gameplay, user experience. The purpose of the framework is to give a player experience in improving their skills. In this study, the DPE framework is adapted and enhanced to provide a serious game framework for assessing, identifying and monitoring dyscalculia students. The assessment result will be used to identify whether or not the student has a learning difficulty in mathematics. The enhanced framework is called 3D dyscalculia Assessment Game (3DAG). Games that are applied with the 3DAG framework will notify where the students misconception are, so that the teacher can monitor and improve their mathematics accordingly.

Keywords: : Design Play Experience, Game Development Framework, Dyscalculia, Assessment, 3D Games

1. INTRODUCTION

Learning disability is a general term for various types of disability encountered in listening, speaking, reading, writing, and arithmetic [1]. Physical or mental disability and the environment's influence are not causing learning disability, but because of the disability factor that comes from within an individual when perceiving and processing information on seen objects. Other terms of learning disability are learning disabilities and learning differences. This paper focuses on learning disability on the difficulty in academic learning, namely dyscalculia. Dyscalculia is a learning disorder that may happen particularly to individuals[2].

The person with a particular learning difficulty, such as dyscalculia, has average or high intelligence. In other words, the person with dyscalculia seems like normal children

or individuals in general [3]. This makes dyscalculia is challenging to detect [3]. The following Table I illustrates students with dyscalculia in several countries.

Teachers usually assume that children who cannot work on mathematics problems that are given in class are lazy or stupid in mathematics. This condition will negatively impact students, namely reduced self-confidence and having difficulty following the subject matter [4]. This paper proposes a framework to find out earlier detection about the problems experienced in learning mathematics.

The framework proposed is adapted from the DPE framework by Winn [4]. The DPE framework is a framework suitable for game-based learning or serious gaming purposes [5][6]. The proposed game-based learning or serious gaming framework has an assessment component.

The assessment component may have a role to gather information relevant to the student [5][6]. In this research, may focus in difficulty learning of mathematics.

TABLE I. PREVALENCE STATISTICS OF STUDENTS WITH DYSCALCULIA

Author	Country	Sample	Prevalance	Number of Student
(Devine et al., 2013; Kosc, 1974)	Slovakia	375	6.4%	24
(Badian, 1983; Devine et al., 2013)	US	1476	3.6%	53
(Devine et al., 2013; Gross Tsur et al., 1996)	Israel	3029	6.5%	197
(Devine et al., 2013; Mazzocco, & Myers, 2003)	US	210	9.6%	20
(Devine et al., 2013; Geary, 2010)	US	238	5.4%	13
(Eng et al., 2014)	Sabah, Malaysia	91	5.5%	5
(Raharjo, Kawuryan, & Nur Ajyani, 2011)	Kudus, Indonesia	209	9.57%	20

2. BACKGROUND THEORY

A. Dyscalculia

Dyscalculia is a learning disorder experienced by a person in Mathematics ability [1][2][7]. Learning disorders experienced by students, such as difficulty in understanding or knowing basic Mathematical concepts for operations of addition, subtraction, multiplication, division, and understanding symbols.

B. Dyscalculia Symptoms and Indicators

The following are common dyscalculia symptoms [1][3][7][8]:

- 1) The student has a problem distinguishing geometric shapes.
- 2) The student faces difficulty dealing with symbols in Mathematics.
- 3) The student has a problem understanding mathematics operations such as adding, subtraction, multiplication, and division.
- 4) The student has trouble solving mathematical problems in the form of story problems.
- 5) The students read numbers tens in reverse. For example, number 62 will be read as 26, number 17 will be read as 71.

The following list is known as dyscalculia indicators:[7] [9] [10] [11]:

- 1) The student has a problem expressing opinions.
- 2) The student has difficulty recognizing the concepts of number and numbers.
- 3) The student has difficulty understanding story-based Mathematics problems.
- 4) The student it hard to distinguish geometric shapes (circle square square length and triangle).
- 5) The student could not understand the concepts of symbols + , - , x , and / .
- 6) The student faces difficulty counting sequentially.
- 7) The student has trouble dealing with performing the counting.

C. Dyscalculia Assessment

Assessment is the process of gathering information relevant to students, where the results of the collection of information will be considered to make decisions relating to the student[3]. Based on the definition of assessment in line with the process of collecting data, information and utilizing the collection results to make decisions. In this paper, the assessment activities could be stated as identification.

The identification result based on student misconception answers during the assessment will be used to determine the treatment for student weakness. So, the student could improve their mathematical capabilities.

The indicator for the assessment will be a focus on the student in first grade of elementary school, are:

- 1) Addition.
- 2) Subtraction.
- 3) Less than.
- 4) Greater than.
- 5) Equal .

D. Design Play Experience (DPE) Framework

This section will discuss the DPE framework to overcome the needs of the serious game or game-based learning [4] [12]. The Design Play Experience framework has expanded to notice the side of Learning, Storytelling, Gameplay, and User experience. Figure 1 shows the expanded Design Play Experience framework [4].

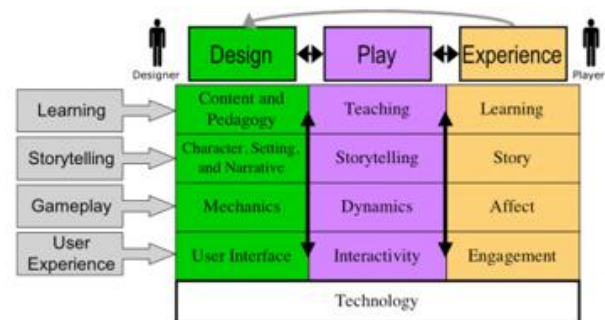


Figure 1. DPE Framework

The Expanded DPE framework consists of several layers, as follow [4]

- 1) Learning
This layer mentions the designer compose the material content and pedagogy, which is lead the player has the learning experience when playing the game. The learning layer conclusion leads to a set of learning outcomes gaining from the overall experience.
- 2) Storytelling
The story designer creates a story that designed for the game. The designer's story set the stage, set the challenge for providing gaming purposes and engagement, convey the content. The story designer concern on these factors are the setting, character design, and narrative.
- 3) Gameplay
The gameplay layer is defined to determine what the player may do during playing the game. The player can make a choice to make in the game world and what gamifications those choices by the player will be affected on the rest of the game.
- 4) User experience
The user experience layer is a layer that pays attention to the appearance of the user interface to give users comfort in playing games. so that the element of fun is still felt by the user.
- 5) Technology
The Technology layer is represented media delivery for conveying the game.

E. Digital Storytelling

Storytelling is an art to convey a message with techniques that entertain the audience [13]. The message can be well received by those who listen to the story. The age of storytelling is as old as the journey of human life on this earth [14][15]. Storytelling is still being done until modern times [13][16].

Along with changing times, storytelling techniques began to get a touch of technology. The storytelling technique by getting a touch of technology is called digital storytelling [13]. Digital storytelling is a modern expression by utilizing technologies with multimedia elements such as still images, audio, video, and animation. In the delivery of stories, digital storytelling has structures/models such as three-act structure, five-act structure, Petri net structure, the string of pearls [13][15][16].

The utilize of storytelling in games has an impact on players by feeling involved as characters in the game[16]. The storytelling, makes the player feel to enjoy playing the game and does not feel bored. The following games example shows the game that has utilized of storytelling:

- 1) Don Key Kong[16].
- 2) The World End with You[16].
- 3) Final Fantasy VII[16].

Structure in the storytelling is essential in making a digital storytelling work. The structure of creating a story is crucial in supporting the narrative element and the game element [13][16]. Besides, the story structure supports determining the nature of interactivity in the story [13]. There are several structures for making a work of storytelling. The structure in digital storytelling is as follows:

- 1) Three Act Structure [13] [16].
- 2) Branching Structure [14][16].
- 3) The Critical Story Path (The string of pearls structure) [13].
- 4) The Modular Structure [13].
- 5) Petri Net Structure [15][17].

F. Game

The game is an activity that implicates physical and psychological to provide pleasurable conditions and amuse the person or group of people who do it. Even though the game has a rule (reward and punishment) and goals[18], the game is carried out by all ages range (from children to adults).

In the early days of humankind's history, the game activity played in open areas and fully implicated physical activity and provided pleasure [19]. People may play the game in pairs or groups. The following visual representation of game activity shows the traditional game Malaysia in open areas. Show in the figure 2 as follow



Figure 2. Visual Representation of game activity in the open area (<http://papieretuncrayon.blogspot.com>)k

Along with the development of technology[13], aims that were initially played in open areas began to move into games that were run using electronic devices such as computers, consoles. The game computer, the game console, provides an excellent graphical image that attracts people to play the game and provides the same fun and pleasure effects[13][19]. The visual representation of the computer game is shown in figure 3 as follow



Figure 3. Visual Representation of game activity in the open area (<http://papieretuncrayon.blogspot.com>)

The attractive graphical show in made people change their habit in-game activity; they leave the game activity in an open area and play the game on electronic devices [19].

The game computer or electronics game is a fun activity that created within a set of rules that specify an object to be attained and the permissible means of attaining it [18]. Players in playing the game are restricted by game designers' restrictions (in open areas game, also constrained by the rule of game). In other words, in a computer game, players can access every place in the game environment but are still limited by the game designer[18].

G. Monitoring Device

Technologies will accompany game applications for educational purposes in some circumstances. Technology devices such as virtual reality (VR), Augmented Reality (AR), and webcam, for playing a game have a role in material delivery media or to monitor the student [20] [21][22].

In this research, the technology used is a webcam. One of the benefits of using a webcam for academics is to monitor the user's or student behavior while playing the educational game without the presence of a teacher in the class[21][23].

3. DISSCUSSION

Dyscalculia is a specific learning difficulty for mathematics that influences an individual student's ability [2] [7] [9]. Dyscalculia is a hidden disability and may happen to ordinary people, whether they are normal or brilliant students [3] [9]. If the dyscalculia problem is not treated correctly, it will result in students becoming left behind in Mathematics. Thus, this condition will affect the confidence of the students concerned, such as worry to make activities, worry about people's judgment according to their Mathematics ability, and worry about making a friend [24][25]. There are two methods for handling dyscalculia are intervention and Identification. Intervention is a way to deal with a student that may have dyscalculia. Furthermore, Identification is a way to gain information on whether a student may have dyscalculia or not. In this paper, the study focuses on the Identification of dyscalculia.

Dyscalculia has not received particular attention like other learning difficulties, such as dyslexia. Dyscalculia is challenging to detect [3] [26]. Therefore, not much research has also been conducted or explicitly paying attention to identifying of the dyscalculia problem. Moreover, the effort may involve the following concerns:

- 1) Students being tested may have Mathematics anxiety during the assessment [8] [9] .
- 2) Formal screening tests using computer-based [4]and formal test (paper-based) screening equipped with teaching aid such as a cube, dice, card, marbles [1][8]. The detection may be required to make the situation conducive. Situations that are not conducive will make students not be optimal in running the test.
- 3) Screening tools for dyscalculia students based on the game concept (Learn and Playing) is limited. That can be seen on Table II

TABLE II. THE EXISTING SCREENING TOOLS FOR LEARNING DIFFICULTY

Authors	Application	Formal Test	Computer	Game
(Butterworth, 2003)			✓	
(Cangöz et al., 2013; Ciecalska, 2018)			✓	
(Ciecalska, 2018)		✓	✓	
(Rasli et al., 2018)	✓	✓	✓	✓(dyslexia)
(Hasan, Mohtaram, Che pee, Shibghatullah, 2017)				✓(dyslexia)
(Hornigold, 2015)			✓	
(Emerson et al., 2010)		✓		
(Suhaimin & Mohamed, 2017) *		✓	✓	
(Afiati & Azwar, 2016)		✓		
(Moreau, Wiebels, Wilson, & Waldie, 2019)	✓(neuro image)			
(Peters & De Smedt, 2018)	✓(brain image)			

*equipped with teaching aids such as picture, dice, marbles, cube

From Table II, there is a need to develop an early detection for dyscalculia through games. In this study, by utilizing 3D games that can be used for the common benefit of teachers, parents, and practitioners. Game has several benefits such as[12][26]:

- 1) Games provide the player the active fun activity.

- 2) Games engagement the player to learn something by playing game.
- 3) Games are a social medium may provide the player an experience such as human-to-human interaction and emotional responses.
- 4) Games may have a participatory aspect that provide the player with feature customized rapid feedback.
- 5) Games are pleasing. Games may have participatory aspects that give the player their full attention. Games demand full consideration (wise) of planning and decision making. Furthermore, provide experiences that require learning to be successful. If the player could not take a lesson while playing the game, so the player may have not to succeed.

The 3D game that was built aims to identify students who have difficulty learning mathematics. So that, the game that is made is a serious gaming category. To fulfill the serious gaming content needs a framework that is adapted from the DPE framework. The next paragraph discusses the proposed framework that is enhanced from the DPE framework.

The serious game is a digital game whose primary purposes aim for training, assessing individuals, improving skill, and not solely for amusement [5]. The serious game contains a learning element that makes a difference from an entertainment game. The Expanded DPE framework is said to be a framework appropriate for serious game development because it has learning elements [4].

According to [4], serious game design has three elements: theory, content, and design. The three-elements that linked to each other was called “The Heart of Serious Game Design” [4]. Figure 4 shows the visual illustration with the linkage of the elements



Figure 4. The elements of serious game

The three elements in figure 4 become bases in the Expanded DPE framework. The expanded DPE framework contains learning, storytelling, gameplay, user experience, and technology to fulfill serious game purposes. The research will propose a framework for identifying dyscalculia students adapted from the expanded DPE framework. One

of the adapted elements from the expanded DPE framework is the learning layer change to dyscalculia assessment.

This research’s domain is serious games and based on the existing theoretical framework [4]. This framework has three main theories that encompass serious game development for this research are (1) Dyscalculia Assessment, (2) Content, and (3) Game Design. Therefore, our proposed game development framework’s corresponding theoretical framework consists of the three main elements, as shown in Figure 5. This study’s proposed framework is called 3DAG (an acronym for 3D Dyscalculia Assessment Game).

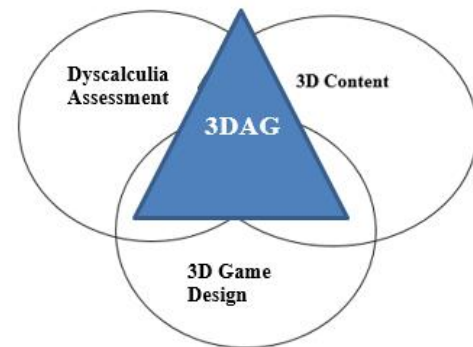


Figure 5. The elements of 3DAG

In this this research, the researcher still adapts the framework by scoping the theory to cover dyscalculia assessment only. Games design is used to build and increase students’ motivation during the dyscalculia assessment process, while 3D content is applied in the digital storytelling of 3D game development. The proposed elements adapted from the existing expanded DPE framework are mentioned in Table III, which contains the proposed framework elements for identifying and monitoring dyscalculia assessment.

TABLE III. FRAMEWORK ELEMENTS

Layers	Design	Play	Experience
Dyscalculia Assessment	Dyscalculia assessment materials, constructivist problem-based learning	Assessment using games	Dyscalculia Identification
Storytelling	Character, Setting, Narrative & Structure	Storytelling flow	Mathematics Problem Based Story
Gameplay	Mechanics	Dynamics	Affective Assessment
Monitoring	Petri Net based Monitoring Scripts	Feedbacks	Effective Monitoring for Intervention purposes
User Experience	User Interface	Interactivity	User Experience
Technology			

The proposed framework has been implemented in a small adventure game about counting objects and addition operation. The prototype game implementation is to perceive how the game captures the misconception in basic math operations such as addition operations.

The game prototype created in adventure detective genre [18]. The detective genre chosen refers to the characteristics of mathematical problems that contain elements such as solving puzzles, looking for missing objects, solving problem-based in a story [18][19][27]. The adventure detective game designed is based on the consideration as follow [16][18] [28]:

1) Game Story

The game story outline generally is about a player playing as a detective in helping his/her mother and a young man to solve their problems. Here are examples of scenarios in the game:

On a Sunday morning, the little detective is preparing a breakfast with his/her mother. While preparing the breakfast, the mother needs five eggs and asks him/her to search from the egg holders. After the little detective has found the eggs and s/he should count the number of eggs to be exactly as five eggs. After counting the eggs, the mother stirring the eggs with sugar, milk, flour, and melted butter and finally cook a pancake with the little detective.

The little detective has finished breakfast and asks for a permission to go to the town nearby. While walking in the town, the little detective meets with a young man. The young man looks confused because his bucket contains three mangoes out of five mangoes. The little detective must determine how many mangoes are missing to fill-up the bucket with five mangoes. After helping the young man, the little detective buys some snacks and goes home.

2) Game Character

The game character that plays a role in-game are:

- a) The main character of the little detective is a boy eight years old. The following figure 6, illustrate of the game character



Figure 6. The Boy Detective

- b) The others character is the mother and young man (figure 7). These two characters have a role as a person who needs the little detective help to solve the problem



Figure 7. The Young man Character

c) Nonplaying character

The illustration of non playing characters in the game are shown in Figure 8



Figure 8. The Non Playing Character

3) Game environment

The game is using a 3D environment to visualize daily life. The daily life environment would feel like they are in an everyday life environment when playing the game. The visual illustration of the 3D environment is shown in Figure 9

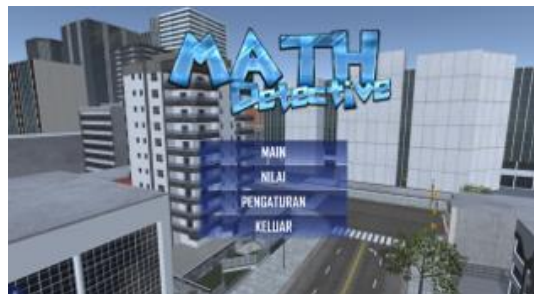


Figure 9. Visual Representation of the 3D Game Environment

Figure 9 shows the 3D environment designed for the adventure game. The theme setting is resembling a town environment

4) Objectives

The game objectives are determined based on the mathematical problem for the dyscalculia students. The mathematical issues implemented in this game are counting objects and adding operations. Table IV describes the game objectives implemented on the game level design [29].

The following Figure 10 and Figure 11 illustrate the scene of misconception and right answer situation.



Figure 10. Visual Representation of Misconception Scene

Figure 10 illustrate a scene when the player does not fulfill the objective given in the game because of misconception



Figure 11. Visual Representation of Right Answer Scene

Figure 11 shows a scene when the player manages to fulfill the objective given in the game.

4. RESULTS

The little game adventure builds on the proposed framework and plans for piloting to first-grade primary schools. However, due to the pandemic, many schools have switched to online teaching and learning activities. The pandemic situation prevents students from coming to school and push the student learning from their homes. So that, the researchers are currently unable to conduct a direct trial.

The researchers conducted a trial in the laboratory. The researcher take a measurements about the user experience. In the User Experience Questioner(UEQ), six parameter are

measured: Attractiveness, Efficiency, Perspicuity, Dependability, Stimulation, and Novelty. The result of the UEQ is as shown in Figure 12

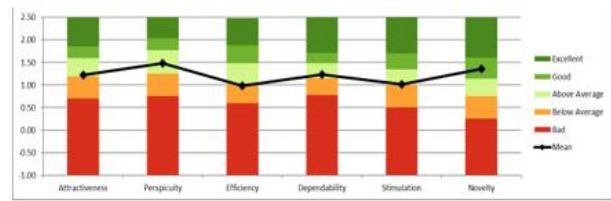


Figure 12. UEQ Chart

The UEQ Chart on figure 12, mentions the UEQ scale that is shows in the following table V

TABLE V. UEQ SCALE

Scale	Mean	Comparison to benchmark
Attractiveness	1.23	Above average
Perspicuity	1.49	Above Average
Efficiency	0.99	Below Average
Dependability	1.24	Above Average
Stimulation	1.01	Above Average
Novelty	1.35	Good

Based on the data inform in Table V and UEQ chart, we can resume the results as follows :

- 1) Attractiveness values is above average. It means the user feel enjoy and pleasing with the game.
- 2) Perspicuity values indicated the user has a clear and good understanding of the application.
- 3) Efficiency mention that user may not comfortable with interface organisation.
- 4) Dependability mention the application could fulfill the user expectation.
- 5) Stimulation has given an information about user has a good interesting and motivation about the application.
- 6) Novelty mention about the application is innovative

The UEQ result mentions in the UEQ scale associated with the element layer in the 3DAG framework. The following table VI



TABLE IV. GAME OBJECTIVES

Level	Mathematical Problem	Description	Objective	Reward / Punishment
1	Distinguishing number 2 and 5	The little detective helps the mother search for the egg and must take precisely five eggs to fulfill the mother's request	The little detective should count exactly five eggs	In this game the punishment will not shown as you lost or defeat or other words indicate losing. The punishment will be shown as encouraging words.
2	Solve the adding operations	The little detective helps young man find 3 mages to turn the number of mages to five.	The little detective should pick the right number	In this game the punishment will not shown as you lost or defeat or other words indicate losing. The punishment will be shown as encouraging words.

TABLE VI. UEQ SCALE ASSOCIATED WITH 3DAG FRAMEWORK LAYER

UEQ Scale	3DAG Framework Layer	Description
Attractiveness	Storytelling, Gameplay	The layer storytelling and gameplay consist of elements that associated with attractiveness aspect such as pleasing, enjoying.
Perspiciuity	Assessment, Gameplay	The perspicuity indicates an aspect that associated with a clear and good understanding so that the application must convey the assessment subject matter and gameplay clearly.
Efficiency	User experience	User experience layer consist of an interface aspects that related with efficiency.
Dependability	Dependability	The application must meet the user's expectation which is to provide an identification of dyscalculia students.
Stimulation	Assessment, Gameplay, Storytelling	The assessment, gameplay, and storytelling layer should provide stimulation when the user using the application.
Novelty	Assessment	Assessment to identify student whether has a learning difficulty in mathematic or not.

Therefore, The UEQ benchmark mention the application could fulfill the user expectations. However, there is a factor that must be improved in the future, namely efficiency.

Besides paying attention to the UEQ benchmark results, the researcher is concerned about the Cronbach alpha result for considering an aspect to be improved. In this research, the researcher found that some aspects such as efficiency, dependability, and novelty did not qualify for the Cronbach alpha threshold ($\alpha > 0.6$) Table VII mention the cronbach alpha

The efficiency, dependability, and novelty aspects could not qualify the threshold may be caused by a negative correlation between items due to the inconsistency respondent to answer the UEQ questioner. The three constructs will be a concern in future testing and evaluation.

TABLE VII. CORRELATION AND CRONBACH ALPHA (UEQ VARIABLE)

Attractiveness	
Items	Correlation
1,12	0.57
1,14	0.15
1,16	0.54
1,24	0.37
1,25	0.42
12,14	0.09
12,16	0.71
12,24	0.65
12,25	0.83
14,16	0.42
14,24	0.42
14,25	0.25
16,24	0.61
16,25	0.74
24,25	0.69
average	0.50
alpha	0.86



Dependability	
Items	Correlation
8,11	-0.04
8,17	0.19
8,19	0.34
11,17	0.11
11,19	0.38
17,19	0.07
average	0.17
alpha	0.46

Stimulation	
Items	Correlation
5,6	0.26
5,7	0.29
5,18	0.45
6,7	0.73
6,18	0.55
7,18	0.50
average	0.46
alpha	0.78

Novelty	
Items	Correlation
3,10	0.07
3,15	-0.23
3,26	-0.02
10,15	0.08
10,26	0.34
15,26	0.25
average	0.08
alpha	0.26

5. CONCLUSION

The proposing framework has been implemented in a small 3D game with the detective adventure genre. The adventure game is equipped with the misconception (capture the student mistake) feature. The game adventure is visualized in the detective theme, so the player must solve the problem to gain a reward. However, if the player could not comply with the aim, the player will be received a notification such as thank you for kindness (so the player keep motivated to play the game).

Because of the pandemic situation, the researcher could not thoroughly test the game for the student. However, the detective game that is implemented in-game makes a player comfortable for playing it, referring to table V and Table VI. Furthermore, The Cronbach-alpha result will be a concern to improve the game.

In the future, the researcher will be developed a fully complete assessment based on a 3D game. The 3D game

will be equipped with a feature that gives detailed information about the student's misconception and record in the database. The misconception that is recognized such as misread numbers, symbols, cannot understand the technique of storing numbers in addition operations and hard to decide symbol +, -.

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