Application of Dynamic Difficulty Adjustment on Evidence-centered Design Framework for Game Based Learning

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***Abstract*— Evidence-centered Design (ECD) framework has been used to design an effective assessment plan for student. The assessment process often uses game as a tool to make the activity more active, goal-oriented and could give a direct feedback. A difficulty level in the game need to be suitable with student's skill to create a fun, comfortable assessment environment. The result of assessment process usually need some times to be processed and the student could not experience it right away. This paper applies Dynamic Difficult Adjustment (DDA) to create a dynamic game content suitable with the student's skill based on the result of assessment process within the game which is designed using ECD. The presented scheme produce winning rate value of 67%. The students who were participated in the test also find the game to be fun and the dynamic content inside the game could motivate them to use the game to help them learn.**

***Keywords*—skill assessment, ECD, dynamization, DDA, game.**

I. Introduction

One of the challenge on providing a successful teaching method is to give suitable teaching environment based on student's knowledge and skill [1]. Some researches stated that a good teaching method consists of an active, goal-oriented, interesting activity, [2], [3], [4], [5] gives a direct feedback and also gives challenge suitable with student's knowledge and skill [6]. The last two characteristics (direct feedback and challenge) are also owned by an activity called game [7], [8]. This is the reason of why game often used to support teaching activity which is called game based learning.

In the age where technology is growing rapidly, game based learning is often developed as a digital game where students play it using a computer or any kind of console that could support digital games. These games could improve student's learning performance by 51% [9] and also improve their skills and behaviour [10].

To gain a successful learning activity using a digital game, the design of game base learning become an important factor [11]. A game developed for learning has to be able to combine fun and education which can help the student learn while feeling the fun provided by the game. The learning content in the game also has to fit with student's knowledge and skill to create an effective learning activity. To gain the information about student's knowledge, an evaluation could be done while students are playing the game. This process is done by analysing their action and behaviour in the game [12].

Recent research on designing and evaluate student skill using game has been done by Argasinski and Wegrzyn in 2018. They developed a fire simulation game using a framework called Evidence-centered Design (ECD) [13]. This framework provide a uniform and systematic design pattern to evaluate student's skill effectively. The result of assessment process usually take some time to be processed as learning content and the student couldn't experience it right away. A mechanism which could use the evidence of student's knowledge and skill for dynamically adjust the content of the game is needed so it'll fit with the student's skill while they play. With the help of evidence, a more effective and accurate dynamization process can be done.

Based on aforementioned problem, the contribution of this paper is to use ECD framework's evidence as an input to create a dynamic game content using Dynamic Difficulty Adjustment (DDA). To choose the suitable dynamization method for this paper, surveys have been made on some researches about DDA method in game. An experiment by Kok Wai Wong, Chun Che Fung, Arnold Depickere and Shri Rai has created a dynamic difficulty mechanism in game using Backpropagation Neural Networks (BPNNs) where difficulty level is divided into three kinds : easy (20%), normal (50%) and difficult (95%) [14]. Another experiment on DDA is done by Peizhi Shi and Ke Chen using Learning Constructive Primitives. In this experiment, difficulty in the game is divided into 5 level of difficulty [15]. A dynamic difficulty in game's attribute and tactic has been experimented by Pieter Spronck, Ida Sprinkhuizen-Kuyper and Eric Postma using a Difficulty Scaling of game AI [16]. A simple and quick method of DDA also introduced by Lach [17]. This method use a dynamic adjustment value based on the player's skill.

Based on the surveys, the method used for dynamization in this paper is Full Dynamic Difficulty Adjustment for a Computer Player (FDDACP) by Lach. The reason for choosing this method is because the value used to adjust the difficulty level using this method is dynamic and is based on the player's condition and attribute value in the game. Another reason is the method's success rate on creating the dynamic game content is higher than the one with AI because AI techniques are complex and sometime couldn't be used in real time.

This method works by processing the data from the player and the enemy in the game and change the difficulty level based on the player's skill. The attribute of the player and enemy in the game is changed to create a dynamic content. If the player is skilful, the game will provide a limited resources and a harder enemy to be defeated and if the player is in the verge of losing, the game will help the player by giving weaker enemy and more resources.

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The rest of this paper is organized as follows : The proposed dynamic mechanism is presented in Section II. Performance Result and Evaluation of the proposed scheme are shown in Section III. Section IV discuss about the whole scheme as well as the conclusion of this paper.

II. METHOD

ECD has been used to design an assessment plan for students to gain information about their knowledge and skill. The result is called evidence and often used as a reference for giving a suitable learning content for the students. In this research, dynamization mechanism using DDA is applied to dynamically adjust the learning content based on the evidences. The scheme of used in this paper is explained below.

A. System Overview

The scheme used in this paper is applied in a digital quiz game. In this game, player has to fight a dragon by answering the questions on the game screen. The form of question provided in the game is mathematic teaching content. Player could choose a teaching content they wanted to practice. There are six teaching contents applied in the game : mathematic operations, power of numbers, square roots of number, two-dimentional figure and geometry, data and also greatest common divisor and least common multiple. Each teaching content has 15 mathematic problems and have to be solved in limited time. If player doesn't solve it before the time runs out, the dragon will attack the player and the damage will decrease player's health point.

The player is considered as win if they answer all of the questions and they still have some health point remained. If the player's health point reaches 0 in the middle of the game, it'll be a game over for the player. The result of their game session will be displayed on the screen once the player win or lose the game. It shows player's current game session's score, the time used by the player in current game session as well as player's highest score and best time of the chosen teaching content. Value of best time is the amount of minimum time used by player on winning the game.

Dynamic difficulty adjustment is applied based on the condition of each attributes owned by player and enemy in the game. Score owned by the player, the value of health point and time used by the students to answers the questions become evidence and is used to change some of the attribute's value in the game such as maximum time provided for student to answer the questions. ECD is used to design evidences and attributes which applied in the game. Learning content applied in the game is mathematic for grade 5 of Indonesian elementary school class.

B. Evidence-centered Design

Evidence-centered Design or ECD for short, is a framework used to design a competency model and assessment method to gain information of student's knowledge and skill on each competency [18]. By using this framework, teacher could define the learning goals and skill needed by the student to reach it, as well as how to assess it. This framework consists of three models :

1) Student Model which defines knowledge, skill and ability which is evaluated in the learning system. One of the sample of student model used in this paper is illustrated in Table I.

TABLE I. STUDENT MODEL

STUDENT MODEL	
Knowledge, Skill and Ability Assessed	**Detail**
Number	Student is able to count multiple numbers using one or mixed operation
Two-Dimentional Figure and Geometry	Student will be able to define the area and circumference of a two-dimentional figure and volume of geometry.
Data	Student will be able to read, analyze and define conclusion of data provided on the form of sentences or diagrams.

2) Evidence Model consists of attributes which represents performance and behaviour of students in the learning process. This model also defines the experience needed to be applied in the assessment process, and also the desired result for the student from getting the experience provided. For example, in an assessment process, student does not only can answer question, but has to be able to answer within a short time, or able to solve same question in the different form. This way, students can prepare themselves on facing a real exam.

The attribute mentioned in this model acts as evidence and has the information whether the student has the knowledge and skill defined in the student model. The sample of evidence model used in this research is illustrated in Table II.

TABLE II. EVIDENCE MODEL

EVIDENCE MODEL		
Experience Provided in the game	**Desired Results**	**Evidence**
Student will be able to do operation of numbers in limited time Variety of questions provided (using variety of sentences form or using pictures)	Student will be used to solve a mathematic problem within a limited time. This condition simulated a national exam where students have to answers all questions in 120 minutes. With variety of questions form, students will be used to read and solve different form of questions.	Time needed by student to solve the problem. Numbers of questions which cannot be solved by the students Numbers of adjustment needed to make the game easier / harder.

3) Task Model defines the activity which should be done by the students to provide attribute value in the evidence model. Task model usually consists of three information. They

are : form of activity for the students, responses needed to be done by students and also attributes and rules in the activity. The sample of task model used in this paper is illustrated in Table III.

TABLE III. TASK MODEL

TASK MODEL		
Challenge	**Action**	**Attribute**
Game will provide mathematic problems Students have to answer the question before the time runs out If the student gives wrong answer or the time is up, the game will decrease the student's health point.	Students choose the correct answers.	***Score*** This attribute represents points collected by the students from solving the problems. ***Health*** This attribute represents total mistakes could be done by students. If the health point reaches zero, the game will be over. **Timing** This attribute represents the time needed by the student to solve the problems

The assessment design by ECD framework is used as reference for designing the genre and attributes in the game. Based on the task model, the action should be done by students is to choose an answer of a question provided. This result become this paper's reference on choosing a genre for the game. The genre for the game suited for this action is a quiz game.

C. Full Dynamic Difficulty Adjustment for Computer Player

Full Dynamic Difficulty Adjustment for Computer Player of FDDACP for short, uses attributes in the game as an input for making a dynamic difficulty level. The attributes value will be processed to gain an adjustment value. This value will be added on the same attributes to create a new attribute value. Since a dynamization process should not be too obvious for the player, the value of the attributes usually is hidden or the process is applied on the next part of the game.

This method divides game's attribute into 2 categories. They are BVBP and SVBP. BVBP represents attribute where bigger value means better player. The example of this attribute is score. Player who collects more score is considered as a more skilful player. While SVBP represents attribute where smaller value means better player. The example of this attribute is speed. If player solves a problem provided in the game in a short time, this player will be considered as a skilful player.

In this paper, attributes used as an input for FDDACP method is based on the evidence mentioned by design result of ECD framework. The division of these attributes for player and enemy based on the design of evidence's attributes are described in Table IV.

TABLE IV. GAME'S ATTRIBUTES

Subject	Attribute Group	Evidence Processed	Attribute in Game
Player	BVBP	Numbers of correct answers	Score
	SVBP	Time needed to solve problems	Action Time
Enemy	BVBP	Student skill to solve problem with different form of questions	Power
	SVBP	Student skill to solve problem in limited time	Enemy Speed

FDDACP uses maximum and minimum value on each attribute as reference on calculating the adjustment value. To define maximum and minimum value of the attributes used in the dynamization process, surveys have been done on Prosedur Operasional Standar Penyelenggaraan Ujian Sekolah Berstandar Nasional or POS USBN, an Indonesian exam standard, as a reference for the value of these attributes. The results could be seen in Table V.

TABLE V. MAXIMUM AND MINIMUM VALUE OF EACH ATTRIBUTE

	Attribute	Value
Maximum Value	Score	100
	Action Time	210
	Enemy Power	10
	Enemy Speed	210
Minimum Value	Score	56
	Action Time	0
	Enemy Power	0
	Enemy Speed	60

Building dynamic game content using FDDACP is done in 5 main processes.

1) Calculate each attribute's skill value. This process is done by calculating attribute's skill value using (1). This formula count player's and enemy's skill based on the value of current attribute in the game (Fval), and also maximum (Fmax) and minimum (Fmin) value of each attribute.

$$efF_i = \begin{cases} \frac{Fval_i - Fmin_i}{Fmax_i - Fmin_i} & for\ BVBP \\ \frac{Fmax_i - Fval_i}{Fmax_i - Fmin_i} & for\ SVBP \end{cases} \quad (1)$$

2) Calculate total value of player's and enemy's skill. To define the total value of player's or enemy's skill (ef), (2) is used.

$$ef = \frac{\sum_{i=1}^{n}(efF_i * weight_i)}{\sum_{i=1}^{n} weight_i} \quad (2)$$

Formula (2) count all attributes skill value with the weight of each attribute. This weight represent the importance of an attribute on defining player's skill. Weight used as a base or dynamization process is described at Table VI.

TABLE VI. ATTRIBUTE'S WEIGHT

Attribute	Weight
Score / Power	0.8176
Action / Enemy Speed	0.1824

This value is based on research done by Lee, Chen, Hsieh and Liao [19]. The research said that the weight of score (BVBP) attribute on a game with Experience Point System genre is 81.76. And the total weight of attribute experience Point System genre is 1. So the SVBP attribute's weight will be 1 – 0.8176 which is 0.1824.

3) Compare enemy's and player's skill. Player's and enemy's skill value is compared to decide whether the adjustment are needed. This process is done using (3). efp is the value of player's skill and efo is the value of enemy's skill which is calculated using (2).

$$diffef = |efp - efo| \quad (3)$$

4) Decide the need of difficulty adjustment using (4). diffef is the difference value between player and enemy. If the value is higher than percentage of enemy's skill (plim), the difficulty level is adjusted. The value of plim used in this paper is 5%. This value is based on a research done by Lach, Lach and Wojciech on 3 types of players (beginner, middle and advance). The result of this research said that 5% is the most stable value on the process of dynamization using FDDACP [20].

$$diffef > plim * efp \quad (4)$$

5) Calculate adjustment value and change enemy's attributes. The adjustment of the game's attribute is done using (5) and (6).

$$adjFi = \begin{cases} diffef * (Fmax_i - Fmin_i) & for\ BVBP \\ -diffef * (Fmax_i - Fmin_i) & for\ SVBP \end{cases} \quad (5)$$

$$Fval_{O,i} = \begin{cases} FvalOld_{O,i} + adjF_i & for\ efp > efo \\ FvalOld_{O,i} - adjF_i & for\ efp < efo \end{cases} \quad (6)$$

adjF is the value needed for the adjustment while $Fval_{O,i}$ is the new attribute value which has been adjusted based on player's skill. If player's skill is lower than enemy's skill, the system will lower the previous attribute of enemy's skill ($FvalOld_{O,i}$) so it's easier for the player to defeat it and vice versa. This process is done until the game is ended (player has solved all the problems or stopped because their health points reach zero).

D. Application of FDDACP Method in the Game

The process to apply the dynamic difficulty mechanism using FDDACP is shown in Figure I.

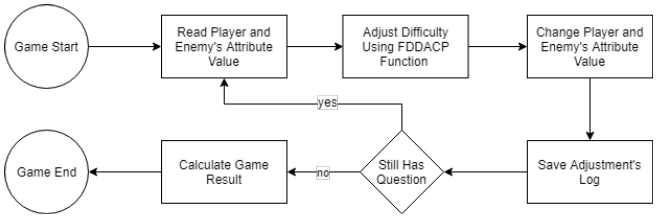

FIGURE I. FLOW PROCESS OF DYNAMIC DIFFICULTY ADJUSTMENT IN THE GAME

This process is done each time a question is provided for the player. There are 4 main processes in the application of FDDACP method in the game.

1) Read Player's and Enemy's Attribute Value. This process collects all the attribute value in the game and used it as an input for FDDACP method.

2) Adjust Difficulty Using FDDACP Method. This step processes attributes value provided by the first step and calculates the adjustment value using FDDACP method. The result of this process will be : the decision of difficulty adjustment and also the value of adjustment needed to be adjust on each attribute.

3) Change Player and Enemy's Attribute. If adjustment is needed, the next step is to change the attributes value based on the adjustment value needed for the player. For example, if player is in the verge of losing, then the game will added more time for the player to answer next question so the player can try to answer it in peace.

4) Save adjustment Log. This process will save the adjustment process done by the game so teacher can see the information on where the student need an adjustment.

The processes above is done each time player is provided with question in the game. The change of attribute will be done on the next question as long as player still has some health remaining. The reason on why the change of attribute is done on the next question is to avoid a sudden change on the game which might confuse the player.

III. SYSTEM PERFORMANCE

To analyse the performance of the system, testing is done by measuring the dynamization process and also the flow experience of the game. The testing is done on 39 elementary students of grade 5. Every student played one level in the game which consists of 15 mathematic questions where they are given 120 seconds to solve each question.

A. Dynamization Performance

The goal of this testing is to measure the dynamization performance applied in the game. This is done by counting the winning rate achieved by the student. Winning rate is achieved by dividing the amount of students who can finish the game until all problems has been answered with the total amount of the students.

Based on test result, the winning rate is 67%. This value meets the standard winning rate for a good dynamization mechanism which is slightly above 50% [21]. This result shows that the dynamization process applied in the game could motivate the player, in this case the students, to keep playing the game. Which in term of learning, the students is motivated to use the game to support their study.

B. Flow Experience of the Game

The goal of this testing is to measure the flow experience given to the player. Flow experience describes how the players feel while playing the game. To measure this performance, some questions are given to the students after they played the game. The questions used to represent the flow experience is described in Table VII.

TABLE VII. FLOW EXPERIENCE QUESTION

Indicator	Question
Learning	Do you like playing the quiz game?
Engagement	Is it hard to concentrate while playing the game?
Engagement	The game helps me concentrate
Engagement	I like playing the game
Immersion	I am immersed with game
Challenge	The game is challenging
Challenge	I want to finish the game
Skill	It is easy to play the game

The questions above are asked to the students using binary questions of "yes" or "no" which represents student's agreement or disagreement with the experience applied in the game. The result for testing scenario on flow experience of the game is shown in Table VIII.

TABLE VIII. QUESTIONAIRE RESULT

Flow Indicator	Yes	No	Mean
Learning	35	4	0.897
Engagement – 1	35	4	0.897
Engagement – 2	35	4	0.897
Engagement – 3	30	9	0.769
Immersion	35	4	0.897
Challenge – 1	35	4	0.897
Challenge – 1	35	4	0.897
Skill	35	4	0.897
Flow Experience			0.881

Value in column yes and no are the amount of students who agreed and disagreed with the question. Based on the result, the mean value of flow experience in the game is 0,881. This result shows that most of the students are agreed that the game has provided the flow experience needed in the game.

IV. CONCLUSION AND FUTURE WORK

This paper proposes a scheme where difficulty level dynamization is used on the evidence attribute which is designed by an assessment framework called Evidence Centered Design. The method used for dynamization process in this scheme is Full Dynamic Difficulty Adjustment for a Computer Player. The dynamization process is referenced and done on game's attribute which represent the evidence of student's skill. Evidence is used as a reference for the dynamization process to create a more effective and accurate dynamization.

To test the scheme, two testing scenarios were done on 39 elementary students of grade 5. The first scenario measure the dynamization performance of the scheme by using winning rate. The result shows the winning rate of students is 67%. This result shows that the game has met the standard of dynamization in a game. Second testing scenario measures the flow experience in the game. Some questions are asked to the students and the results shows that the mean value is 0,881. This high Mean value shows that the game has a good flow experience. The students also mentioned that the dynamization applied in the game help them learn and also motivate them to keep using the game to support their study.

Despite the positive feedback from the students, the game still has some weaknesses related to the learning material applied in the game. The students often forget the formula used to solve the problem mentioned in the game. The game doesn't provide help for the formula which could lead to students feeling frustrated while playing the game. A dynamization on this matter could be added on the future work to help the learning process using this scheme become more effective and suitable for the student. Another suggestion is to use gamification concept while designing the game to create a better flow experience.

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