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# The Study of Using Digital Game-Based Learning to Develop Critical Thinking Skill through Self-Assessment Process

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## Abstract

Critical thinking (CT) is one of the important leadership skills in the industry to assess the information from the digital work environment and the ability to apply the new technologies in the firms. The industry nowadays needs graduates who possess great CT skills to produce innovative solutions for their firms. Meanwhile, self-assessment (SA) is one of the critical thinking processes where a learner criticizes and review the quality of his or her work based on the recognized criteria. In the traditional learning environment, CT skills may be nurtured through the test as an assessment. The results of the test were feedback by the educators to the learners in terms of scores and comments. A previous study found that game-based learning may develop CT skills. However, there is relatively little research focusing on learning SA through the game. This study sought to investigate using the digital game-based learning (DGBL) approach to learn the assessment process among undergraduate students. A digital mobile game named Inventors of Future, (IoF) is developed by gamifying the SA process. In this paper, the results of the

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findings are presented through a single pre and post-test study. A product-oriented problem-solving instrument is created and applied to evaluate the findings. The results indicated that IoF significantly enhances students' assessment knowledge. In particular, the study found that rubric is the key element when learning the SA process through DGBL. The rubric must consist of learning outcomes that the students were expected to learn in a DGBL environment. These results offer a promising basis for further exploration of game-based SA for learning to achieve intended outcomes for different subject matters.

**Keywords** Digital game-based learning; Critical thinking; Self-assessment; Product-oriented; Problem-solving

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## Introduction

Critical thinking (CT) is one of the important learning skills needed in the 21st century (Laar, Deursen, Dijk & Haan, 2020). Critical thinkers developed the ability to make a decision based on the obtained information and communication (Laar et al, 2020). The ability to filter the incoming information to make a judgement is the key to 21st-century skills (Laar et al, 2020). Besides learning skill, CT is one of the important leadership skills in the industry nowadays in order to assess the digital information in the work environment and apply the new technologies in the firms (Guzman, Muschard, Gerolamo, Kohl & Rozenfeld, 2021). However, based on the feedback from the industry, the graduates are inadequately prepared for the emerging jobs and lacking in the CT skill (OECD, 2019).

According to OCED (2019), self-assessment (SA) is one of the CT processes to identify a problem, study how a problem can be resolved and understand the consequences that results from a person's decision. The advantage of SA may come from increase engagement awareness of students' learning or thinking process and thus improve their learning (Andrade, 2019; Vasileiadou & Karadimitriou, 2021; Yan, Brown, Lee, & Qiu, 2019). SA is also an important skill that students need for their future career development and lifelong learning (Vasileiadou & Karadimitriou, 2021).

Although the previous studies suggest the effectiveness of SA in improving learning performance, applying SA in the process of thinking is still limited for some students. There is a lack of intention to use SA in learning due to boring text and unclear academic jargon (Pui, Yuen & Goh 2020; Groenendijk,

Karpati & Haanstra, 2019). Moreover, there is a lack of research focusing on students' intention to conduct and practice SA (Yan, Brown, Lee & Qiu, 2019). Hence, Pui et al (2020) suggested that sufficient training, instructional aids and cues can assist students to practice SA. Thus, this paper presents the research findings on the use of a novel mobile game, Inventors of Future (IoF) as instructional aids and cues to gain the knowledge of the SA process among undergraduate students. The aim of this study is to examine how digital game-based learning with IoF can be applied in a private university context of Malaysia.

## Background

### *Game-Based Learning*

Game-based learning (GBL) is a student-centred approach that incorporates game elements with learning material to learn a wide range of skills (Cardinot & Fairfield, 2019). According to Prensky, GBL should encompass six elements that can be gamified on the learning content: goals, rules, interaction, feedback, problems and narrative or fantasy (Wang & Maizatul Hayati, 2021). Compared to the GBL, digital game-based learning (DBGL) refers to include lesson content in a digital game to provide instruction or assessment to the learners (Bawa, 2020). Meanwhile, gamification in the education context is the process to convert non-game activities into a game to achieve learning objectives (Tan, 2020). In the teacher-led gamification approach, learning content can be gamified through the off-the-shelf game or use a bespoke educational game created by the teacher (Tan, 2020). Tan and Maizatul Hayati (2019) proposed seven steps of gamifying learning content in DGBL that includes seven elements: primary emotion, gamification goal, gameplay, genre, interaction model and social interaction mode, game space and game story. Compared to the GBL, elements in DGBL have a difference in terms of interaction and game space. In DGBL, a player is represented as a virtual avatar in the game-based scenario (Tan & Maizatul Hayati, 2019). As the player is represented as a virtual avatar, the game space may be set in a 2D or 3D virtual environment (Tan & Maizatul Hayati, 2019).

DGBL approach was found to be effective in developing critical thinking skills among the students (Duncan, 2020; Hussein, Own, Cheong & Thong, 2020). Tariq and Abonamah (2021) have demonstrated the effectiveness of using a game in leadership class to develop CT skill in tertiary education. Researchers suggest instructor provide guidance to the students throughout the game treatment session due to some challenging features found in the leadership game (Tariq & Abonamah, 2021). A study found game-based learning motivates engagement among Grade 3 students in developing CT skill (Duncan, 2020). Compared

to the Likert scale survey, assessments using rubrics are more comprehensive in observing the actual use of the CT skills through the game (Duncan, 2020). Hussein et al (2020) found DGBL effective in developing CT skill through making decisions whereby the players' progress influence by their decision. The performance of the students is assessed through own multiple-choice questions instrument particularly designed for science subject. (Hussein et al, 2020). Roodt and Ryklief (2019) showed DGBL is effective in improving motivation and academic achievement among vocational education students, mainly in computer programming lessons. The aforementioned studies however examined the use of DGBL in primary, secondary, vocational education and tertiary education. There is relatively little research focusing on DGBL in SA among undergraduate students.

***Critical Thinking***

According to John Dewey, CT is a process that begins with an issue and ends with an answer and self-interpretation (Alsaleh, 2020). This issue should raise the interest of the students to learn and solve the issue (Alsaleh, 2020). Ennis (1993) refers CT as a reasonable reflective thinking process that helps a person to make a decision. OECD refers to Gaccione's definition where CT includes inductive and deductive reasoning, making correct analyses, inferences and evaluations (OECD, 2019). Researcher Renatovna and Renatovna (2020) denotes CT as the ability to analyze, express opinion based on evidence and conclusion, professional knowledge, reflect on a person's own way of thinking and correct mistakes when necessary.

There are several types of research that explain the process of CT. According to Ennis (1993), the CT process includes visualizing concepts, being clear about the direction in the process of making a decision, not making an assumption based on a rough idea. In the context of education, Bloom's Taxonomy divides CT into a structural way where the cognitive process is divided into six levels mainly remember, understand, apply, analyze, evaluate and create (Saputra, Joyoatmojo, Wardani & Sangka, 2017). Anticipation-Action-Reflection (AAR) cycle from OECD Education framework 2030 divides CT into three iterative processes, which are anticipation, action and reflection (OECD, 2019). Anticipation is an important step where students self-assess to understand the issues, study how issues can be resolved and realize the costs that result from their actions (OECD, 2019). Among the processes that are proposed by the researchers, AAR cycle clearly highlights the importance of SA that can develop CT among students.

***Self-Assessment***

Self-assessment (SA) is a process where an individual criticizes and review the performance of his work based on the recognized criteria (Vasileiadou & Karadimitriou, 2021). In the context of pedagogy, Panadero et al. (2016) and Epstein (2008) also defined that SA is a self-monitoring technique for students to evaluate the quality of their learning process or product (Andrade, 2019). The process of SA includes i) establish assessment criteria ii) show students how to apply assessment criteria and provide necessary practice time to apply them iii) provide students with feedback on the results of applying those criteria in their work iv) setting learning goals and strategies to achieve in future (Vasileiadou & Karadimitriou, 2021).

There are several studies that show positive results in learning through SA. A study found that primary school students who used rubrics to self-assess increased their performance in writing (Vasileiadou & Karadimitriou, 2021). At the secondary level, students who wrote physics lab reports demonstrate significant improvement in lab report writing through the SA rubric (Faletic & Planinsic, 2020). At the higher education level, students who perform SA through daily programming quizzes performed 73.1% better in the programming lesson (Alzaid & Hsiao, 2018). Agost, Company, Contero, and Camba (2020) highlighted that an accurate SA can help computer-aided design (CAD) students to improve their modelling skills without self-bias in a self-paced and distance learning class. Candrlic (2020) suggests SA is one step towards improving presentation skills and develop a team player. However, Pui et al (2020) found students' SA may not represent an awareness or reflection in their learning. A previous study showed that the weaker students could not assess their work effectively and have a tendency to overestimate their abilities (Pui et al, 2020).

The assessment rubric is the key element in the learning SA process. The designed assessment rubric criterion must consist of learning outcomes that students were expected to learn (Chu & Fowler, 2020). Groenendijk, Karpati, and Haanstra (2019) suggested rubrics that contain visual formats are helpful to perform SA. Therefore, for this study, rubrics will be utilized as a method to perform SA in the educational game. In the context of this study, 7W1H (who, what, when, where, why, whose, which, how) rubrics and D.U.M.B.S (Doable, Usable, Marketable, Bankable, Sustainable) rubrics are selected as an assessment guideline in learning SA process (Tan & Yong, 2018). This assessment guide is useful to innovate new product ideas (Yong, 2021). Compared to R&D and firms, this guideline only has simple constructs that can be used by any person in the process of innovating a product (Tan & Yong, 2018). In the past research, D.U.M.B.S has demonstrated to be a useful evaluation tool in a board game to learn how to assess invention

(Tan, 2020). Therefore, both rubrics may be applied in an educational game to learn product idea creation in this study.

***Inventors of Future (IoF)***

The bespoke Android mobile educational game named Inventors of Future (IoF) is developed in this study. The learning objective of this game focuses on creating a product idea through the learning of SA. Player role-plays as a student character from an invention academy to learn product invention. The student character is displayed as an avatar in the game to create a positive emotional experience among the learners (Kogilah, Ahmad & Tan, 2021). The assessment rubric is embedded in IoF as in multiple choices questions with the guided answers as shown in Figure 1. A progress bar and count down timer in the game are the indicators that provide formative feedback to the player, to indicate the progress of completing the game. Meanwhile, a virtual badge reward is a summative feedback that is shown to the player once they have completed the game.

In this game, a problem that is presented to the player according to the game is *"You dislike bring many books to the college. Invent a product that can solve this problem"*. After the problem is presented, the player performs the SA learning using assessment rubric *7W1H* (Tan & Yong, 2018) to identify the root cause of the problem (Figure 1).

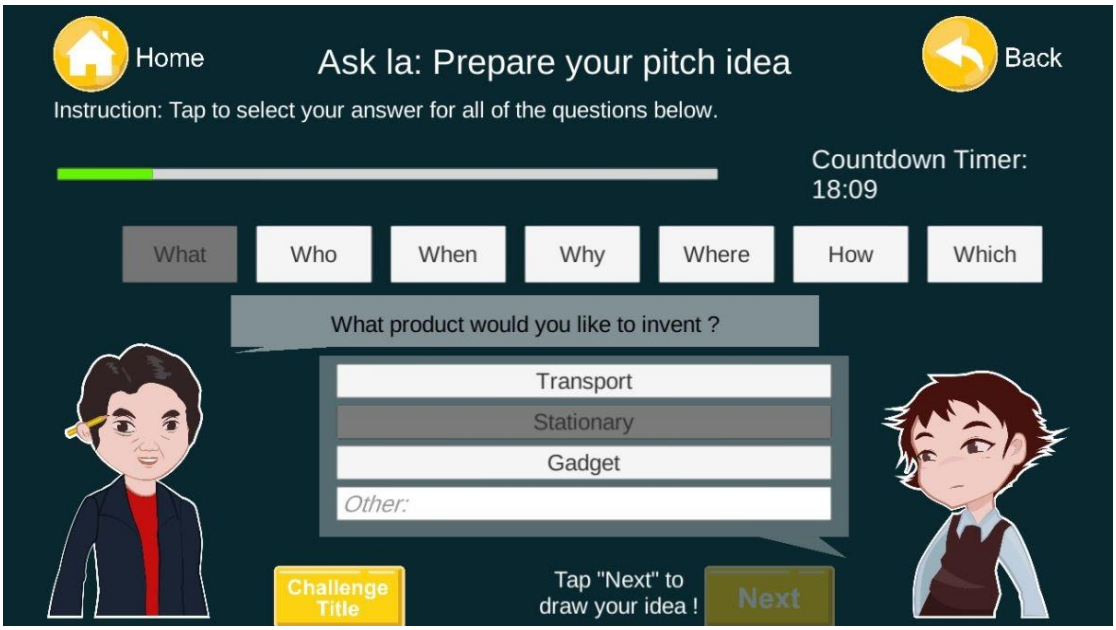


Figure 1 IoF Educational Game with 7W1H Self-assessment Rubric

After the 7W1H is filled, a product idea is generated based on the reflection in 7W1H (Figure 2). The player may start to illustrate the product idea in the IoF once the Next button is selected (Figure 2). Meanwhile, the player may also select the Back button to modify the product idea as well.

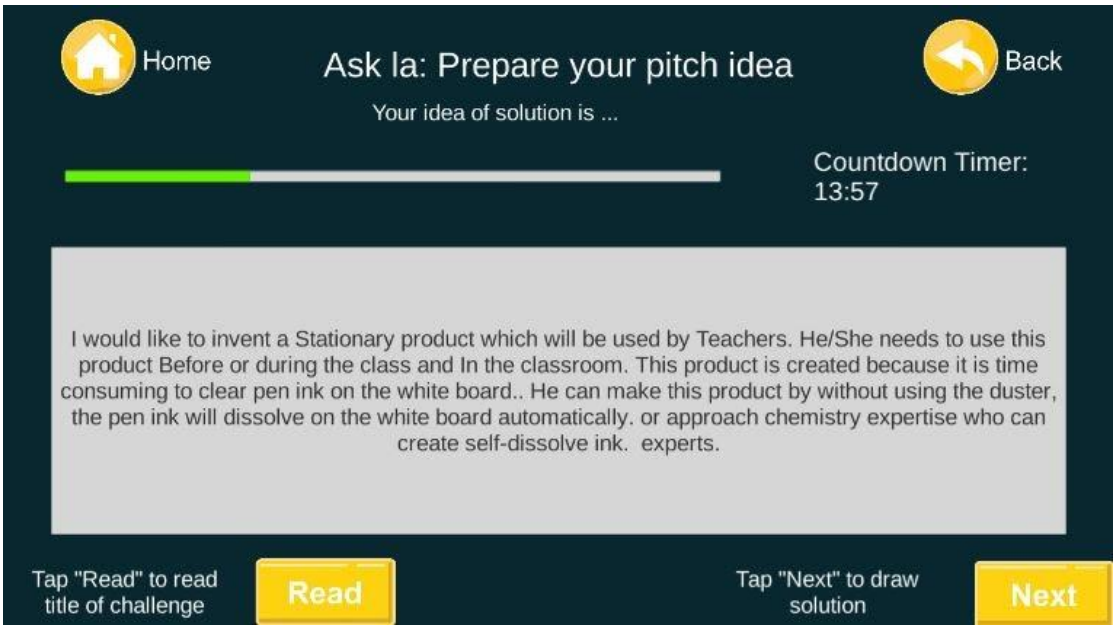


Figure 2 The Product Idea was generated from the 7W1H Self-Assessment Rubric

After the product idea is illustrated, the player applies assessment guideline D.U.M.B.S to assess own product idea quality. This activity is unlocked after the completion of sketching the product's idea. In Figure 3, the player chooses the suitable guided answer to assess whether the product's idea is "sustainable" through "use affordable material for invention", "market overseas" or "sell in varieties of colours or features". The green progress bar increases according to the completeness of assessment in D.U.M.B.S.

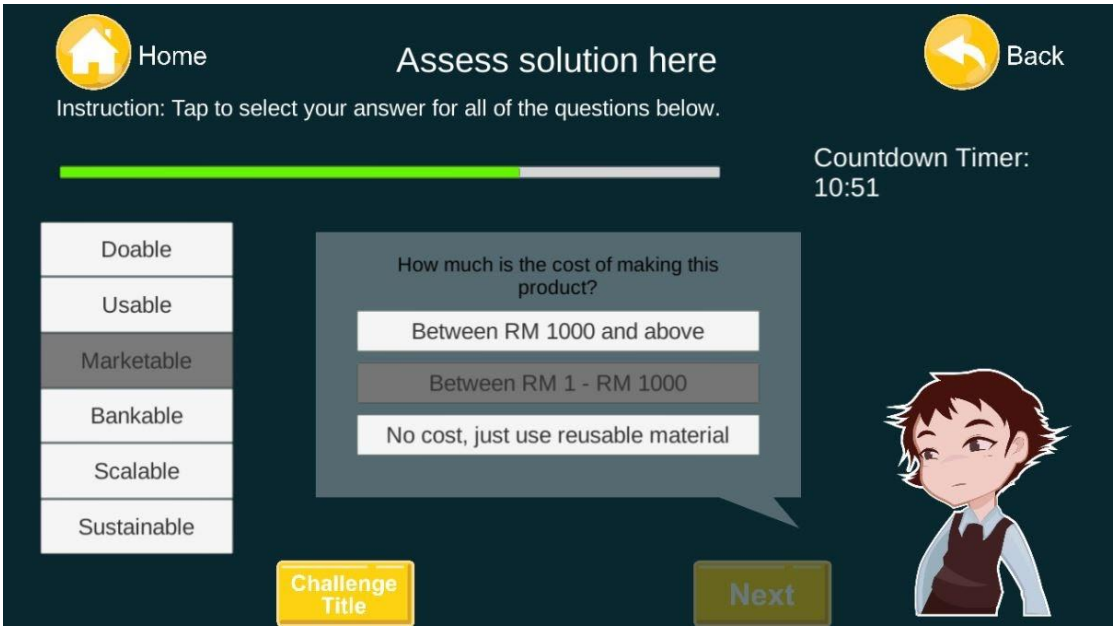


Figure 3 Using D.U.M.B.S Rubric to Assess Solution in Iof Game

Before the product idea is submitted, the player may select the "Assess" button to view the self-assessment list generated from the D.U.M.B.S rubric (Figure 4). In the meantime, the player may also select the Back button to modify the product idea before the submission. The result will be received by the researcher to monitor the participation of the player in completing the game remotely during the study.

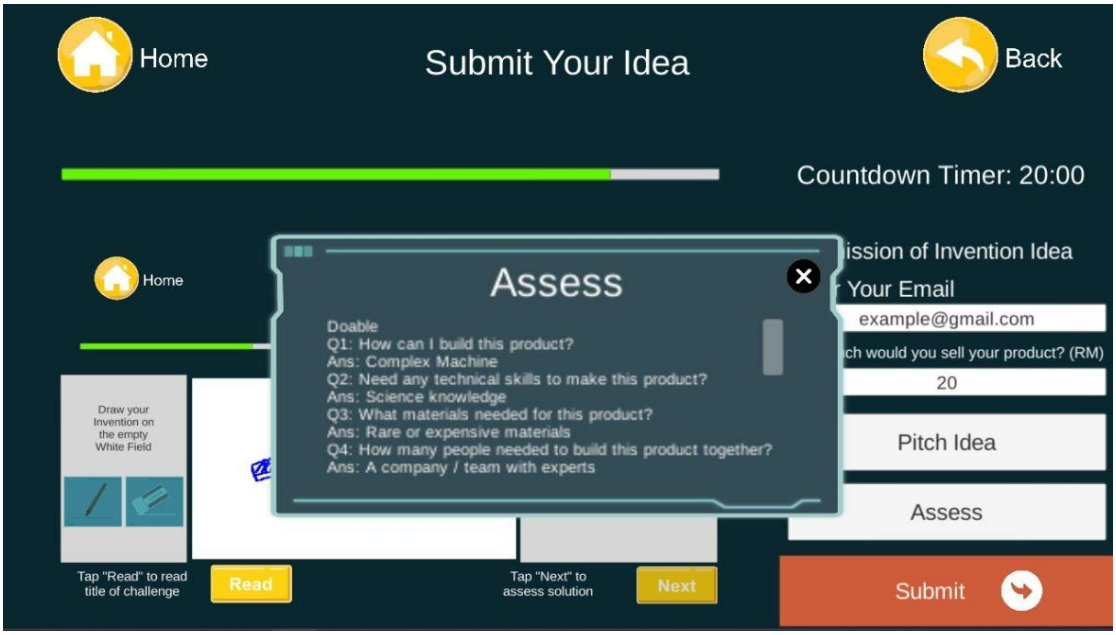


Figure 4 Self-Assessment Checklist Generated for the Player to Perform SA of the Product Idea Quality before the Submission.

## Methodology

This study focuses on whether undergraduate students can gain the knowledge of SA process. The knowledge of SA processes includes demonstrating how to apply assessment criteria, provide feedback on the results of applying criteria in their work. The SA criteria in the educational game IoF are limited to 7W1H and D.U.M.B.S in assessing a product idea. The assessment criteria and educational content IoF have obtained a coefficient of 0.800 in content validity results.

Based on the review of the literature, two research questions are formulated:

i. Does the 7W1H rubric in educational games cause any significant effect on undergraduate students' SA process?
ii. Does the D.U.M.B.S rubric in educational games cause any significant effect on undergraduate students' SA process?

### *Participants*

This study investigates a group of undergraduate students from a university. A total of fifty bachelor degree student participants from year 1 to year 3 were recruited to participate in this study. The age range of the students is between 19 to 26 years old. The average age of students is (M = 21; SD = 1.239). Participants were not invited to participate if they were not from a private institution or have graduated from the study. Demographic data collected from the students include age, gender and degree program that they pursue. There are (N=36) males which are 72% and (N=14) females which are 28% participated in this study. Participants do not have prior experience in receiving this treatment.

### *Instrument*

To study the respondents' SA performance, pre-test and post-test questions are designed and distributed to the participants. The same test was used as a parallel test for pre-test and post-test formats. The pre-test and post-test questions comprised of nine open-ended questions. Participants need to create product ideas to solve the problem based on the scenario given in the question. The questions are divided into three parts a) identify a problem, b) create product idea, c) assess product idea as displayed in Table 1.

Section A "identify the problem" questions are designed to recognize the ability of the participants to identify the problems based on the scenarios in the game. Then, the participants were prompted to list down how they identify the problems using their methods in pre-test or using 7W1H in the post-test. Next,

section B "create product idea" questions are designed to recognize the ability to generate the product idea among participants. Participants describe and illustrate their product idea based on the problems they identified in section A. Lastly, section C "assess product idea" questions are designed to recognize the ability to assess the product idea that they generate in section B. Participants assessed the product idea that they generated using their guidelines in the pre-test or using D.U.M.B.S in the post-test.

Table 1 Pre-test and post-test questions

| Section | Question |
|---|---|
| **A- Identify problem** | 1. Please identify a problem based on the scenario above. |
| | 2. Why do you think the problem you identified above is actually a problem? |
| | 3. List down all the questions you asked yourself when searching for potential solutions of the problem you identified above. |
| **B-Create product idea** | 1. What would be your product idea to the problem you identified above? |
| | 2. Please draw a picture or diagram your product idea here. |
| | 3. Please describe your product idea based on your visualization above. |
| **C-Assess product idea** | 1. Please assess your product idea here. |
| | 2. What checklist and guideline do you refer to when assessing your product idea? |
| | 3. Please describe how you assess your product idea from Section C here. |

The pre and post-test questions had been verified by the content expert from the academic, innovator, and game with high reliability and content validity coefficient of 0.987. The questions were distributed to the participants through Google Form in the online platform, Google Classroom.

***Procedure***

A single pre-test and post-test experimental group were carried out. The participants were recruited publicly through email and mobile phone applications. The research was conducted remotely through a computer equipped with an internet connection. Participants were invited to join the pre-test and post-test through Google Meet. In the beginning, participants were introduced to the researcher, informed of the general objective of the study, and provided a description of the game completion process. The researcher stayed in the Google Meet without helping the participants to complete the experiment.

Once the participants completed the pre-test, a 10 minutes break time was given to rest. Instructions were explained to all participants for downloading and installing the IoF game on a mobile device. The length of time to play IoF was not fixed. However, participants spent approximately 90 to 120 minutes per session, although they started to play IoF at the same time at their own pace. The game ended

once all the participants collected the "Inventor of Future" virtual badge in the game. After the participants finished playing the game, they were given a 10 minutes rest time. Later, they were required to answer a post-test with similar questions to the initial pre-test.

The research design is displayed in Table 2. The difference between O1 and O2 as O1-O2 is assumed to be an experimental (treatment).

Table 2 Single pre-test and post-test design

| **Variables** | **Pre-test** | **Treatment** | **Post-test** |
|---|---|---|---|
| | $O_1$ | X | $O_2$ |
| **Identify problem** | Three questions were completed by the respondents. | The participants completed the 7W1H section of the IoF game. | Three questions were completed by the respondents. |
| **Create product idea** | Three questions were completed by the respondents. | The participants completed the Draw product idea section of the IoF game. | Three questions were completed by the respondents. |
| **Assess product idea** | Three questions were completed by the respondents. | The participants completed the D.U.M.B.S section of the IoF game. | Three questions were completed by the respondents. |

***Measures Used and Data Collected***

A novel product-oriented problem-solving (POPS) instrument is designed in this study to measure the performance of students in the learning SA process. POPS instrument is a relatively new and novel rubric designed based on the framework proposed by the authors in recent studies. (Tan, Tan, Cho, & Ahmad Zamzuri, 2020; Tan, Tan, & Ahmad Zamzuri, in press). The instrument is divided into three sections that identify a problem, create a solution and assessment respectively. Each question consists of a score range between 1 to 5 where a score of 1 is the lowest score and 5 is the highest score in SA skill development. The score is given based on the pre-test and post-test results collected from the experiment. The score is calculated from the instrument is then entered and analyzed in SPSS software. Table 3 displays the instrument built to measure SA performance.

Table 3 POPS Instrument to measure the SA performance

| Question / Marks | 1 | 2 | 3 | 4 | 5 | Total |
|---|---|---|---|---|---|---|
| **Section - Identify problem** | | | | | | |
| 1 | Not able to explain a problem. | Able to partially explain a problem. | Able to explain most of the problem accurately. | Able to explain most of the problem accurately and clearly. | Able to explain a problem very clearly, accurately with underlying issues. | |
| 2 | Not able to organise and analyse gathered information and fails to define the factors that contribute to the problem or explain the root of the problem. | Able to in organise and analyse gathered information but does not describe the factors that contribute to the problem nor explains the root of the problem. | Able to organise and analyse gathered information, briefly describe some factors that contribute to the problem or briefly explain the possible roots of the problem. | Able to organise and analyse gather information, clearly describe some factors that contribute to the problem or explain the possible roots of the problem. | Able to organise and analyse gathered information, clearly describe most of the factors that contribute to the problem or explain the root of the problem. | |
| 3 | Not able to apply the 7W1H questioning technique to identify the problem. | Able to apply the 7W1H questioning technique partially to explain a problem. | Able to apply the 7W1H questioning partially technique to explain a problem clearly. | Able to apply most of the 7W1H questioning technique to explain a problem clearly with accuracy. | Able to apply most of the 7W1H questioning technique to explain a problem clearly with accuracy, and detail. | |
| **Section - Create a product idea** | | | | | | |
| 1 | Not able to solve problems or offer alternative solutions. | Able to solve problems partially or offer alternative solutions. | Able to solve problems or provide alternative solutions clearly. | Able to solve problems or provide alternative solutions clearly with accuracy. | Able to solve problems or provide alternative solutions clearly with accuracy, and detail. | |
| 2 | Unable to generate a simple product's idea but not relevant or appropriate. | Able to generate a simple product's idea but not relevant or appropriate. | Able to generate a simple product's idea that is relevant and appropriate, has few similarities with the old | Able to generate a product's idea that has the potential to improve the situation or solve the problem. | Able to generate a product's idea that has the potential to improve the situation or solve the problem, and | |

| | | | | | |
|---|---|---|---|---|---|
| | | | product's ideas/solution. | | novel in nature. |
| 3 | Not able to describe any new product's idea. | Able to describe a simple product's idea but not relevant or appropriate with the illustration. | Able to describe a simple product's idea but has few differences with the illustration. | Able to describe a product's idea as illustrated but lack accuracy and details. | Able to describe a product's idea as illustrated clearly with accuracy, and detail. |
| **Section - Assess a product idea** | | | | | |
| 1 | Not able to assess own solution. | Able to assess own solution partially. | Able to assess own solution clearly. | Able to assess own solution clearly with accuracy. | Able to assess solutions clearly with accuracy, and detail. |
| 2 | Not able to select appropriate guidelines to assess a solution. | Able to select appropriate guidelines to assess solution but not relevant or appropriate. | Able to provide a brief guideline to assess solution using D.U.M.B.S rubric clearly. | Able to provide a brief guideline to assess solution using D.U.M.B.S rubric clearly with accuracy. | Able to provide a brief guideline to assess solution using D.U.M.B.S rubric clearly with accuracy and detail. |
| 3 | Not able to apply D.U.M.B.S rubric for assessing solution. | Able to apply guidelines to assess solutions but not relevant or appropriate. | Able to apply D.U.M.B.S rubric partially to assess solution clearly. | Able to apply D.U.M.B.S rubric to assess solution clearly with accuracy. | Able to apply D.U.M.B.S rubric to assess solution clearly with accuracy and detail. |

## Results

The results presented here focus on the usefulness of the educational game for learning the SA process that was included in (Tan et al, 2020). Hence, no control group was applied in this study. A normality test was carried out on the pre-test to determine the normality of the data. The test result in Table 4 shows that the Kolmogorov-Smirnov significant value is (p=.088) which is greater than 0.05. Therefore, the data of the pre-test score is normally distributed for the sample data collected from the students.

Table 4 Normality test

| | Kolmogorov-Smirnov[a] | | | Shapiro-Wilk | | |
|---|---|---|---|---|---|---|
| | Statistic | df | Sig. | Statistic | df | Sig. |
| Total Pretest Score | .116 | 50 | .088 | .964 | 50 | .131 |

Therefore, a paired sample T-test was conducted to compare the SA skill before after playing the IoF game. Table 5 displays the difference between pre-test and post-test scores for each section including identifying problems, generate a solution and assess the solution. The score was analyzed in an analysis of variance with the students as the independent variable. Section A received an average score (M =-3.24, SD = 3.18), Section B obtained (M=-3.72, SD =3.57), and Section C received (M=-3.72, SD=4.31).

There was a statistically significant difference between total pre-test score and post-test score with the mean (M=10.68; SD =8.52), t (49) = -8.87, p < .001 (seen in Table 5). The effect size for the total score (d =1.25) was found to exceed Cohen's (1988) convention for a large effect (d = .80).

Table 5 Paired sample T-test to show the results of SA performance before and after playing the IoF for all students

| | *Paired Differences* | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | *95% Confidence Interval of the Difference* | | | | |
| | *M* | *SE* | *SEM* | *Lower* | *Upper* | *t* | *df* | *p* |
| Section A: Identify problem Pre-test marks for the whole section – Post-test marks for the whole section | -3.24000 | 3.18517 | .45045 | -4.14522 | -2.33478 | -7.193 | 49 | .001 |
| Section B: Create product idea Pre-test marks for the whole section – Post-test marks for the whole section | -3.72000 | 3.56880 | .50470 | -4.73424 | -2.70576 | -7.371 | 49 | .001 |
| Section C: Assess product idea Pre-test score for the whole section – Post-test marks for the whole section | -3.72000 | 4.31438 | .61015 | -4.94613 | -2.49387 | -6.097 | 49 | .001 |
| Total Pre-test Score - Total Post-test Score | -10.68000 | 8.51754 | 1.20456 | -13.10066 | -8.25934 | -8.866 | 49 | .001 |

***Research Question 1***

*Does the 7W1H rubric in an educational game cause any significant effect on undergraduate students' SA process?*

In section A question 1, participants were able to identify a problem that they faced in their daily life now. One of the participants responded, "Not having enough exercise daily." In the same section question 2, the same participant further analyzed the root cause of the problem with the response "For most healthy adults, the Department of Health and Human Services recommends aerobic activity. We are advised to get at least 150 minutes of moderate aerobic activity or 75 minutes of vigorous aerobic activity a week, or a combination of moderate and vigorous activity.". Lastly the same participant self-assessed the problem by using the 7W1H rubric with the response "What kind of product can I come up with to counter this issue? Who is able to use this product/solution that I have come up with? When and where can this product be used at? How can I make this product or solution work? Which area of expertise do I need in order to achieve this goal of mine? Whose idea is this initially?" Based on the response, the participant is in the process of thinking about the possible product or solution that he will make to solve the lack of exercise problem. For instance, before generating a product idea or solution, the participant analyzed who has made this product before and which knowledge that he should expertise in making this product.

Meanwhile, Section B and section C obtained the same mean score and were higher than section A. From the data in section B, it is evident that some of the product ideas are likely to improve the current condition or solve the problem identified in section A. In Section B question 1, one of the participants proposes a product idea to solve his daily house chores problem. The participant responded "[I would like to invent a] robot to perform vacuum and mopping at the same time." In the same section question 2, the participant was able to sketch a product idea to describe his solution as displayed in Figure 2. In question 3, the participant described how this product idea can be operated in detail. "When the machine moves, it will vacuum all the dust and dirt on its position before mopping it".


Figure 2 An Illustration of Product Idea Sketch by the Participant

***Research Question 2***

*Does the D.U.M.B.S rubric in an educational game cause any significant effect on undergraduate students' SA process?*

In section C, many of the participants applied the D.U.M.B.S rubric successfully to assess the product idea that has generated in Section B in the post-test. In section 3 question 1, participants were able to assess their product. For example, one of the participants responded "It can be done using cheap materials, can be used anytime by anyone, and uses affordable materials, by providing multiple design variations." There are some participants who assess their solution generally by highlighting the pros and cons of the idea. For example, "The product is easily customizable to meet individual needs but it requires access to support and permission to the linked devices." Meanwhile, for question 2, participants used the D.U.M.B.S as the guideline to assess their idea. For instance, "I refer to the D.U.M.B.S when having the solution because we need to know who is the target user and how we going to solve the problem in order to come out the solution. After that, we also need to determine the product is doable for implementation and useable for this problem." However, there are 15 participants who still prefer not to use any guidelines, rather use 7W1H or refer to the search engine and video tutorial from the website to assess their idea. In question 3, participants generated a SA list to assess their product idea quality. Likewise, "Doable: Should be programmed easily by any IoT technician. Usable: It should be usable in daily life, especially before bed. Marketable: It should be able to publish to the public, especially to the people who have the problem of lack of sleep. Bankable: It only needs small funding to accomplish the product Sustainable: It should be sustainable, the material used depends on the lamp and phone the users using. Scalable: Everyone can use this product". There is one participant who uses personal instinct or imagination when assessing the product when assessing the idea. The participant responded "this is my only one image in my mind. I am not sure whether this water machine is in the market now."

## Discussion

The educational game IoF has successfully demonstrated how to apply assessment criteria and provide feedback to the learners.

### *Research Question 1*

Based on the findings, participants have applied 7W1H to generate a product idea through the educational game. The data revealed that the mean score for Section A 12.9% is lower compared to Section B and Section C. The qualitative data from the pre-test has further discovered that the students have known to use the Six Honest Questions from Rudyard Kipling (Stenros, 2013) in the pre-test to perform SA when identifying a problem. However, this study did not examine whether the player is able to pitch the product idea verbally caused by the gameplay.

### *Research Question 2*

As with the results of the second research question, understanding the D.U.M.B.S rubric was identified as having the more significant difference. From the post-test results, 34 participants successfully generated the SA checklist based on the D.U.M.B.S criteria to assess the quality of their own product idea. The rest of the students do not use the D.U.M.B.S rubric. This could be due to unfamiliarity with the new self-assessment rubric or lack of practice using this rubric.

From the study, it was found that all the post-test sections showed significant improvement. The finding from the result is consistent with the previous studies that students may understand the problem and learnt how to solve the problem through SA (OECD, 2019). The result from the post-test score is also aligned with the study that students who received game-based rubric feedback improved their performance in learning (Chu & Fowler, 2020).

The outcome of this study seems to be unaligned with Pui et al (2020) who indicated that students' SA may not represent an awareness of their learning progress. Students focused on what teachers wanted in the rubric criteria compared to developing CT skill (Pui et al, 2020). However, the study focused predominantly on the subject taught traditional learning environment whereas this study is conducted in a DGBL environment. This finding indicated that the process of learning SA influence by the learning environment, the familiarity of the subject the clarity of the assessment rubric. In terms of similarities between (Pui et al, 2020) and the current study, both utilized the SA process to develop CT skill among

the students. This difference could lead to promising future studies to apply the SA rubric in other games that teach knowledge from a different discipline.

The limitations of the study need to be highlighted. Although the test has shown significant improvement in SA after the game treatment, it is determined that the test may be repeated to analyze the long-lasting effect of the CT (Roodt & Ryklief, 2019). This study is focused on investigating the effectiveness of the game to learn self-assessment. Therefore, no post retention test is further conducted.

Future research of this study should explore a larger sample size in a face-to-face environment to avoid technical issues. Also, since the aim of this study is to examine how DGBL can be applied in a private university context of Malaysia, there might be a limitation on how the results and findings may be generalized to non-private university contexts. Nevertheless, the same study may be conducted with students from any public university for the sake of comparison in the future. Furthermore, this study may seek to identify different universities within the country and in different countries.

## Conclusion

SA is a form of self-reflection process that makes learners aware of the subject that they are learning. This project has successfully embedded the SA process with the game (Andrade, 2019). By understanding how the SA process works, students may learn from their mistakes because the mistakes are a crucial part of the learning method (Chu & Fowler, 2020). Besides learning the SA process, the post-test results revealed that the students have increased their awareness of assessing the quality of their own work to generate a solution. By practising SA in product idea creation for the long term, future graduates may prepare themselves for the emerging jobs in the industry (OECD, 2019).

In conclusion, the game-based learning approach has successfully gain students' knowledge in understanding how the SA process works. In future, educators may adopt the same approach to design a similar educational game to develop CT skills in different knowledge disciplines.

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