The Usability of Digital Game-based Learning for Low Carbon Awareness: Heuristic Evaluation

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***Abstract*—Digital Game-based Learning (DGBL) that attracts many practitioners to engage students in promoting low carbon awareness has been understudied. The evaluation phase plays a crucial part in determining the usability of the learning material. This study aims to identify the usability of DGBL which consists of four components: game usability (GU), mobility (MO), playability (P), and learning contents (LC) from the perspective of targeted end-user using heuristic evaluation. This study will also provide recommendations to help improve the quality of any related DGBL for novice designers or practitioners. A prototype of DGBL was developed which aims to promote low carbon awareness by learning about fuel cell. The study was designed in two phases, which are (1) developing the heuristic evaluation instrument validated by experts and (2) playtesting to identify the issues of usability in DGBL via heuristic evaluation by targeted end-users, which are forty-six selected students aged fourteen years old. Hence, it shows that the DGBL prototype developed for fuel cell learning has succeeded in achieving learning objectives while promoting low carbon awareness.**

Keywords*—Heuristic evaluation; digital game-based learning; usability; low carbon awareness

I. Introduction

Digital game-based learning (DGBL) refers to the combination of digital games and educational content because it can create an interesting yet challenging learning environment [1]. The problem with DGBL is that it is complex and often involves multiple components, such as game mechanics, instructional design, and user interfaces. As a result, identifying and addressing usability issues can be challenging [2,3]. Furthermore, DGBL may be used by learners with varying levels of technical proficiency and familiarity with gaming conventions, which can further complicate the usability evaluation process. For example, a game mechanic that is intuitive to one learner may be confusing to another.

Usability can be done in a variety of ways, including thinking aloud, cognitive walkthroughs, laboratory usability testing, questionnaires, and guideline reviews [4]. Heuristics evaluation is one usability evaluation that identifies usability problems based on usability principles or heuristics [5]. However, existing heuristics proved to be very generic and some were not validated [6]. Therefore, the issue for the usability of DGBL using heuristic evaluation is how to effectively apply heuristic evaluation methods to identify and address usability issues in DGBL systems, taking into account the complexity of the system and the diversity of user profiles. This will enable designers to create more effective and engaging DGBL systems that support learning outcomes.

Digital game-based learning (DGBL) has become a popular choice for younger learners as it can enhance motivation and active learning [7, 8]. DGBL's flexibility and accessibility make it an effective tool for enhancing motivation and learning, which has prompted researchers to investigate its advantages [9]. The use of attractive features such as audio, graphics, and animations in DGBL has proven to be effective in motivating students, especially for complex subjects like science or chemistry [10].

DGBL can also be a powerful strategy for achieving the goals of environmental awareness education, which aims to change the younger generation's mindset toward preserving nature [11,12]. Environmental issues, such as carbon emissions, have caused a significant increase in climate change and have impacted human health due to high levels of industrialization and urbanization [13]. A case study on the impact of a DGBL called “2020 Energy” was carried out that focuses on Spanish and American teenagers aged 12 years old and above aimed to explore issues of climate change [14]. The findings show that the game has a positive influence on the student’s intention towards low-carbon activities which is related to the attitudes toward environmental awareness.

Low-carbon technologies such as solar, wind, and fuel cell have increasingly become a priority study in promoting environmental sustainability. Fuel cell technology, particularly which uses hydrogen as fuel, has the potential for zero-carbon emission. This study used a DGBL prototype that has been developed to increase the awareness of secondary students towards low carbon emissions by focusing on fuel cell technology. This study aims to (1) develop a heuristic evaluation using a set of questionnaires validated by experts and (2) identify the issues of usability in DGBL via heuristic evaluation through playtesting by targeted end-users.

In conclusion, DGBL presents challenges in evaluating its usability due to its complexity and diverse user profiles. Heuristic evaluation is a potential method for addressing usability issues in DGBL systems. DGBL is an effective tool for enhancing motivation and learning for younger learners, and it can play a crucial role in environmental awareness education. This study aims to address usability issues in a DGBL prototype focused on fuel cell technology by developing questionnaires validated by experts and applying

heuristic evaluation through playtesting by targeted end-users. By addressing usability issues, designers can create more effective and engaging DGBL systems that support learning outcomes and contribute to environmental sustainability.

II. Literature Review

In this section, related work on the usability of DGBL and Heuristic evaluation will be discussed as the key themes of this study.

A. Usability of DGBL

A good DGBL is capable of encouraging players to learn and enjoy learning content while keeping the players motivated throughout the gameplay [15]. However, to understand the whole gameplay experience, the usability of the DGBL cannot be disregarded. Usability proposes basic requirements for the functionality of an object in use [16] and, in this context, refers to the capability of a DGBL to be understood, learned, operated, and attractive to users when used to achieve the determined goals. Moreover, it can be evaluated through the interface review and user experience using heuristic evaluation [17].

Measuring usability is crucial for any DGBL application, especially in the early stages of development [4, 18]. Several studies on the design of heuristic questionnaires have evaluated usability issues in DGBL areas. One study suggested that the intended end-users may contribute by involving them as co-designers either in the development or evaluation stage [19] as this helps ensure the effectiveness of DGBL. All essential stakeholders in [20], including language experts and targeted students, were involved in the study of the usability of DGBL for language through heuristics and think-aloud approaches. A study that involved end-users in their heuristic evaluation also shows that it has improved the quality of their electronic health record (EHR) [21]. By involving end-users in the usability phase, designers and developers can create a DGBL that is designed with the user in mind. This will help develop a user-centered design that meets the needs and preferences of the target audience.

B. Heuristic Evaluation

Heuristic evaluation was introduced by Nielsen and Molich [22] and consists of usability components to be evaluated in any product such as application software, digital games, or mobile applications but not specifically for DGBL. However, it has become widely researched and has been applied across varieties of disciplines including educational technology. Defining specific domains of heuristics for evaluating the usability of DGBL by upgrading an existing domain of specific heuristics is cost-effective [4]. A set of systematic procedures that include usability evaluation methods that can easily detect usability problems within a limited time frame should also be established [17].

While heuristic evaluation is a useful tool for evaluating the usability of DGBL, it still has some limitations. The number of heuristics used may not cover all aspects of usability in the context of DGBL and more comprehensive heuristics that are specifically tailored to evaluate the usability of DGBL need to be developed. Furthermore, heuristic evaluation is typically conducted in a controlled laboratory setting, which may not accurately reflect the real-world context in which the DGBL will be used [16]. These limitations can restrain the generalizability of evaluation results and may not fully capture the complexities of user interactions with the DGBL in real-world settings.

Heuristic evaluation involving targeted end users is a usability evaluation approach that involves the direct participation of end users in the evaluation process. This approach is based on the premise that end users are the best judges of usability and can provide more meaningful feedback to improve DGBL [6] in terms of the DGBL interface, navigation, game mechanics, and overall usability [23]. The advantage of involving targeted end users in heuristic evaluation is that they can provide valuable insights into the usability of DGBL from the perspective of the intended audience. By incorporating end user's feedback in the evaluation process, the DGBL can be designed to meet their specific needs and preferences leading to a more effective and engaging learning experience.

III. Methodology

In this approach, end users were given a set of heuristics or usability principles and identified any usability issues based on these heuristics using the DGBL prototype. All the items proposed for this usability testing use Bahasa Malaysia (the Malay language), which is the national language of the targeted end-users, as the mediated language to make it easier for them to evaluate the usability of the DGBL.

A. Heuristic Evaluation Components

A review of pertinent literature served as the first step toward identifying the required data. In this context, the heuristic evaluation consists of four components that cover all the usability aspects in DGBL, which are Game Usability (GU), Mobility (MO), Playability (PL), and Learning Content (LC) adapted from [24].

The GU component focuses on the interaction between the game design interface and the player's responses through the gameplay. The MO component represents how the player can easily enter the game world without any technical difficulties. The PL component describes the gameplay of the DGBL and includes the player's experience throughout the gameplay session that involves interactions between the players with the game mechanics and rules. The LC component concentrates on the learning content incorporated in the DGBL as the players should understand and acknowledge the specific learning contents when playing the DGBL prototype.

The study was designed in two phases that consist of (1) developing heuristic evaluation using a set of questionnaires validated by experts and (2) playtesting to identify the issues of usability in DGBL via heuristic evaluation by targeted end-user which are forty-six selected students aged fourteen years old. All research processes and procedures for both parts of this study were adapted from [17] as shown in Fig. 1 because it recommends specific and clear instruction from developing heuristic, validation processes by experts until usability testing using the developed heuristic.

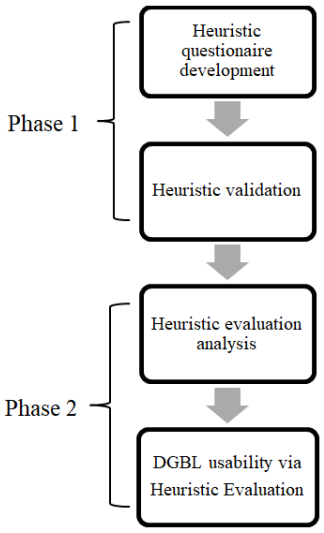

Fig. 1. Heuristic evaluation development process.

B. Phase 1

The first phase consists of developing and validating the heuristic evaluation. A questionnaire was developed that comprises 32 items based on the four components that specifically measure the Game Usability, Mobility, Playability, and Learning content. The questionnaire was rated using a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree) as recommended by [25] to allow respondents to indicate their level of agreement or disagreement with the items stated.

Next, all the items underwent a series of checking and review from a panel of experts to ensure the validity from the perspective of experts [26]. The expert panel review started with the sending of invitations via e-mail to the identified experts: three authorities from DGBL experts, a game developer, and a schoolteacher specializing in science secondary subject as shown in Table I. These experts, who did not take part in the design or the development of the DGBL, were given a set of heuristic evaluation questionnaires and a set of content validity instruments containing items adapted from [27]. Then, the findings from the panel expert review were calculated to determine the content validity level by dividing the total expert score (x) by the total maximum score (y) and then multiplying by 100%. These items for validation include the checking of the content for correctness in each item in the heuristic evaluation and verifying that the language is well chosen for the intended population.

TABLE I. EXPERTS PROFILE FOR HEURISTIC VALIDATION

Expert	Position	Academic qualification	Affiliation	Years of experiences
A	Associate Professor	PhD	School of Creative Industry Management & Performing Arts, Universiti Utara Malaysia (UUM)	21
B	Game Developer	Bachelor Degree	Nusantara	10
C	Practitioner	Bachelor Degree	SMK Seri Indah	15

C. Phase 2

The second phase involved conducting usability testing on forty-six students aged fourteen years old from selected schools in one state in Malaysia (Selangor) via the final heuristic evaluation. They are selected using purposive sampling with characteristics similar to the target end users. The characteristics of the students include the following: (1) already learned the topic of "air" in science subject taught in secondary school, (2) exhibit extremely high interest in playing mobile games, and (3) with prior experience in playing a game-based learning application at least once.

The Standard Curriculum for Secondary School (KSSM) is a curriculum designed by the Ministry of Education Malaysia for secondary students' comprehensive and integrated science education. Topics on "air" covers the various types of environmental pollution, including air, water, and soil pollution, and the impacts of pollution on human health and the environment [28]. All the students that have been selected participated in a playtesting session using the DGBL prototype to gather feedback on their experience to improve the gameplay, identify any usability issues, and evaluate the overall user experience.

There is no specific playtesting period as they can freely take their time to test and explore the DGBL, then answer the heuristic evaluation through a set of questionnaires given after the playtesting session. This is to ensure that the playtesting session happens in a natural setting without having any formal circumstances [24]. Therefore, evaluating aspects such as game usability, mobility, playability and learning content of the DGBL can be determined by the player's feedback based on their experience.

IV. RESULTS

A. Heuristic Validation Result

The heuristic evaluation applied in the evaluation process by targeted end users is shown in Table II. The GU component was extended from having 10 items [24] to 14 items based on Expert A's suggestion to specify the component in more detail.

The LC component was also extended from 4 items to 5 items [24], where LC5 focuses on language as one of the components and aims to evaluate the language used to ascertain whether it is understandable or not by the targeted end-user. This is a very important aspect of usability testing that can show the educational content's relevance in the DGBL. The content validity scores from the expert panel for all the items in the questionnaire obtained an average of 96.7%, as shown in Table III. The content validity level is considered high when the value is more than 70% which indicates that the items are acceptable [27, 29].

B. Heuristic Evaluation Analysis

Table IV provides the results of the heuristic evaluation. The first component of the evaluation is GU. As seen in Fig. 2, mean = 4.079 (SD = 0.951) indicates all items, except for items 10, 11, and 13 have high mean scores between 4.0 to 4.3. The high value of GU shows that usability in a digital application gives a big impact on the interaction between the interface and the interaction of players throughout the gameplay. Overall, the

respondents are satisfied with the game's visual graphics, game layout, and suitable audio used in this DGBL. However, respondents reported that there was an issue with using the game controls.

TABLE II. HEURISTIC COMPONENTS

Tag	Game Usability Component
GU1	Interesting game visual graphic
GU2	Suitable audio with the game
GU3	The Screen layout is visually pleasing
GU4	The interface is used for their purposes
GU5	The Navigation menu is easy to use
GU6	Control keys are consistent
GU7	Control keys follow standard conventions
GU8	The Interactive features provided are sufficient
GU9	Game controls are flexible
GU10	Game controls are convenient
GU11	The game gives feedback on the player's actions
GU12	The player cannot make irreversible errors
GU13	The player does not have to memorize things unnecessarily
GU14	The game contains help
Tag	**Mobility Component**
MO1	The game and play sessions can be started quickly
MO2	The game accommodates with surroundings
MO3	Interruptions are handled reasonably
Tag	**Playability Component**
PL1	The game provides clear goals
PL2	The player sees the score progress in the game
PL3	The players are rewarded in the game
PL4	The player is in control of the game
PL5	Challenges in the game are in balance
PL6	The game is fun to be repeated
PL7	The game story is meaningful
PL8	There are no boring tasks
PL9	The game does not stagnate
PL10	The gameplay is consistent
Tag	**Learning Content Component**
LC1	The content can be learned easily
LC2	The game provides learning content
LC3	The learning objective from the game is achieved
LC4	The content is understandable
LC5	The language used is understandable

TABLE III. CONTENT VALIDITY SCORES

Expert	Total score	Content validity
A	10	100%
B	9	90%
C	10	100%
	Mean	96.7%

TABLE IV. MEAN AND STANDARD DEVIATION OF HEURISTIC COMPONENTS

Statistic	Heuristic Components			
	GU	***MO***	***PL***	***LC***
Mean	4.079	4.036	4.107	4.304
SD	0.951	1.017	0.925	0.782

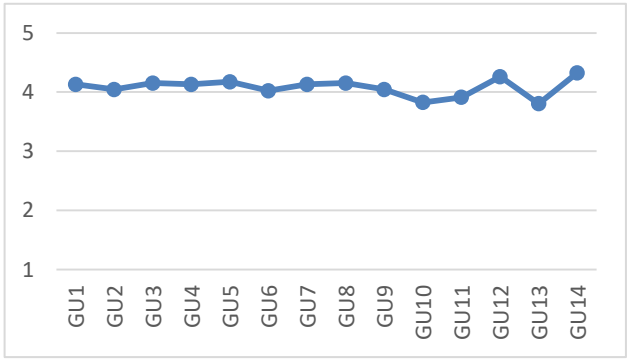

Fig. 2. Average score of game usability.

Respondents agreed that the MO of this DGBL prototype is high with an overall mean = 4.036 (SD = 1.017) as shown in Fig. 3. This indicates that the player can easily enter the game world without any technical difficulty.

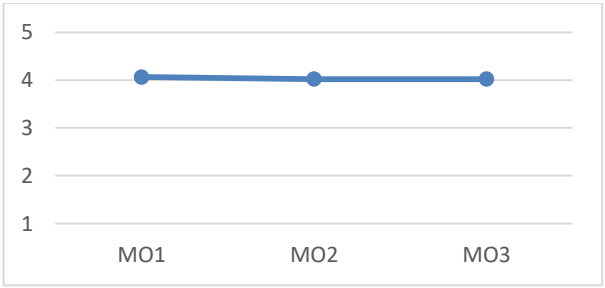

Fig. 3. Average score of mobility.

For the PL component, the relatively high mean = 4.107 (SD = 0.925) in Fig. 4 indicates that the respondents have a good experience throughout the gameplay session that involved interactions between the players with the game mechanics and the game rules. However, some respondents found that the task in bonus round is tedious due to repetition (item PL8 with mean = 3.956).

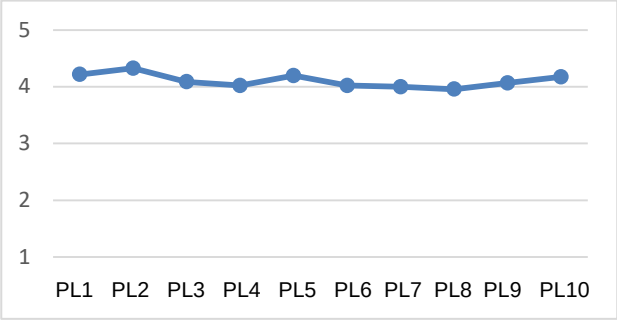

Fig. 4. Average score of playability.

For the LC components, the result in Fig. 5 shows the highest mean = 4.304 (SD = 0.782) compared to the other heuristic components. The majority of the respondents agreed that they can easily understand and acknowledge the specific fuel cell learning content when playing the DGBL prototype.

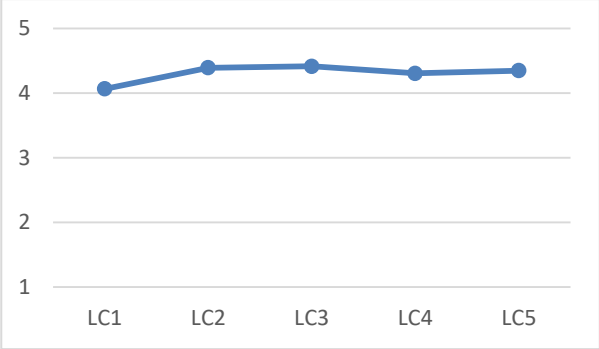

Fig. 5. Average score of learning content.

V. Discussion

The expert panel's review findings verified that the language used was appropriate for the intended audience and validated the content's accuracy in each item's heuristic evaluation. The experts also agreed that all the items given are appropriate and can be used to test the usability of DGBL based on the four components stated.

According to the GU component results, the user interface, gaming controls, and user experience all have an impact on how the game plays out. Due to bugs found in the game controls, there are instances where gameplay is not running smoothly. These bugs need to be fixed to avoid the player feeling burdened and dissatisfied throughout the gameplay [23]. Game control is important in DGBL because it helps to create a structured learning experience that is effective in achieving the desired learning outcomes. Game control can also help to increase learner engagement and motivation. By carefully controlling the game mechanics, DGBL designers can create a sense of flow, where the player is completely absorbed in the game and loses track of time [30].

Finding form MO components emphasizes the importance of mobility in enhancing the overall user experience of the game. If the game is difficult to access or requires technical expertise, it can discourage players from engaging with it [24]. On the other hand, if the game is easy to access and play, players are more likely to enjoy the game and be motivated to continue playing. This highlights the need for designers to prioritize accessibility and ease of use in game development to ensure a positive user experience.

The playability results showed that the respondents enjoyed their gaming session. However, several responders thought the bonus round work was boring because of the repetition. In the bonus stage, as shown in Fig. 6, the players need to drag Platinum, Hydrogen, and Oxygen molecules into the fuel cell. The task focuses on the correct locations of Platinum, Hydrogen, and Oxygen molecules in the fuel cell parts such as electrodes, Anode, or Cathode. The task was designed to be repeated three times in each phase of the bonus stage, where which will help the player to understand and remember the basic concept of the fuel cell. This was also supported by studies where repetitive tasks can help in memorizing as well as increasing understanding of basic knowledge [31, 32]. In order to keep player interest throughout the games, this task needs to be improved, for as by raising the level of difficulty in each bonus stage.

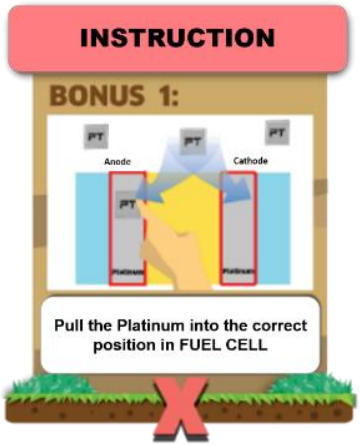

Fig. 6. Screenshot of the bonus stage.

Most of the participants in the survey acknowledged that, after using the DGBL prototype, they could quickly comprehend and acknowledge the particular fuel cell learning content. This is because the learning content itself has gone through a validation process from experts and a focus group test in the design phase of the DGBL. The learning content is also aligned with the players' existing knowledge as supported in Constructivism theory, e.g., the shape of Hydrogen molecules was designed by referring to their KSSM science textbooks used in standard schools (Fig. 7). This concern is supported by other studies where it is important to understand the basic knowledge to help in promoting environmental awareness [12, 33].

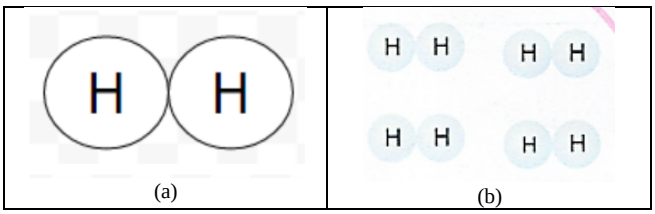

Fig. 7. (a) Shape of Hydrogen molecules in the DGBL prototype, (b) Shape of Hydrogen molecules in KSSM science textbooks.

The findings of this study can help improve the design and usability of DGBLs that can better promote low carbon awareness. By developing a set of questionnaires validated by experts and involving targeted end-users in playtesting, DGBL developers can obtain more meaningful feedback on the usability of their products. This can help identify and address usability issues early in the development process, leading to more effective and engaging DGBLs. While each study may focus on different aspects of usability, such as navigation, interaction design, or visual design, the use of heuristic evaluation allows researchers to identify potential issues and make recommendations for improvements. Additionally, the development of specific heuristics for evaluating the usability of DGBLs can provide a cost-effective and efficient way to detect usability problems within a limited time frame.

VI. Conclusion and Future Work

Heuristic evaluation is an effective method for evaluating the usability of DGBL as this approach involves directly targeting the end user by applying a set of heuristics or guidelines to identify potential usability issues in the DGBL. This ensures that the game is more user-friendly, intuitive, and engaging for the targeted user group. By involving end users in the evaluation process, designers can better understand their needs and preferences, leading to more meaningful improvements to the game.

The heuristic evaluation in this work was adapted and extended for some items to specify the components accordingly. The findings may benefit any novice designer or practitioner in evaluating DGBL usability as this study provides a systematic guideline that can easily be followed. However, researchers and designers need to continue exploring new methods and approach for evaluating DGBL usability, particularly in the context of emerging technologies and changing user needs, to further improve the design and implementation of DGBL systems.

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