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Design and Development of Fuel Cell Learning through Digital Game-Based Learning to Raise Awareness of Low Carbon Emissions

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Abstract*: *Fuel cell technology is currently being widely promoted to the general public as one of the most promising sustainable energy sources that can contribute to reducing carbon emissions. Considering this, digital game-based learning (DGBL) was created to educate the general public about fuel cells, with a focus on the younger generation such as secondary school students. This paper discusses the design and development phases, during which instructional design and game elements are integrated into producing a fuel cell DGBL prototype. Five-panel experts examine the learning content to make sure it is valid in the design phase. Next, two testing cycles were conducted on the developed fuel cell DGBL prototype: one internal group test and one focused group test including five 14-year-old students from a chosen secondary school. During the testing, three different approaches to collecting data were used: written surveys, in-person interviews, and observation. The outcome presents useful information that may be applied to enhance the game's efficacy and playability. Therefore, any novice designer or practitioner can benefit from these findings' helpful advice while developing an effective DGBL.

Keywords*: *Fuel Cell Learning, Low-Carbon Awareness, Digital Game-Based Learning, Secondary Education.

I. INTRODUCTION

In recent years, global warming and climate changes have been caused by an annual increase in carbon emissions from transportation, industry, and residential use. This situation has driven the promotion of low-carbon technology such as solar power, wind turbines, hydropower, and fuel cells to reduce the impact on environmental changes [1]. Fuel cells are electrochemical devices that use hydrogen gas to transform chemical energy into electrical energy and have been considered one of the most promising green technologies that have been found to have zero carbon emissions [2][47]. Therefore, it is essential to raise public awareness of fuel cells to facilitate the acceptance of this promising low-carbon technology. Fuel cell learning is included only in selected higher education programs but is considered nonformal learning in lower education levels [3]. However, it is important to introduce students to the fundamentals of fuel cell technology at an early age, such as secondary school, as this will help them to accept this new technology and become more conscious of low-carbon emissions, especially if they are intended end users soon [4]. Thus, digital game-based learning (DGBL) showed great potential for accomplishing environmental awareness education's objectives, which include influencing the younger generation's perspective on protecting the environment [5, 6] [48].

A case study on the effects of a DGBL named "2020 Energy" was conducted to examine climate change issues with a focus on American and Spanish youths who are 12 years of age and older [14]. According to the results, the game positively affects students' intentions to engage in low-carbon activities, which is correlated with their attitudes toward environmental awareness. Another research of a DGBL named "Home RUN" was carried out in the United States to investigate how to raise awareness of potential actions that could result in more sustainable behavior to lower their carbon footprints through altering their patterns of food, energy, and water (FEW) use. After playing the game, the majority of respondents agreed that they had an improved understanding of how FEW resource consumption affects greenhouse gas emissions [7]. The findings suggest that these games effectively contribute to raising environmental awareness and DGBL emerges as a dynamic and engaging tool that can play a crucial role in shaping the perspectives and behaviors of the next generation. DGBL is seen as a promising tool in 21st-century education that could enhance learning, enabling individuals to develop their cognitive abilities especially popular used by the younger generation [8].

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DGBL is the deliberate utilization of digital technology tools to support real-world situations or a combination of game elements in a learning environment to improve student learning by raising motivation and engagement levels [9]. Through DGBL, students can gain new information on difficult and complex disciplines like science and chemistry that were previously too time-consuming or boring for them. This is because the platform is easy to use, accessible, and enjoyable. Due to their motivation to play the game and understand all of its elements through to the finish, students can appreciate and have fun while playing [10, 11].

Digital Game-Based Learning (DGBL) offers a range of benefits as a learning tool, leveraging the engaging and interactive nature of games to enhance the educational experience. DGBL promotes active learning, requiring students to make decisions, solve problems, and apply knowledge in a dynamic environment [12, 13]. Through the use of analogies that are recognizable to students' prior experiences, DGBL's capacity to shape their real-life perceptions ensures that the learning is relevant. Moreover, it will increase students' confidence by continually making judgments within the game's well-structured levels. Students will feel satisfied when they complete a challenging task because the rewarding element of DGBL reinforces their motivations [14, 15].

Effective DGBL experience design and development still pose substantial challenges, despite the potential advantages of DGBL for enhancing motivation, engagement, and learning outcomes [16]. Creating a balance between the game aspects and instructional design is a major problem in the design and development of DGBL. The learning objectives may be obscured by gaming aspects, even if they can increase motivation and engagement [14]. This requires careful consideration and balance in the design and development process to ensure that the game elements serve the intended learning outcomes.

One significant challenge in the design and development of DGBL is addressing technical issues and ensuring optimal performance. DGBL platforms must operate smoothly, with minimal lag or downtime, to offer users a seamless and enjoyable learning experience. Technical issues, such as slow loading times or system crashes, can disrupt the learning process and diminish the effectiveness of any DGBL [17]. Users, especially students, expect a reliable and responsive interface. Thus, developers must pay careful attention to the technical issues to mitigate these challenges and provide a consistent and high-quality user experience [18] [48].

Another challenge in DGBL design is ensuring that the content aligns with specific learning objectives and educational standards. Balancing engaging gameplay with learning content that is relevant and aligned with the intended learning outcomes can be a complex task [19]. DGBL must support the learning objectives established by standards and curriculum, not just provide entertainment. Designers face the challenge of incorporating meaningful learning content into the game mechanics. Ensuring that engagement and instructional value are properly balanced is essential [20, 21]. The foundation of learning materials, which can address any desired purpose, is the development of new knowledge and increased awareness. Achieving a balance between these technological and pedagogical aspects is essential for the effective design and development of a DGBL.

This research aims to develop a fuel cell learning DGBL app called “Hidro-G” that provides basic knowledge for secondary school students on fuel cell technology and applies the knowledge to increase their awareness of low carbon emission. This paper discussed the design and development phase of fuel cell learning using DGBL. The learning content will be validated by expert panel review while the prototype of the fuel cell DGBL will be tested in two cycles which are the internal group and focus group testing to identify the functionality, learnability, and playability of the developed DGBL.

II. INSTRUCTIONAL DESIGN OF DGBL

Instructional design in developing DGBL refers to the process of designing and developing educational games that align with specific learning objectives and promote effective learning outcomes. The instructional design process involves identifying the learning objectives, selecting appropriate game mechanics, designing game elements, and integrating assessment methods to evaluate student learning [22]. The design phase of the developed instructional design of DGBL emphasizes the integration of learning theory into learning strategies to guide designers in ensuring that the learning objectives are achieved. A literature review served as the first step towards identifying the data that are necessary to design suitable instructional design for DGBL. In this context, The DGBL instructional design for fuel cell learning as illustrated in Fig. 1 is adapted from the DGBL–instructional design model [9] which is based on the ADDIE model. Previous studies have shown the potential of the ADDIE Model as the generic model and suitable in guiding the development process of any instructional design [23, 24]. The DGBL-ID model is a comprehensive model that incorporates both the instructional design model and software engineering model, which is a very helpful guideline for any novice designer. Targeted end users also have the opportunity to contribute by involving them as co-designers either in the design or development stages with an active involvement between the designer, developers, and stakeholders [25].

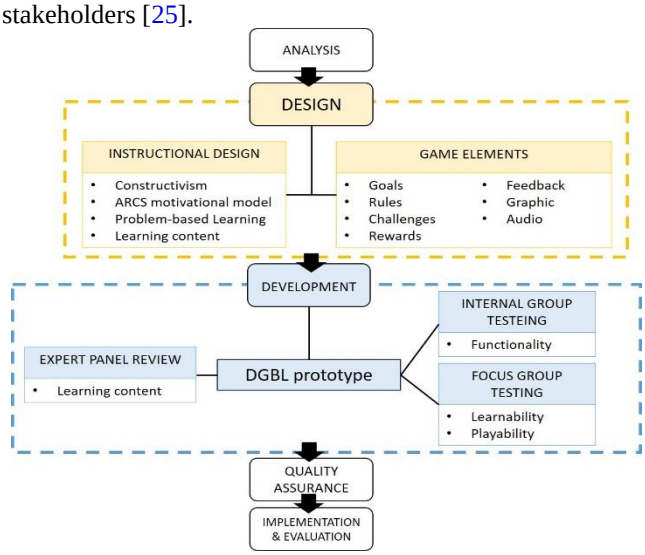

Fig. 1: DGBL Instructional Design Model

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The process in Fig. 1 shows the five steps in the development process starting from analysis. It consists of the process of determining the learning objectives and identifying the requirements needed to develop the DGBL [24].This is a very crucial step in helping designers analyze targeted students' characteristics, such as their perception and their existing knowledge, via interviews and questionnaires. The second step is the design phase where the game storyboard will incorporate all the learning theories, learning strategies, and game-based learning environment into designing the DGBL. The storyboard will include the gameplay, where the storyline, rules, and challenges in the game environment will be determined because it shows how a player will play the DGBL.

Learning theories such as constructivism believe that a student's prior knowledge and the context in which a concept is presented both have an impact on learning. In other words, the process of learning involves the assimilation of new information into prior knowledge by students. Students are allowed to investigate newly acquired knowledge, create their interpretations, and combine them with what they already know [26]. This learning principle supports a student-centered learning environment that aims to help students be more motivated in learning new knowledge [27]. According to the findings of an analysis conducted during the game's first development phase, students chose to use Malay as the intermediate language [28]. The reason for this is that most secondary schools employ Malay as their common and frequent language of instruction. Furthermore, it facilitates and eases the learning process for students.

Another new instructional strategy that can help create successful learning environments is problem-based learning (PBL). Playing games has been shown to promote an engaging and hands-on learning environment [29]. Several studies have used the attention, relevance, confidence, and satisfaction (ARCS) motivation model to enhance learning motivation [20, 30]. The game elements manage to provide enjoyment and amusement while providing educational content that aligns well with motivational ideas. Other game elements such as game rules, goals, and challenges in the game provide enjoyment and passionate involvement which can attract and engage students in playing any DGBL [31].

During the development phase, an expert panel will analyze the validation of the fuel cell learning content that has been developed into a prototype of DGBL that can be played from start to end. Internal and group testing will be conducted as an early assessment of the design ideas that initially focus on the internal structures of the design. It is to ensure the functionality, learnability, and playability of the developed prototype that can work logically [32]. Improvement will be done based on the feedback from the internal and focus group testing. From there on, the well-developed DGBL prototype will be tested again during the quality assurance step to different players who have the same characteristics as the targeted students. The test is aimed at checking the usability of the DGBL before the final version is implemented. Finally, in the implementation and evaluation step, the final version of the DGBL prototype will be evaluated by the target respondents. The findings are to show the impact of DGBL on these expected outcomes: students' knowledge, motivation, and awareness.

III. METHOD

The design and development phase of fuel cell learning using DGBL was covered in this work. First, the learning content was validated through an expert panel review. It is to ensure the validity of the fuel cell learning content in the game from the expert perspective [33]. The expert panel review process started with the invitation via email to the identified experts which are three experts from the fuel cell and environmental engineering field and two science secondary teachers who are specialized in science Form 2 subject (Table 1). These experts, who did not take part in the design or the development of the DGBL received a set of fuel cell learning contents and a set of content validity instruments containing nine items adapted from [34]. The items for validation include having a subject matter expert check the content for accuracy and having an experienced teacher review the way the content is presented to ensure that the language is appropriate for the target audience. 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%.

Table-I: Experts Profile

Expert	Position	Academic qualification	Expertise	Years of experience
A	Associate Professor	PhD	Fuel Cell	15
B	Associate Professor	PhD	Fuel Cell	13
C	Associate Professor	PhD	Environmental Engineering	15
D	Practitioner	Bachelor Degree	Science (KSSM)	10
E	Practitioner	Bachelor Degree	Science (KSSM)	10

Next, the fuel cell DGBL prototype will undergo two rounds of testing, namely internal group and focus group testing, to determine its functionality, learnability, and playability. The development team conducts playtesting internally to evaluate the game's features and functionality. Every mistake and technological problem, including bugs, has been tracked down and examined for enhancement.

Purposive sampling was utilized for focus group testing to obtain useful data from potential target end users in a short amount of time and at a low cost [32]. The game prototype will be evaluated to determine whether it is boring, frustrating, or challenging by a set of testers who share the same characteristics as the intended end user. Five 14-year-old secondary students two female and three male voluntarily joined the focus group for prototype testing during this phase.

The testing process employed triangulation techniques to guarantee the quality of tester feedback, which may be utilized to enhance the prototype [32].

A written survey, one-on-one interviews, and observing the students play the games are the approaches used. The primary objective was to get input regarding the game's playability and learnability from the focus group tester. Additionally, this can be determined by watching how the tester acts during the playtesting and interview process [35].

IV. FINDINGS

The findings of this study include learning content validation from panel expert review, internal group testing, and the focus group testing of the fuel cell DGBL prototype.

A. Learning Content Validation

Table 2 shows the results of the expert content validity score on the fuel cell learning content by 95.1%. The content validity level is considered high when the value is more than 70% which indicates that the fuel cell learning content is good and acceptable to be used [36].

Table-II: Content Validity Level of Experts

Expert	Total Score	Content Validity Level
A	41	91.1
B	42	93.3
C	44	97.8
D	45	100
E	42	93.3
Mean		95.1

The findings from fuel cell panel experts and science teachers suggested that the fuel cell learning content can be improved by emphasizing the impact of carbon dioxide emissions on the environment and health in the future. It will help students to realize the importance of relating the fuel cell knowledge that the students get and applying it to real-life situations. This is because DGBL would allow the player to connect between the game world and reality as it helps to accelerate the knowledge transfer [37].

B. Internal Group Testing

Table 3 shows the relative presence of technical errors that could have negatively impacted the gameplay through their effect on the player experience. For instance, references to specific "bugs" at particular points of the "Hidro-G" game such as performance problems, visual layout quality, audio quality, etc. Based on the findings from the internal group testing, some improvements will be made to make sure that the game is effective and can be playable by the target end user [38].

Table-III: Feedback from Internal Group Testing

Bugs categories	Feedback	Suggestion for improvement
Performance	In the bonus round 3, the game suddenly stopped and the screen froze	Rewrite logics
Design	In the bonus round, the player cannot reset the game.	Add reset button
Artificial intelligent (AI)	The player is not supposed to lose a score when hitting the car but only when hit by carbon dioxide gas that attaches at the back of the car	Rewrite logics
Text	Font for pop-up instructions were too small for the screen	Resize the font to fit the screen
Graphic	Incorrect infographics sequence in the bonus round	Inserted the correct infographics
Audio	No sound effects for right or wrong movements	Add sound effect

C. Focus Group Testing

Table 4 shows the overall ratings given by the students for the game are the average of 7 out of 10 which indicates the game was playable. The responses obtained from the interview session and open-ended questions were transcribed and thematically coded. The observation from the playtesting session was also analyzed and two primary themes emerged from the qualitative feedback which is playability and learnability.

Table-IV: The Overall Rating is Given by the Focus Group

Student	DGBL rating
R1	7/10
R2	7/10
R3	6/10
R4	8/10
R5	7/10
Mean	7

As observed, students in the focus group managed to play and finish the game within an average of 10–15 minutes, however, all of them repeated the game more than 5 times throughout the playtesting session. In the first round of playtesting, all of the students showed that they were very eager to start the game. The feedback from the students based on the one-to-one interview session and the questionnaires showed that they were having fun while playing the game. This was also reflected by comments like "The game is fun. I learn new knowledge today [R1]" and "I like it. It's interesting [R3]". The graphic for the player and game background was noted as "attractive and colorful [R5]". Majority of the focus group stated in the survey that the player movement is hard to control. "Ish! Why the player is not jumping? [R4]" while R2 mentioned, "At first is hard to control. Later on I get used to it".

Most of the students showed interest in learning more about fuel cells after the session ended, "Can we use this fuel cell on other things? Do we have fuel cell cars in Malaysia? [R1]". R3 mentioned in the interview session "I want to google fuel cell after this. I never heard about it. This is interesting". Based on the students' feedback, it showed that they can understand the objectives of the game and manage to describe the storyline of the game. The students were able to point out all the materials needed in the fuel cell such as platinum, hydrogen, and oxygen gasses that showed in the game. All of the students were able to identify all the icons for gases and metal used in this game.

V. DISCUSSION

Based on the results from the expert panel's review it was verified that the fuel cell learning content used was appropriate and acceptable for the intended audience. The fuel cell learning content for this DGBL will be developed based on the references from "Fuel Cells And Hydrogen: From Fundamentals To Applied Research" [39] and "Fuel Cell System Explained [40]. The experts also agreed that the learning content is also aligned with the secondary school science curriculum [41] as it is important to make sure that it can be understandable and relevant for the targetted learner.

A previous study suggested that an effective DGBL depends on how the fantasy context of the game blends in with the learning content [42]. To support meaningful learning and a problem-based learning environment, the content in the game world is represented parallel to the real-life situation. For this reason, the fuel cell DGBL has been developed to be an adventure game where the player is given a mission to save the world from global warming caused by greenhouse gasses specifically carbon dioxide emitted by cars. To "save the world", the player has to build a fuel cell instead of the internal combustion engine used in a car to help reduce carbon emissions. The learning content is designed based on the outline in Table 5 so that the learner can understand while having fun playing the DGBL. Based on students' existing knowledge, the fuel cell learning content will focus on the cause of the Greenhouse effect and how it will affect the environment (Fig. ***2***). In each level of this DGBL, exposure to fuel cell knowledge such as the components of fuel cells and the fuel cell reaction will help students to get more understanding of fuel cell technology specifically for car application. It is expected that through fuel cell learning, students can apply the knowledge that they build and promote awareness of low carbon emissions.

Table-V: Outline of the Fuel Cell Learning Content

Topic	Title	Purpose
1	Greenhouse effect	To explain the cause of carbon emissions. To discuss the effect of carbon emissions on the environment.
2	Basic components of a fuel cell	To identify the basic components of a fuel cell
3	Fuel cell reaction	To explain the reaction occurring in a fuel cell
4	The usage and advantages of fuel cell technology	To give examples of usage of fuel cell technology. To apply the knowledge regarding fuel cell technology in everyday life.

Fig. 2. Screenshot of the Introduction Story in DGBL

Feedback from internal group testing shows some major problems that occurred during testing involved high bug levels like the game screen suddenly froze or the game didn't follow the actual game flow. The logic needs to be rewritten to make sure the game can be functional accordingly. The navigating mechanic for player movement in the game should be fixed accordingly as it does affect the gameplay. Students from the focus group suggested using the "control button" for easy handling of the player's movement such as jumping and moving to left and right. Audio such as sound effects also play an important role in the game as they alert players and prevent them from making any mistakes during gameplay [43].

Table-VI. The Mapping of Game Elements in Fuel Cell DGBL

Game Element	Justification
Goal	To save the earth from greenhouse gasses by using fuel cell cars.
Rules	The player must collect all materials needed to build a fuel cell: Platinum, Hydrogen, and Oxygen. The player must avoid Carbon Dioxide produced by the cars.
Challenges	There are three levels with different materials to collect. There are three bonus rounds with different tasks to accomplish.
Feedback	There is feedback if the player makes mistakes during the gameplay.
Rewards	There are rewards such as words of encouragement and stars
Graphic	Colorful background and attractive graphics
Audio	Fun background music and sound effect

Goals, rules, challenges, feedback, rewards, graphics, and audio are some of the crucial components that must be taken into account when designing a game to enhance learning. This will make the game more visually appealing and encourage student participation [25, 44]. Table 6 shows the mapping of the game elements that have been included in designing the fuel cell DGBL. The goal and game rules should set a clear objective for the player to achieve to draw them in. Since they can stay more engaged and concentrated until they finish the game, this will boost players' motivation [45]. In this context, the game storyline will emphasize the adventure played by the learner in three stages by collecting all the basic materials that will be used in a fuel cell: Platinum, Hydrogen, and Oxygen. Throughout the game, the players will have full control of their gameplay where they can utilize the game navigation controller to make the move or jump while avoiding the moving obstacles, i.e., Carbon Dioxide (Fig. 3). Challenges in the gameplay must consider the different abilities of every student so as not to easily induce boredom while playing. Incremental levels of difficulty will provide challenges that can keep the students engaged throughout the game [20]. In this fuel cell DGBL, the player will be given different goals and obstacles that will challenge the player to upgrade the level of the game. These game elements also supported the problem-based learning strategies which applied throughout the gameplay.

Fig. 3: Screenshot of the Gameplay

The use of rewards throughout the gameplay are very effective strategy that can give satisfaction to players [14]. The timing and scale of rewards can also affect the learner's motivation such as giving multiple small rewards repeatedly other than a big one at the end of the game [45]. Therefore this game was designed to give rewards such as words of encouragement after completing every stage of the game as it can maintain learner engagement while playing the game (Fig. ***4***). While playing, the player will receive immediate feedback about their scores at every level. This was designed to encourage the player to get higher scores on the next attempt and create competitiveness within themselves that eventually will result in satisfaction with their achievement.

Fig. 4: Example of Words of Encouragement as A Reward

Throughout the gameplay, attractive infographics containing useful information on fuel cells will be shown at the end of every stage. It is to make sure that the player can understand the fuel cell components and how a fuel cell can produce electricity. Moreover, audio such as sound effects also plays an important role in the game as it can alert the players and prevent them from making unnecessary mistakes during the gameplay [46]. Background music can also help to motivate and engage players to continue the game until the end [25].

VI. CONCLUSION

Fuel cells have been identified as one of the most promising technologies for the clean energy industry of the future for Malaysia. This research aims to design and develop a fuel cell learning using DGBL apps called "Hidro-G" aimed to provide basic knowledge on fuel cell technology and students are expected can apply the knowledge to increase their awareness of low carbon emission. The target group is secondary school students aged 14 years. The integration of learning theory, learning content, and game elements in the design phase plays a crucial part in making sure the learning outcome of the DGBL can be achieved. In the development process, the learning content was under review by panel experts to ensure the content validity of the learning content that will be the input fuel cell DGBL. Then, the developed fuel cell DGBL prototype was tested in two cycles: internal testing and focus group testing aimed to identify the features functionality, and playability of the game prototype. Findings show lots of room for improvement, especially in solving technical errors and bug problems. Feedback from panel experts and focus groups is valuable and can be used to improve the learnability and playability of the game for the next phase of this DGBL development.

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