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Design and Development of Periodic Table Game for Students in Secondary School

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Abstract

Development of chemistry games seems to flourish with the increase of its usage in the classroom. In line with rapid technological advances, digital-game based learning (DGBL) creates more engagement to the topic being learned. It has potential to bridge the gap between education and entertainment by taking advantage of people's natural interest in games to comply with challenging topic such as periodic table of elements. As a foundation of the chemistry subject, periodic table is the most important chemistry reference

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that students need to master. However, student always think that the topic is difficult to learn, uninteresting and requires a memorization skill. Therefore, this research aims to propose a Chemi-Chronicle game, a periodic table game that may help memorization tasks become more enjoyable. Subsequent to this, the game is developed to serve as a learning aid for Form 4 students who take chemistry subject. At the same time, it helps students with less skills of memorizing periodic table. This study adopted ADDIE method for game development which involves five phases: analysis, design, development, implementation and evaluation. Several interview sessions with chemistry teachers were done in the initial stage to identify appropriate game activities for students. Besides this, games design principles is identified to inform the developer in designing the games that is playful and motivating while achieving desired goals. It is strongly recommended that the periodic table game could appear as a promising educational aid technology for improving and strengthening knowledge in chemistry subject.

Keywords Digital game based learning; Game development; Educational games; Periodic table, Chemistry subject

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Introduction

The use of games in an educational context is not a new phenomenon. Many of us have been exposed to game-based techniques even though sometimes not being aware of it (Stojanovska & Velevska, 2018). Game Based Learning implemented a wide range of subjects such as science, mathematics, foreign languages, cultural heritage, health, software engineering, business and logistics (Caponetto et al., 2014). To date, scientific disciplines such as chemistry has been attention to be taught in an interesting way as it always thought to be difficult and memorizing subject (Bayir, 2014). As reported, Malaysian students' achievement in chemistry is less encouraging (Lay & Osman, 2018). Studies by Wan (2019) revealed that the periodic table, which is the basis of chemistry, is considered as difficult to learn. Students are always confused between the change in physical properties when going through the group and chemical properties of the group (Wan, 2019). Moreover, teachers also struggle to teach due to the abstract nature of the topic which lets them suggest students to memorize the periodic table (Mokiwa, 2017). Oral recitation is a strategy that is commonly used to memorize this table, but students often think this task is a boring memory learning (Franco-Mariscal, 2014). Many memorization techniques have been used for learning the periodic

table, but digital games have been unexplored to apply these techniques (Traver, Leiva, Martí-Centelles. Rubio-Magnieto, 2021).

In accordance with enjoyable learning, the usage of digital games is undeniable. In fact, Digital Game Based Learning (DGBL) is one of the promising approaches to educate the digital native. Pew Internet & American Life Project Reports stated that youth's consumption of digital games is compelling, which indicate that 99% of boys and 94% of girls play digital games (Pew Research Center, 2008). Reportedly, play is a social-centred process which able to boost motivation among the player (Dichev & Dicheva, 2017). Clearly, it shows that students are more challenged by the difficulty in playing games rather than facing the difficulty in understanding the lesson. In this case, a change in chemistry instructional approaches is critical. This is in line with 21st century chemistry education in Malaysia with a greater emphasis on a combination of cognitive, sociocultural and motivational aspects (Lay & Osman, 2018). This is to ensure that students are equipped with knowledge, skills and values relevant to the new digital world. In this case, penetration of digital games seems to have potential in education especially in science and technology subjects. Therefore, this study aims to answer these questions:

i. What are the games design principles for developing periodic table game for students?
ii. How to develop periodic table game for students?

Related Studies

Digital Game Based Learning (DGBL)

DGBL takes place when game characteristics and principles are embedded within learning activities. By definition, DGBL means using games in educational contexts to reach educational objectives (Connolly, Boyle, MacArthur, Hainey, Boyle, 2012). The aims of DGBL are always associated with learning and behavioural change (Connolly et al., 2012). In fact, the importance of integrating DGBL into the learning activities is always referred to in literature. DGBL has significant benefits in terms of increasing students' motivation in learning (Papastergiou, 2009), enhancing their learning effectiveness (Nathan & Berahim, 2018), enhancing their academic achievement (Lay & Osman, 2018) and acquiring new knowledge and complex skills (Nathan & Berahim, 2018). Literature shows that the context of DGBL can be used to for great benefits in an education setting.

Chemistry Games

The chemistry games have been widely built around the world as a teaching tool. Based on previous study by Stojanovska and Velevska (2018), many successful games covered a variety of chemistry topic such as environmental chemistry (Pippins et al., 2011), laboratory equipment (Kavak & Yamak, 2016), physical chemistry (Daubenfeld & Zenker, 2015), organic chemistry and biochemistry (Angelin & Ramström, 2010; Costa, 2007; O'Halloran, 2017; Silva & Ribeiro, 2017), periodic table and nomenclature (Franco-Mariscal, Oliva-Martínez, & Gil, 2015; Kavak, 2012; Martí-Centelles & Rubio-Magnieto, 2014; Moreno, Hincapie, & Alzate, 2014; Morris, 2011; Sevcik, Hicks, Schultz, & Alexander, 2008). Similarly in Malaysia, most of the games focus on various topics such as scientific apparatus, separation techniques, group of elements, properties of elements and chemical bonding (Lay & Osman, 2018). It is vital to master chemistry knowledge as it essential to comprehend most of the fields of science, technology and engineering (Balaban & Klein, 2006).

The Periodic Table

The periodic table of elements has been introduced by Dmitri Mendely in 1986 which is the first to predict the properties of the known elements (Mokiwa, 2017). Periodic table is an arrangement of chemical elements that has been organized followed by the atomic number. The International Union of Pure and Applied Chemistry (IUPAC) has accepted the used of periodic table as an important guide in learning chemistry. It was stated by Zolotov (2007) that the IUPAC has approved the long form of the periodic table and recommended it for use. In chemistry subject, the first task for students is to learn the names and symbols for the main chemical elements. Therefore, the periodic table is the basic tool used by teachers to teach the position of the elements in the periodic table and explain its properties (Martí-Centelles & Rubio-Magnieto, 2014). In Malaysia, learning the periodic table of elements is a key tool to face the chemistry learning outcomes in Form 4 according to KSSM National Curriculum. However, periodic table is considered a difficult topic (Wan, 2019) and uninteresting topic (Franco-Mariscal, 2014) by most of students. Moreover, it is usually taught through a passive way of teaching, where the teacher is a transmitter of the contents (Franco-Mariscal, 2014). Due to that, it is very important to support this learning process with the use of games, which is proven in generating more benefits rather than the traditional method.

Principles of Chemi-Chronical Game

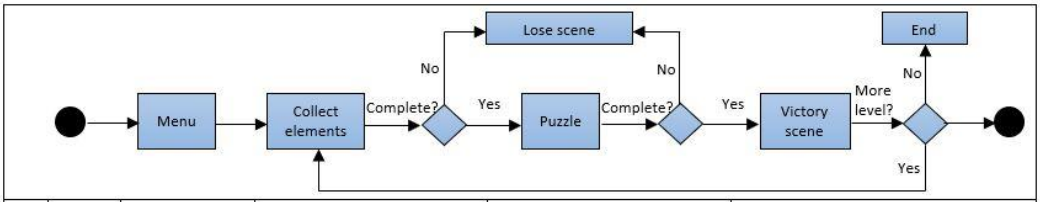
It is critical to incorporate games design principles when creating a serious game. This is to ensure the game can deliver the objective or transmit the education purpose to the player, while at the same time it gives excitement to the player (Mat Sin, Talib & Norishah, 2013). According to Laine & Lindberg (2020), implementing game principles in developing a game helps game designers to develop a great serious game and better understanding of the entire game concept. The first principle that is applied in Chemi-Chronicle game is a direct and accurate set of rules and goals of the game. All games have rules that govern the activities and events that take place in the game world (Laine & Lindberg, 2020). The game's boundaries are established by the rules, which include the game's goals and how to achieve them. To be motivating, the game's goals and rules must be clear, flexible, and coordinated with the goals and feedback, so that the player understands how to manipulate the game world. Also, the gameplay should not become overly limiting, and the player does not feel burdened while playing the game.

The second game principle is freedom, which is to encourage the player to explore the game world and its contents. This principle supports the discovery, navigation, and control motivators by allowing the player to feel more in control while exploring and completing the game level. Curiosity (cognitive and sensory) motivation factors are also supported, as exploration may necessitate the player's sensory and cognitive abilities (Laine & Lindberg, 2020). In this game, the player should be able to explore the game world and experiment with its features without fear of serious consequences.

The third important principle is challenge which is stressed by Clark & Mayer (2011) that online environment must involve a competitive activity with a challenge to achieve a goal, a set of rules and constraints, and a specific context. At the same time, the game challenge is relevant for the psychomotor development of the player (Stiller & Schworm, 2019).

The fourth principle in Chemi-chronicle game is motivation. A game should provide feedback or rewards, such as scoring system, win or lose, cut-scene right or wrong, and incentive structure to the player. These features motivate learners to stay engaged over long periods through a series of game features that are of a motivational nature (Plass, Homer & Kinzer, 2015).

Based on this, the related games principles (rules, freedom, challenge and motivation) are mapped into the flowchart of Chemi-chronicle the game. Figure 1 shows how the games principles are embedded into a game's flow based on gaming and learning context.



Gaming	Action	Selection	Collecting elements	Matching	See performance evaluation
	Goal	Explore game	Move to next step	Solve puzzle	Maximize performance
Learning	Action		Repetition	Imitating	Reviewing
	Goal		Provide learning guidance	Remembering	Understanding
Principle of periodic table game		**Rules**	**Freedom**	**Challenge**	**Motivation**

Figure 1 Principles of Games and Learning for Chemi-Chronical Game

Methods

The game was developed based on ADDIE model which consist of five fundamental phases: Analysis, Design, Development, Implementation and Evaluation. It is depicted in Figure 2 and the elaboration of each phase is as follows:

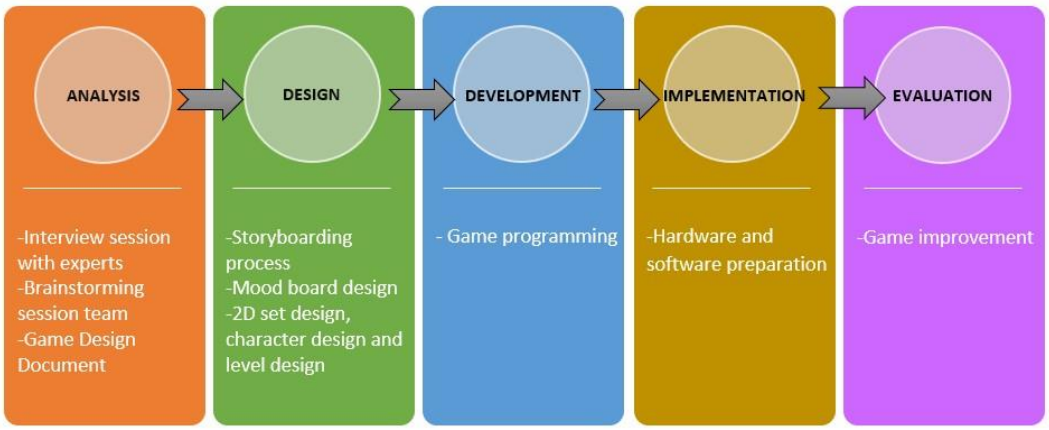


Figure 2 Chemi-Chronicle Game Development

Analysis

In the early phase, some input were gathered from interview sessions with three experts in Chemistry subject. The session was done in a semi-structured interview with teachers who have experience in teaching Chemistry subject for more than 10 years. The questionnaire mainly covered the importance of periodic table, its content and suitable method to learn periodic table. Then, the brainstorming session was done with a team member analysing the gathered data to get the foundation in designing the game. The key

activities in this session were discussions and blending ideas about the game concept design (GCD). This includes the game elements (concept, genre, theme, platform, content, target audience, unique selling point, gameplay and rules), competitive analysis and SWOT analysis (strength, weakness, opportunity, threat). The gathered data from the interview with experts and brainstorming session with team members were presented as GCD in Table 1:

Table 1 Game concept design (GCD)

Item	Description
Game Title	Chemi-Chronicle
Game Genre	Education
Game Theme	Science Fiction
Target Platform	PC based
Game Content	Periodic table of elements (Textbook Form 4)
Target Audience	Form 4 students who are taking chemistry subject
Unique Selling Point	Serious game to memorize periodic table in a fun way
Narrative	Dr Dimitri is a chemist who has been duped by BEX Company to invent an element as weapon that is capable in empowering the city. Unfortunately, BEX Company has turned it into Biochemical weapon that brings harm to people. Dr Dimitri must seize all the elements to defeat the bad intention of BEX Company.
Game Goal	1. Collect all the elements in every level. 2. Avoid or defeat enemies. 3. Answer puzzle correctly to proceed to next level.
Game Rules	1. Avoid contact with dangerous elements, traps etc. 2. Finish a level within a limited amount of time. 3. Collect all elements in the current level to unlock the locked door.
Game Feedback	1. If player collect an element, an information popup will appear. 2. If player completes a level, player achievements will appear. 3. If player dies, menu pop up will appear and player can choose whether to retry or go back to main menu

Design

In this phase, the mood board and storyboard were designed based on the GCD. The mood board was divided into few sections such as font type, background, colour palette and inspirational sketches. The use of mood board is to help designers to be consistent on the style and aesthetic, making it on track with the game's goal.

The storyboard is designed for a better visual overview on how the game flows. Initially, the team will sketch it on paper and transform it later in digital form (Figure 3). During storyboarding process, some errors related to storyline, maps, plots and levels were identified. At the end of this phase, the storyboard was evaluated by three experts (chemistry teachers) through a pitching session.

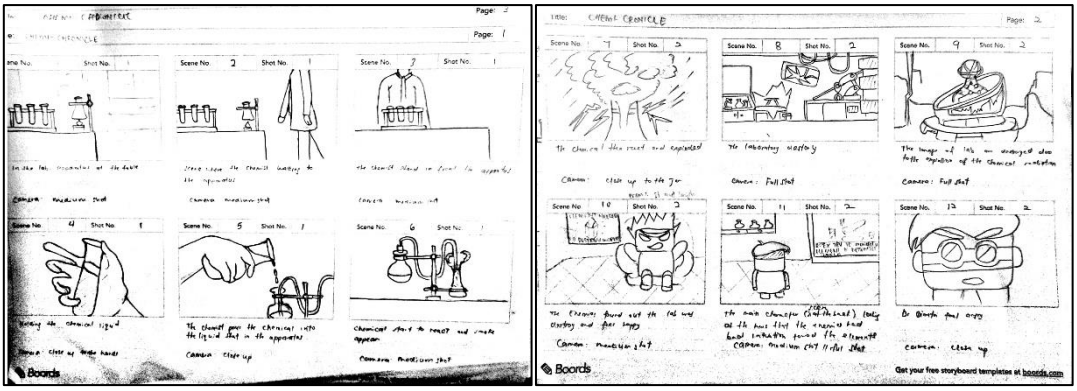


Figure 3 Chemi-chronical Game Storyboard

Then, the process was further developed into 2D set design, character design and level design (Figure 4). The 2D set design includes all the elements in the game world such as user interface (UI/HUD), assets, background, menu, game scene (cut-scene, victory scene, game over scene), visual effects (VFX), audio and animation. Character design involves designing the main and supporting character. Lastly, game level design was created with four levels with different environment and challenge. In each level, a puzzle interface was formed as a student assessment.

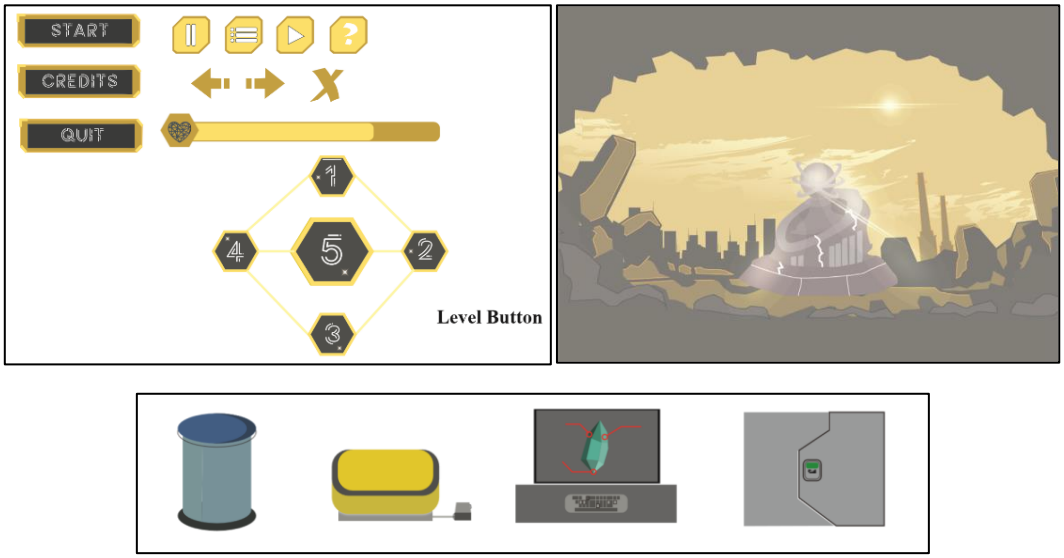


Figure 4 2D Set Design

Development

This phase involves the process of bringing the game design to life. This includes coding and programming using Unity software, sound effects, rendering and testing to get the required game running.

Implementation

This phase consists of deploying the game in the suitable platform. In terms of hardware, equipment such as monitor, keyboard, speaker or headphone was set up for experts to test the game. In term of software, user access to the game was provided by compiling the final version and essential materials in a protected file. With careful implementation, experts may contribute more effectively to evaluation phase. Meanwhile, the game is checked on the programming and necessary changes are made to enhance the usability.

Evaluation

In this phase, evaluation was conducted with a targeted user and two subject matter experts. It was done through an online meeting as presented in Figure 5. The respondents have been given 30 minutes to play the game and they were interviewed based on usability such as effectiveness, efficiency and satisfaction. Meanwhile, the errors and unhandled exceptions in the code were also identified to ensure the game runs smoothly. Then, the gathered data from the evaluation session was analysed qualitatively to improve the game.

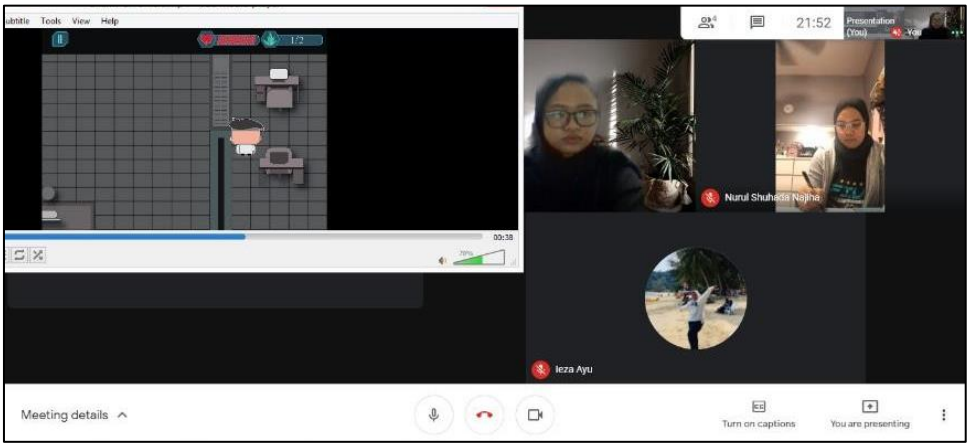


Figure 5 Evaluation with Experts

Result and Discussion

Chemi-Chronicle Game

This project aims to develop a digital game that helps students memorize the periodic table through enjoyment activities. Thus, Chemi-Chronicle game is designed with futuristic science fiction theme surrounded with some adventure in lab environment. It is a single player maze game with Dr Dimitri, a chemist who has been duped by a wicked cooperation BEX Company. He was demanded to invent a new element to create a weapon that is capable in empowering the city. Unfortunately, BEX Company has turned it into Biochemical weapon that brings harm to people. Dr Dimitri must seize all of the elements to defeat the bad intention of BEX Company (see Figure 6(b)).

a) Main Interface b) Game Level 1

Pop-up Periodic table d) Quiz Section

Figure 6 Chemi-Chronicle Game Interface

In the gameplay, a player is required to explore the lab and collect five elements that are hidden at some corner. At the same time, the player needs to avoid the enemies and collect health to reduce the potential of becoming dead. Every time the player finds the element, a pop-up information about periodic table will appear (see Figure 6(c)). At this point, player needs to take time to memorize the table. Basically, the repetition of this popping up table aims to help player to strengthen their memory. When all of the elements are collected, the door will automatically open which allow the player to move to the quiz section.

The quiz section is designed in a form of completing the puzzle (see Figure 6(d)). In the quiz section, player must drag the element and put it in the correct place within the time given. If player puts the elements in the wrong place, it will bounce back. If the player completes this puzzle, he will be brought to Level 2. When the player finishes the whole level, he can repeat the game to improve their memorization. The structure of game level is shown as Table 2.

Table 2 Structure for each game level

Game level	Maze Challenge	Puzzle Challenge	Total of Periodic Table display
1-Easy	1 enemy in lower speed	Arrange 12 elements in 30 sec	7 times
2-Medium	3 enemies in faster speed	Arrange 13 elements in 40 sec	5 times
3-Hard	5 enemies with multiple speed	Arrange 23 elements in 1 min	3 times

Each level has different level of challenge in terms of number of enemies, number of elements to memorize and time. The higher the level, the more difficult it will be for both maze and puzzle parts. The Figure 7 below shows the group of elements that was tested in each quiz.

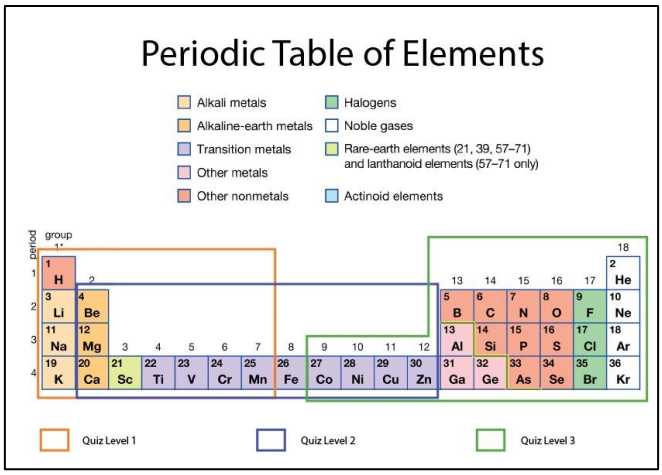


Figure 7 Group of Elements for Each Quiz (adopted from Periodic Table of Elements)

The results from the gameplay indicate that this set of game provides an entertaining way to facilitate students' learning about elements, compounds, and the periodic table. Memorizing the names, symbols, and exact horizontal and vertical positions of the elements in the periodic table can be achieved by the repetition process which is applied in the gameplay.

Evaluation of Chemi-Chronicle Game

The evaluation focuses on criteria such as effectiveness, efficiency and satisfaction. The results from interview session with experts were delineated into three categories of themes such as compliment, criticism and further improvement. The list of them is shown in Table 2. Effectiveness is refers to participants' comments related to overall measure of how well the game performs. Efficiency refers to participants' comments related to time required to use the interface and the likelihood of making errors using the game. While satisfaction refers to participants' comments related to satisfaction with game.

Table 2 Qualitative feedbacks from experts

Expert	Feedback categories	Compliment	Criticism	Further improvement
Expert 1 (user)	Effectiveness	- Overall, I am able to understand the game's objective and goals when playing this game. - I am able to gain knowledge when playing this game.	-	Create more challenges in the gameplay to make the game more intense.
	Efficiency	-	It takes some time to complete all the game.	Maybe adding a little bit of time or hints at the quiz section.
	Satisfaction	I enjoy the game environment. I play with emotion when I play the game.	-	The background music can be enhanced to give more impact.
	Others	-	-	Add more character in the gameplay and storyline to make it more interesting.
Expert 2 (SME)	Effectiveness	- The game is very accurate with the objective. - The game has great explanations and easy to understand.	All the games' levels are easy to complete.	It would be interesting if this game added more level on it to complete the periodic table.
	Efficiency	I was able to complete the challenges.	-	Give more challenge in the level to immerse the skill of problem thinking.
	Satisfaction	I love the game interfaces. It is very creative at the same time it influenced my problem thinking to solve the problems.	-	Enhance in terms of colour backgrounds.
	Others	I like the way the	-	- Maybe add a character

		storyline gives impacts to the user.		in the game to make the story more interesting.
Expert 3 (SME)	Effectiveness	The game interactions are very useful and have formative assessment.	-	-
	Efficiency	-	The gameplay is quite challenging	Reduce a bit of the time taken of the enemy.
	Satisfaction	- I found the game is easier to play and less frustrations. The interactive tutorial given provides user to perform in better play. - I like the interface in this game. The interface is minimalist and followed with the theme. It is suitable for student and teachers like me. - I like when this game is very accurate with the related learning area.	-	- Enhance the game background colours. - Make more about the game contents.
	Others	-	-	Add more animate character and more background music to make the game more interesting.

Based on the evaluation, Chemi-Chronical game receives a compliment due to the goal of the game which makes players easy to explore the game. It also has several features that makes player enjoy the game such as good interface and interaction. However, the game also has some weaknesses in terms of game challenge in which the game level is hard for certain players and too easy for others. For further enhancement, the game is suggested to have more challenges and levels to make it more intense and suitable for the target player. Furthermore, several multimedia elements were proposed for additions such as hints, background music, animations, characters and background colours. Overall, when these data are mapped into design principles (rules, freedom, challenge and motivation), the game only needs some minor modifications in terms of challenge and motivation.

Conclusion

This study has developed Chemi-Chronical, a periodic table game with the aim to make the memorization technique a fun activity by students. In particular, the development process is described in detail in each important phase. This game incorporated four game design principles which are rules, freedom, challenge and motivation. To ensure this game is aligned with academic requirements, collaboration with game developer and academician is made. As a result, the game may assist students' memorization skills through interactive way of learning. It can be used by students to reinforce their knowledge, review during lesson and as preparation before examination. Altogether, digital game-based learning in chemistry is a growing multidisciplinary research. Further research should get insights into the concept of memorization of periodic table through game and the effect of respective game on cognitive functions.

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