Jurnal Kejuruteraan 32(4) 2020: 559-568
https://doi.org/10.17576/jkukm-2020-32(4)-01

Popular Game Elements Used in Designing Game-Based Learning STEM Application for School Students – A Review

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Received 19 July 2019, Received in revised form 29 March 2020
Accepted 03 May 2020, Available online 30 November 2020

ABSTRACT

There are a variety of educational games produced for studies in game-based learning (GBL) with a specific design to achieve the most efficient stage of learning for school students. However, there is a lack of evidence showing the most suitable and effective game element instilled in the GBL STEM application. Most of the papers studied on GBL have proven the effectiveness aspect in other STEM subjects, however very little discussed in the domain of sustainable energy. Thus, this study aimed to analyse the most common game element applied in designing GBL that achieved the best result for students in learning the STEM subjects. Each game element targeted a different kind of learning results such as student's learning performance, knowledge level, cognitive effect, and enjoyment. A systematic review was conducted following the specification of the PRISMA checklist to examine past studies. After carefully screening the articles, only twelve published articles met the specification. The finding showed that most common game elements included in designing the GBL, dominated by the level of challenges, followed by rewards/items, feedback, clear goal and time pressure. The finding also included the percentage of most STEM subject studied in GBL and the impact from the GBL STEM application. This review hopes to assist researchers in making a better decision when designing a game application for GBL in sustainable energy subject, from the aspect of students' age and gender.

Keywords: Game-based learning; STEM; Microbial Fuel Cell; School students

INTRODUCTION

Science, Technology, Engineering, and Mathematics (STEM) domain has been deemed to be crucial to prepare Malaysian children for the demanding workforce (Academy of Sciences Malaysia 2015). The need for innovative and educational initiatives for STEM disciplines are critical as Malaysia has to stand out in the competitive and increasingly global market. Based on the Economic Outlook 2019, the Ministry of Finance Malaysia has given out the statistical table on labour market where the employment of professional, scientific and technical increases by only 12.2% in five years range from 2014 to 2018 (Ministry of Finance Malaysia 2019). Renewable energy has been incorporated in the Malaysia Plans from 2001. Due to the rising concern from the global community regarding climate change, renewable energy is included as the Fifth Fuel in the energy mix (Academy of Sciences Malaysia 2017). However, the students' interest in the STEM subject in Malaysia is declining. There were only 44% of students chose STEM streams in 2018, compared to 48% in 2012 (Mestecc 2019). Students shall be equipped with the set of knowledge and enthusiasm to fill in the variety of increasing renewable technology sector such as biogas (Kamarudin et al. 2018) and fuel cell (Hil Me et al. 2020). Thus, the Malaysia education system needs to be conscious by this triggering scenario and starts focusing on nurturing STEM interest in students (Ministry of Education Malaysia 2013) so that local development of renewable energy sector can be realized.

Game-based learning (GBL) describes an environment where game content and gameplay enhance knowledge and skills acquisition, and where game activities involve problem-solving spaces and challenges that provide players/ learners with a sense of achievement (Qian et al. 2016). In order to support the learning process, design of educational games need to integrate cognitive technique for students, into the game mechanism, which can make learning become more engaging and leads to more effective learning (Gauthier et al. 2015). Thus, GBL offers a new way of learning that combines the element of game mechanism into an educational way that comprises the learning context that can bring learning process to become easier yet powerful enough to enhance students' learning progress.

There has been significant development in GBL in the past decades for STEM subject such as Mathematics, Science, Technology and Computing (Boyle et al. 2016; Crompton et al. 2018; Hamari et al. 2016; Ibáñez et al. 2018; Kiili et al. 2018; Kim et al. 2015; Malliarakis et al. 2014). Though many studies have shown the positive impact of GBL (Abdul Jabbar et al. 2015; Chang et al. 2017; Chen et al. 2016; Mclaren et al. 2017; Yeh et al. 2019), the game

design varies, and some of the elements are frequently used to give practical impact to the users. Based on a study, an effective design of gamification in digital learning is not a simple direct process (Fitz-Walter et al. 2017). It is essential to explore the best implementation of game-like rule systems and player experiences in order to gain insights about the potential of gamification in education (Lee et al. 2011). Exploring new ways to implement gamification in learning contexts, so it is not limited to extrinsic rewards is particularly crucial. When gamification is well designed and correctly utilized, it has the potential to improve learning (Dicheva et al. 2015; Zydney et al. 2016). Thus, GBL is said to be an excellent platform of learning for school-children, but the potentiality of a successful game still depends on the design of the game itself.

As in STEM learning, there is a need for a student to be guided by an engaging learning platform (Amadio 2015; Mohd Shahali 2016). The 21st-century skills, which includes the digital age literacy proves that students from this Z generation tend to be attracted to the technology assist in learning (Salehudin et al. 2015). While the mobile game is one of the youngster's phenomena at present, the implementation of GBL has been proven to be educationally efficient and suitable to improve student's knowledge and enhance the particular field of interest (Nordin et al. 2017; Qian et al. 2016; So et al. 2018). Students achieved better in GBL through game's experience so that they can learn significantly more (Brezovszky et al. 2019; Mclaren et al. 2017; Sung et al. 2017). Though STEM education is a challenging subject (Briggle et al. 2015), the element of fun in the game for learning will help to motivate students with higher interactivity so that they can enjoy learning while gaining more knowledge (Abdul Rabu et al. 2017; Barhoumi 2015; Mohd Shahali et al. 2017).

RELATED WORK ON ENERGY AND ENVIRONMENTAL GAME-BASED LEARNING

Recent research shows that digital games have potential in increasing the awareness in sustainable energy, energy efficiency and environment (Beck et al. 2019; Madani et al. 2017; Morganti et al. 2017). For example, Morganti et al. (2017) reviewed studies done on energy efficiency and environmental awareness digital games by highlighting the effectiveness, key features, and the game successfulness impact. They found that both gaming methods: the serious games and the gamification, can engage users in pro-environmental and increase the level of awareness related to energy efficiency, either in mobile phone or web platform. Interestingly, serious games and gamification can be defined differently except the fact that both methods are focusing on employing the game element to support the way of learning and changing the situation experienced. A serious game is a method of a learning experience in a game-like context. As the main game mechanics of serious games are rules, choices, challenges, and fantasy, it has shown the potential in improving people's ability in the real-world task by preparing the real challenges in the game (Arnab et al. 2015; Carvalho et al. 2015; Morganti et al. 2017). Meanwhile, gamification refers to design strategy where game elements are used in non-context to encourage changes in learners' behaviour (Dicheva et al. 2015; Fitz-Walter et al. 2017). In other words, the more lessons or courses completed, the more badges users can earn, the higher the motivational value for the user to achieve the goal (Chang et al. 2016).

Beck et al. discovered that the potential of the game element had not been utilized sufficiently from 57 energy-related apps. The user app ratings increase with the increased use of gamification component. However, the game element and gamification components are not utilized extensively by the developers. Thus, they recommended a more hedonic experience for the game apps and more sophisticated elements of game design used in developing the game (Beck et al. 2019). The level of complexity in a game design, which contains meaningful lessons is insufficient, hence requires implementation in GBL. There are many educational games with simple designs. However, they focus narrowly on learning content and do not utilize the potential function of a game for learning. These matters lead to failure to engage the student on their learning (Qian et al. 2016).

Therefore, there has been a rise in implementing the GBL within the energy and environmental education for students (Bursztyn et al. 2015; Fernández-Cerero et al. 2018; Johnson et al. 2017). Knowledge on infusing the right game elements in those GBL for nowadays gaming style for educational and learning is essential. The studies have proven in the existence of a positive impact on multiple aspects such as cognitive impact, learning experiences, and knowledge gain. However, it is not clear, which of the elements are best for GBL. By observing the five years latest trend (2015-2019) from the studies on GBL, the most popular and commonly used game elements by game developers related to this study will be examined thoroughly.

GAME ELEMENT IN GAME-BASED LEARNING

Game elements are the design elements used in hedonic games (Beck et al. 2019). The game elements used from a review on an energy-apps game by Beck et al. consist of the use of avatars, three-dimensional (3D) environments, narrative context, feedback, reputations (divided into rank/leaderboard and levels), marketplaces, competition, teams, communication systems, and time pressure (Beck et al. 2019). Some of the game element can be a part of gamification component. As mention before, gamification is the use of the game element in a non-context of games. Some context overlaps between the gamification component and game elements, including feedback, leaderboard, levels, and story. Aldemir et al. implemented their game design by categorizing the game elements, which are dynamics, mechanics, and component. Under these categories, the applied game elements are points, badges, leaderboards, challenge, narrative, reward, teams, win-state, and constraint (Aldemir et al. 2018). However, the three categories were

seen used differently in different studies as they are applied based on the aim of the studies. Therefore, the dynamics, mechanics, and the component are unacceptable as a classification for game design elements as other studies used the game element without categorizing the elements into different parts (Dicheva et al. 2015). Dicheva et al. also discovered that there is not yet commonly agreed on the classification of game design elements (Dicheva et al. 2015).

In order to achieve the educational content points from GBL, it is essential to understand the system flow. The flow could be inclusive of game-like rule systems and player experiencing the challenges in the game that can help in achieving the targeted potential of the game (Aldemir et al. 2018). However, the game cannot attain the objective for better learning performance if extensive gamification mechanics were applied (Chang et al. 2016). Other than the game-like rule systems and player experience, a personal characteristic such as gender, studying habits and game-playing habits through the presence of a game element, can change depending on the way the students value the game to aid the learning context (Gauthier et al. 2015).

Elements in game design can lead to active learning by establishing learning theories in the game (Aladé et al. 2016; Caglar et al. 2015; Qian et al. 2016). In a systematic review from 137 papers on GBL, the common elements of game design identified are collaboration, role-playing, exploration, narrative, complexity, competition, strategy, challenge, clear goals, communication, discovery and immediate feedback. Above all, collaboration, most likely the element used followed by role-playing. As the collaboration can give impact to engage the player in social interaction, it leads to persistence of role-playing which can give the player a sense of identity that can enhance students' real-world competency (Qian et al. 2016).

The game element applied in non-game context (Chang et al. 2016; González et al. 2016; Md Basri) is to make the game more exciting and to encourage behaviour change. This strategy has been done in learner logbook smartphone application for young drivers (Fitz-Walter et al. 2017). Although there was no significant change in user behaviour, perceived motivation, and user experience were studied. Thus, by implementing the correct game element suitable with the context of learning, students will be able to learn more, while achieving the context of the gameplay (Carvalho et al. 2015; Hsu et al. 2018). For example, a web-based study aid has been integrated with a game element entitled Vascular Invaders to support medical students' in understanding the human vascular anatomy. Students showed the interaction between the game played (measured as completed task) with the game element: leader views, collecting items as a mini goal and used power-ups. They accessed these elements continuously throughout the game even though it was not necessary to complete the task successfully. The result showed engagement in a gameplay experience where the act of continuity seen from the player (Bray et al. 2016). Thus, the study concluded that the presence of a game element in a non-game context could influence students' learning behaviour in an interactive way (Gauthier et al. 2015; Tsai et al. 2016).

MANUSCRIPT SELECTION PROCESS

Four online research database: ScienceDirect, Scopus, Springer and Google Scholar, were used as a platform to find relevant literature sources. Papers on the subject of digital games for the educational purpose were collected and narrowed down by screening according to specification for this review paper. PRISMA recommendation for systematic literature analysis, as shown in Figure 1, was applied in order to avoid bias (Moher D 2009; Morganti et al. 2017). The paper abstracts and titles were selected, and the full papers later analyzed so that they meet the inclusion criteria. The papers were examined based on the following criteria: a) STEM subject research article; b) information about the element of game-used and c) published in recent years (2015 until 2019 years range).

ANALYSES AND CATEGORIZATION OF GAMES

Articles that met the researcher's specification were analyzed using a qualitative content analyses method. The game categorization was made based on the primary purpose of each game, which revolves within the STEM discipline domain. Papers are selected based on educational games and serious games developed for educational purpose.

RESULT AND DISCUSSION

This section presents the results, focusing on the applied element in game design for STEM subject and the factors influencing the game element used in designing the game.

GENERAL FINDING

Table 1 shows the general information of the paper reviewed. The 12 original papers identified for review were diverse in domain, participant age range, journal publication year, and the number of participants. Specifically, participants from the study reviewed covered a wide range of ages: primary education (42%), followed by middle education (25%), elementary (17%), and higher education (17%). The highest number of science domain observed was from Science (42%) followed by Mathematics (25%) as well as Computer (25%) and Technology (8%).

ELEMENT OF GAME-USED FOR DESIGNING GAME

Previously, a review shows the use of roles of avatars, virtual environments, narratives, animations, and graphics

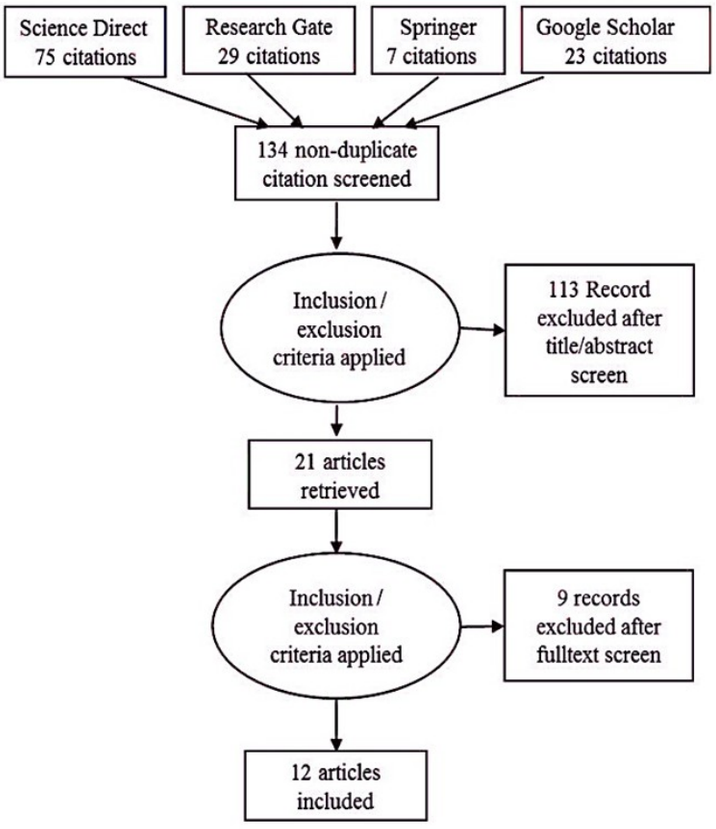

FIGURE 1: Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) (Moher D, 2009)

TABLE 1. Background information on the reviewed article

Author	Journal	Science domain	Educational level	No. of students
Aldemir et al. (2018)	Computers in Human Behavior	Technology	Higher education	118
Brezovszky et al. (2019)	Computers & Education	Mathematics	Primary	1168
Derboven et al. (2016)	Entertainment Computing	Mathematics	Primary school	8
Gauthier et al. (2015)	Computers in Human Behavior	Anatomy	Higher education	46
Gilliam et al. (2017)	Journal of Science Education and Technology	Health Science	Middle school	144
Howland et al. (2015)	Computers & Education	Computer programming	Middle school	55
Law et al. (2016)	Computers & Education	Sciences	Middle school	105
Lester et al. (2014)	Computers & Education	Information Sciences	Elementary	800
Martinovic et al. (2016)	Computers in Human Behavior	-	Primary	41
Mclaren et al. (2017)	International Journal of Game-based Learning	Mathematics	Primary	213
Simões Gomes et al. (2018)	International Journal of Child-Computer Interaction	Computer	Primary	42
Taub et al. (2018)	Learning and Instruction	Science	Higher education	64

for playful learning and discoveries, were most utilized in GBL (Abdul Jabbar et al. 2015). Table 2 shows the game elements' combinations found in several papers.

Figure 2 presents trends of game elements used in GBL from 5 years range starting from 2015 until 2019. The finding showed that the most common game elements used were the challenge followed by rewards/items, feedback, a clear goal, and time pressure.

CHALLENGE

In Figure 2, the game element of challenge is the most popular game elements used in developing a game for education purpose between the year of 2014 until 2018. The challenge element can create a competitive collaboration and can help the player to self-assess (Ronimus et al. 2014). Challenges also give player reinforcement for

TABLE 2. Game elements used by other researchers

Elements	Authors
Badges	Aldemir et al. (2018), Hew et al. (2016),
Challenge level	Howland et al. (2015), Lister (2015), Chen (2016), Derboven et al. (2016), Law et al. (2016), Martinovic et al. (2016), Sung et al. (2017)
Clear goal	Chen (2016), Derboven et al. (2016), Martinovic et al. (2016), Sung et al. (2017),
Clear rule	Chen (2016), Martinovic et al. (2016)
Exploration	Lester et al. (2014), Mclaren et al. (2017)
Feedback	Chen (2016), Martinovic et al. (2016), Sung et al. (2017), Brezovsky (2019),
Leaderboards	Aldemir et al. (2018), Dicheva et al. (2015), Gauthier et al. (2015),
Mini-games	Derbovan et al. (2016), Gauthier et al. (2015)
Module-based	Law et al. (2016), Sung et al. (2017),
Multiple lives	Martinovic et al. (2016),
Narrative	Aldemir et al. (2018)
Rewards or items	Aldemir et al. (2018), Lester et al. (2014), Dicheva et al. (2015), Derboven et al. (2016), Hew et al. (2016)
Power-ups	Lester et al. (2014), Gauthier et al. (2015)
Role-playing	Howland et al. (2015)
Scaffold	Law et al. (2016), Martinovic et al. (2016), Sung et al. (2017),
Score	Gauthier et al. (2015)
Time pressure	Aldemir et al. (2018), Brezovszky et al. (2019), Lester et al. (2014), Derboven et al. (2016)

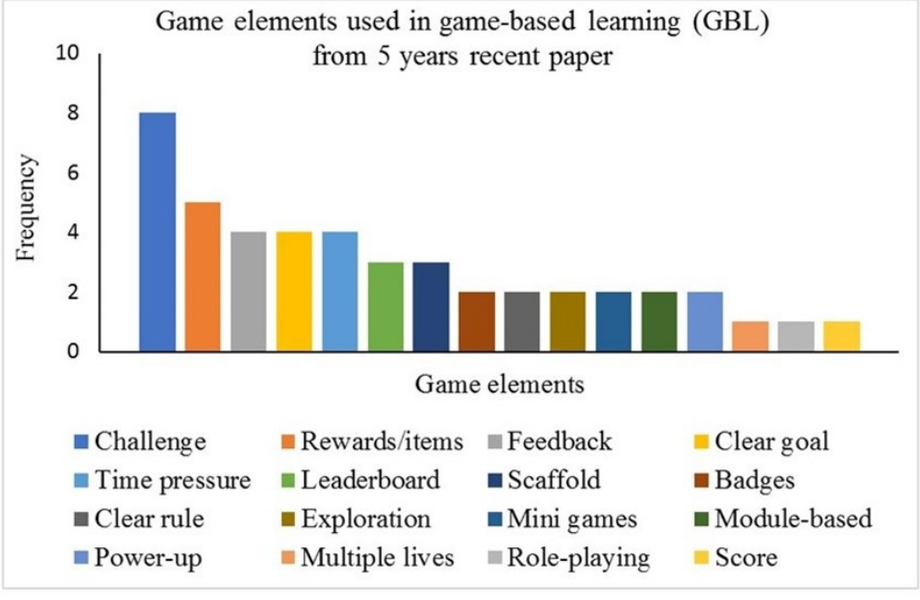

FIGURE 2. Game elements reported in the studies

reading the content and exploring the needed points from the game (Aldemir et al., 2018). Participants perceptions have been observed and recorded based on game elements. Though challenges are necessary for a gamified learning environment, the challenge may not suit with students' abilities, which eventually reduce the engagement and learning as they are frustrated with the result (Abdul Jabbar and Felicia, 2015). The challenges affect participants in many ways as their perceptions were categorized based on their engagement, team skills, collaboration, challenge type, and repetitiveness.

REWARDS OR ITEMS

The rewards/items are related to digital points or points (for short), refers to a token that can be collected by users. The tokens can be used as a status indicator, to unlock access to certain content, or to spend on virtual goods or gifting (Hew et al. 2016). These points can also be in terms of items that will be rewarded to the player in a specific condition. Aldemir et al. (2018) reported in their paper that the majority of the participants like the rewards provided in the game. As in participation, the rewards help to motivate participants

in online and in-class activities. However, the rewards are highlighted as an element that needs to continuously and systematically be in the game (Ronimus et al. 2014). For instance, the participants commented for each activity in a gamified learning environment, to have value and points collection.

FEEDBACK

Johnson et al. (2017) reveal the results of the game element used from 25 primary studies on energy consumption related games collected from the year 2007 until 2014. From Figure 3, the feedback element has the highest frequency of application in energy consumption related games. They reported that the feedback has been useful in promoting energy conservation, as it has become an effective strategy for user encouragement. In the order of application frequency, the game element feedback was the highest, followed by challenges, social sharing, rewards, leaderboards, points, tips, level, rankings, avatars, badges and user-generated content.

CLEAR GOAL

Some research defines the goal or a game objective as a gamification component rather than a game element. However, most researchers agree that a goal for a GBL is included as a game element (Nacke et al. 2017). Based on Chen et al. (2016), their game showed a clear goal on learning the concept of force and motion in Physics. The game helped targeted students to focus on the chosen topics and to avoid distraction from other topics. Martinovic et al. (2016) classified one of the good qualities of computer games is having a clear goal that matched the player skill level. Thus, their research highlighted that engagement in gaming is related to game performance.

TIME PRESSURE

Time pressure element is significant in a way that player has to divide their attention between solving the task and the game mechanics, such as shooting and avoiding traps. The time pressure will create a situation where players have to be fast but at the same time, not losing focus towards the given task (Derboven et al. 2016; Ronimus et al. 2014).

AFFECTING FACTORS FOR THE GAME ELEMENTS USED IN DESIGNING THE GAME

The study aimed to investigate the most popular game elements used in STEM GBL in recent years.

Thus, reviewed papers show the significance of the impact of game elements used in a GBL. As shown in Figure 4, the highest impact from embedding the game element in STEM GBL was in learning performance, which is 33% followed by engagement (21%), knowledge level (17%), motivation (13%), cognitive effect (8%) and enjoyment (8%). The learning performance included the learning effectiveness, identification of learning objective, knowledge on STEM subject, increasing user awareness and gaining conceptual knowledge. The impact of engagement relates to user experience or attitude that they show towards the applied games. The engagement also included the user satisfaction and usability of the game (Johnson et al. 2017). The impact of engagement and motivation has been proven by Pesare et al. (2016) on their study for medical students in STEM GBL learning. Meanwhile, the impact of enjoyment (Aldemir et al. 2018; Fitz-Walter et al. 2017) and cognitive impact (Chang et al. 2017; Huang 2011; Ku et al. 2016) also has been mention in the studies.

The utilization of game elements has been discussed on other related issues regarding users' preferences for a STEM GBL (Aldemir et al. 2018). From a more practical perspective, students need to recognize the importance of problem-solving game elements features. Whenever the game developers manage to identify the vital requirements for the learning process to occur and link to the user, a well-connected of knowledge transfer can be developed, and students can have the opportunities to practice in various STEM topics. (Brezovszky et al. 2019). The added value of GBL depends on the design process, where the learning content integrated and not just added on top of the game-based media (Rice et al. 2018). GBL will allow students to interact with the content in a novel alternative way that would otherwise be unavailable or difficult to achieve in the traditional classroom practice (Arnab et al. 2015).

Currently, GBL is an accessible technology that embedded STEM subject as the focus of research education. Based on several studies, GBL triggers many potential impacts on students learning. Briefly, GBL gives a positive impact on engagement (Abdul Rabu et al. 2017; Aldemir et al. 2018; Gauthier et al. 2015; Gilliam et al. 2017; Ronimus et al. 2014), motivation (Aldemir et al. 2018; Erhel et al. 2013; Huang 2011), in learning (Bano et al. 2018; Brezovszky et al. 2019; Qian et al. 2016; Zydney et al. 2016), for enjoyment (Abdul Rabu et al. 2017; Kao et al. 2017; Ronimus et al. 2014), and producing satisfaction (Aldemir et al. 2018).

The game mechanics incorporated, have positively affected the students' cognitive and behavioural engagements (Hew et al. 2016). Game mechanics used in the education-related course, which are points, badges, and leaderboard offer great help in motivating students to engage in the tasks. It is essential to build students engagement to enhance in students learning and participation (Abdul Jabbar et al. 2015; Hew et al. 2016). A typical application for gamification that leads to engagement is by making the tedious and repetitive tasks in a lesson becomes more interactive and better as a way of learning (Nacke et al. 2017; Pesare et al. 2016). The game immersion also gives an impact on the GBL process (Cheng et al. 2015).

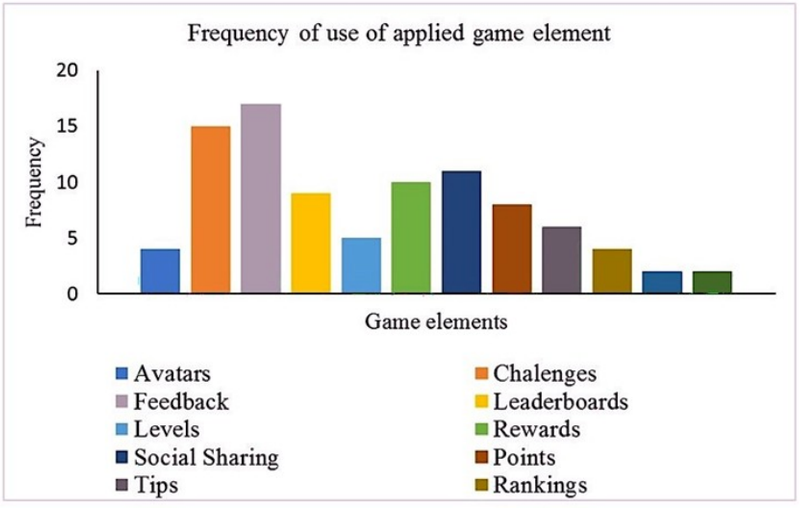

FIGURE 3: Adapted from *Johnson et al. 2017*

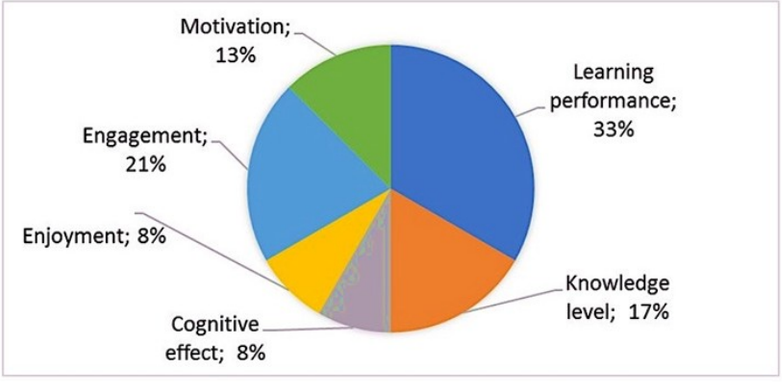

FIGURE 4. Impact of the game elements used

Fabian et al. reported that students learning performance and achievement interlinked with their attitudes towards the use of the mobile device. Positive results on attitude towards mobile technologies give a positive result in terms of students achievement (Fabian et al. 2016). The learning process has been made easier using the GBL platform. The use of mobile digital game has been proven to promote the effectiveness of learning (Boyle et al. 2016; Heflin et al. 2017; Kao et al. 2017; Lister 2015; Sung et al. 2016).

The results from this review have highlighted the most popular game elements used in these recent five years. The game elements stated are challenges, rewards or items, feedback, clear goal, last but not least time pressure. The importance of the game elements in engaging user depends on how the game designer is utilizing those game components and incorporate into the educational setting. Thus, learning through a mobile application is still need to be studied more in-depth, especially in sustainable energy in Malaysia (Abdul Jabbar et al. 2015). As the researcher aimed to develop a better GBL STEM in sustainable energy, this review may help in guiding the process to create better educational tools for STEM subjects.

Nevertheless, the activities in GBL must be carefully developed so that the strengths of the mobile digital game can be fully utilized to promote significant learning (Heflin et al. 2017). Abdul Jabbar et al. suggested to consider more sensory and playful in the learning experience if the learning content can be accessed through a selection of virtual characters, environments, narratives and multimedia elements, (Abdul Jabbar et al. 2015). The learning process can be gained whenever those elements are being integrated and combined to facilitate players' interest and keep their focus maintained.

CONCLUSION

This study highlighted that the most popular and commonly used game elements in STEM context within recent years of 2015 until 2019 are the challenge followed by rewards/ items, feedback, a clear goal, and time pressure. The collected data and informative finding in this study provided insight into the game elements, which actively used for STEM education and can assist in the development of other GBL for students education. The motivating features of the

game element might lead to the digital game becoming a useful new method in students' learning and empowerment.

ACKNOWLEDGEMENT

The authors would like to thank Universiti Kebangsaan Malaysia for the financial support under the grant DIP-2018-014.

DECLARATION OF COMPETING INTEREST

None.

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