SEMARAK ILMU PUBLISHING

Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage:
https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

Using BioBoard-G: A Board Game for Enhancing Understanding of Cell Division for Secondary School

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ARTICLE INFO

Article history:
Received 16 June 2023
Received in revised form 9 December 2023
Accepted 26 December 2023
Available online 30 January 2024

Keywords:
Board games; cell division; biology

ABSTRACT

Gamification uses game design elements in digital or non-digital games to improve students' knowledge and skill acquisition in a learning environment. Previous research found that gamification outperformed traditional instructional methods, but few compared the differences between different game types. This study aims to develop BioBoard-G (an educational board game for secondary biology schools) and to test its effectiveness in enhancing student's achievement in cell division topics as compared to online gamification. ADDIE model was used to develop BioBoard-G. To seek the answers a quasi-experimental technique was adopted. Two groups of students from two different schools were involved in the study which are the experimental group (BOARD-G) (n=31) and one control group (E-GAME)(n=30), and both groups have equivalent characteristics. Correspondingly, each group was taught by the same teacher and participated in the same courses and tests before using different teaching methods. Student achievement was analysed using the mean score of the pre-test and post-test. The main findings show that the mean scores of students who were exposed to newly-developed BioBoard-G are significantly higher than students who were exposed to online gamification in the post test with $t(59) = 2.480$, $p < .05$. The implication of this study can be seen in terms of practice in the school context in which it provides an alternative tool for teaching and learning biology.

1. Introduction

Using board games as teaching aids certainly promises a different learning environment and experience than a one-way learning environment. Previous studies show that the teaching method has brought various positive implications, especially for students. The application of game activities in learning increases learning motivation, engagement, and student concentration due to their challenging and fun nature [1-3]. In addition, the designed entertainment medium also successfully

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https://doi.org/10.37934/araset.38.2.8394

brought about cognitive and understanding changes and even created a positive interaction atmosphere among players [4]. They can play the board game and make mistakes again while learning. In other words, students will not feel pressured and instead learn from their mistakes.

The topic of cell division is one of the essential topics in biology. However, previous studies show that cell division is the most challenging topic to master in biology [5,6]. Studying this topic requires a high level of imagination to precisely understand the concept of cell division. Students cannot see the process with the naked eye but must use a high-powered microscope [7]. The level of understanding and conceptual knowledge of students of various ages and educational levels in cell division is less than satisfactory. Several conceptual weaknesses occur among students on this topic of cell division, among which are not being able to identify the main distinguishing characteristics of mitosis and meiosis well [8,9] and do not understand the importance of mitosis and meiosis in life [10]. Other than that, many students overlook the process of crossover and independent arrangement of chromosomes that occurs during meiosis I causing each gamete cell produced by the same individual to receive different genetic content [8]. As a result, students will not be aware of the effects of the chromosomal treatment that produces variation among children, which is vital to guarantee the survival of a species. Most biology teachers agree that the treatment of chromosome activity during prophase I of meiosis is the most challenging part to explain to students during the learning process. The terminology or terms used in the title of cell division are also entirely foreign and confusing to students [11]. What is more worrying is that the misconceptions about cell division will impact students' understanding of more complex life processes such as reproduction, growth and genetic inheritance [9,12].

The last few studies have used different methods to teach the cell division topic. Some teaching methods also integrate technology in teaching cell division in parallel with the explosion of information technology that occurs today in the production of various gadgets such as laptops and smartphones with various functions. Apart from that, the use of android-based interactive multimedia materials has a positive impact on increasing students' understanding of cell division [13]. Furthermore, adding animation elements in multimedia is proven to help students reduce cognitive load compared to multimedia that uses static diagrams [14]. The nature of animation transitions can guide students' attention and help them focus on important information. It is very suitable to be adapted in learning cell division, which is loaded with changing cell activity and chromosomes.

However, a study conducted by Wiggins [15] on university students found that most respondents prefer to apply non-digital gamification, such as board games or card games, compared to games that use digital simulation during learning. They found that non-digital gamification is more accessible than digital gamification. After all, it does not require technical skills compared to digital games and simulations. The digital gamification teaching approach requires hardware such as a computer or tablet to implement learning. This involves a high financial allocation compared to the more straightforward use of non-digital gamification. Although the hardware for digital games is sufficient, it still depends on the strength of the internet wave to ensure that the videos and visuals displayed are not interrupted [16].

Therefore, it has inspired us to enhance student understanding in learning cell division by developing an educational board game. Board games for learning are relevant in any school subject, and students' needs are exposed to diverse pedagogies in teaching the topic of cell division. However, it must be ensured that it impacts students' conceptualisations that are more meaningful in learning. Hence, learning now needs to focus more on the needs of the current generation, who are always excited to try something new and like to learn creatively and interactively.

2. Methodology

In this research, the teaching and learning method of the cell division topic was the independent variable. In contrast, the dependent variable was student achievement in the pre-test and post-test cell division concepts. The BioBoard-G board game contains two game boards: The Bio-Pirate Quest and The Meiosis Race. The purpose of the game was developed to help students improve their achievement in the topic of cell division. The materials and activities contained in the game are designed based on the contents of the secondary biology curriculum by the Malaysian Ministry of Education. The production design of BioBoard-G is based on the ADDIE development model involving five main stages: analysis, design, development, implementation and evaluation. Table 1 shows the setting of learning standards compiled in both game boards.

Table 1
Setting learning standards in BioBoard-G

Board games	Learning standards
The Bio-Pirate Quest	• Cell division • Cell cycle and mitosis
The Meiosis Race	• Meiosis • Cell division issues against human health

The study began by analysing the level of understanding of 45 students of the basic concept of genetics using the Two-Level Genetic Diagnostic Test developed by Kilic [17], which translated into Malay. The diagnostic test is appropriate and equivalent to the content standards of the biology curriculum used by secondary school teachers and students in Malaysia [18]. Based on the lowest percentage and mean, the findings demonstrate that most students have misconceptions about the relationship between cell division and inheritance. In addition, a poll of 45 biology teachers from secondary schools revealed that more than 70% had never taught cell division using gamification. The primary barrier preventing teachers from using gamification-based teaching aids in cell division is the amount of time required to create appropriate materials.

Subsequently, the design phase is implemented. Researchers focused on designing BioBoard-G, which integrates the theory of cognitive and social constructivism to improve students' achievement in cell division. The use of cognitive constructivism in learning allows students to build knowledge structures based on the cognitive levels of Bloom's taxonomy through the involvement of appropriate thinking skills while handling board games. The selection of social constructivism is created through interaction in pairs, making reflections, listening actively, being able to give feedback, asking questions, making suggestions, formulating, offering guidance and advising [19,20].

In addition, in this phase, the researcher has adopted the steps of the gamification process proposed by Hoe [21] to produce quality games that can positively impact students. According to Hoe [21], five processes must be followed: set goals and game rules, game design, feedback design, game space design and game story design. However, for this study, the researcher only used the proposed four steps of gamification design since the researcher wants to develop does not involve the design of the story part (narrative element). Thus, those elements can be ignored according to the suitability of the gamification design that one wants to develop [21]. The four steps of the gamification process implemented in BioBoard-G are summarised in Figure 1.

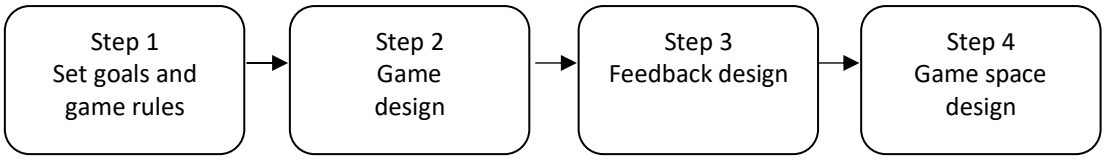

Fig. 1. Four steps of the gamification process adapted from Hoe [21]

After the design phase is completed, the development phase will validate the content, game activities and instruments test set. The confirmation process for the appropriateness of the board game content and the pre-post-test was obtained from four experts consisting of experienced teachers in the secondary school biology curriculum and university lecturers in Malaysia. Referred experts will evaluate the game in terms of design and content. Correspondingly, based on recommendations and assessments from the engaged experts, changes were made to both the board games included in BioBoard-G and the pre-post-test. As a result, BioBoard-G content validity was obtained at 86.79%. Based on Tuckman and Waheed [22], the achievement level of 70% is considered to have reached a high level of achievement for the determination of good content validity. Note that the questions in the pre-and post-test consist of different questions but are equivalent in terms of cognitive level. The question items used in both tests are objective and subjective. The time allocated is merely 30 minutes or a half hour. The pre-post-test created questions were drawn from a database of authentic SPM (Malaysian Certificate of Education) questions from 2010 to 2019. The Kappa agreement value given by the expert assessor for the pre-test is 0.709 and for the post-test is 0.738, respectively.

As a result, BioBoard-G (Figure 4) contains two board games for teaching the topic of cell division. The Bio-Pirate Quest contains a game board, four pawns, twelve checkers, an hourglass, 70 question cards and three answer cards. The game board for The Bio-Pirate Quest was printed on a sheet of glossy art paper measuring A3 and having a thickness of 0.3 mm. Meanwhile, The Meiosis Race consists of a game board, eight pawns, one dice, two hourglasses (30 seconds and 60 seconds), 70 question cards, a marker pen, a DIY whiteboard and student answer sheets. The game board for The Meiosis Race was printed on a square-sized piece of glossy art paper. Figure 2 and 3 illustrate the developed The Bio-Pirate Quest and The Meiosis Race game boards.

Fig. 2. The Bio-Pirate Quest game board

Fig. 3. The Meiosis Race game board

Fig. 4. The sets of BioBoard-G board game

The challenges selected in The Bio-Pirate Quest and The Meiosis Race are race and time pressure, factual knowledge and conceptual reasoning based on eleven challenges suitable for application in educational gamification, as Hoe [21] listed. The challenge features based on the type of racing challenge and time pressure applied in The Bio-Pirate Quest is that players have to deal with obstacles made by other players to slow down the movement of pawns to the treasure site using checkers. Moreover, players are limited by the time allotted for each question, which is only 30 seconds. For the type of challenge based on logical reasoning and factual knowledge, each colour of the site on the board game represents a cognitive level which is low-level and high-level thinking skills.

Meanwhile, in The Meiosis Race, the player who collects the highest score or reaches the finish line first is counted as the winner. In addition, players are also bound by time constraints because the time allocated is only 30 seconds for all types of questions and 60 seconds for drawing diagrams of cell division. Players will be tested with questions about their knowledge and understanding of cell division. Table 2 and 3 show the format of the questions on each question card in The Bio-Pirate Quest and The Meiosis Race board games.

Table 2
The question format is based on the colour of The Bio-Pirate Quest board game

Colour	Questions format
	Matching
	Objectives
	True or False
	Subjective

After the completion of the validation process by experts, the study continues with the implementation phase. In this phase, a pilot study was conducted to obtain the reliability value of BioBoard-G. The researcher developed a questionnaire containing 31 items based on the learning objectives in Malaysia's secondary school biology curriculum. This questionnaire was distributed to 32 biology secondary school students. From the analysed data, it was found that the reliability value of BioBoard-G is at a high level of 0.88. Therefore, the development of BioBoard-G has good reliability according to the student's point of view. After the pilot study was conducted, several improvements

were made to BioBoard-G so that the quality of teaching and learning about cell division could be improved.

Table 3
The question format is based on the colour of The Meiosis Race board game

Colour	Questions format
	Terminology Draw the diagram
	Objectives True or False
	Subjective

Consequently, the study continues by entering the evaluation phase. For the evaluation phase, a quasi-experimental study was conducted in two secondary schools for four weeks. Both schools were observed that have similar characteristics at the beginning of the research, which is essential for reducing bias in the quasi-experimental procedure. The selection bias was decreased in this study by selecting two groups with comparable characteristics in terms of age, subjects studied, the number of students in the class, pre-test scores, and learning environment. After determining which school's characteristics were equivalent, random assignment was used to determine which school would serve as the experiment group and which as the control group. In a quasi-experimental research situation, existing groups need to be used based on certain factors such as the availability of subjects, the study's objectives and established rules [22]. Students in the experimental group were taught using BioBoard-G, while students in the control group were taught online gamification. Figure 5 defines the design of this study.

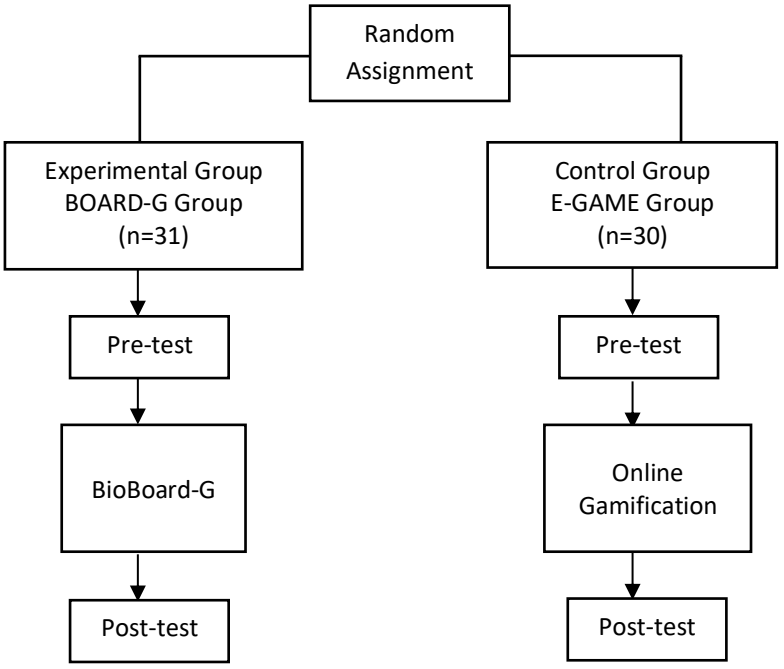

Fig. 5. Pre-test-Post-test comparison group design

Students of the two classes used different instructional approaches (see Table 4). Students of class A (BOARD-G group) students used BioBoard-G, while class B (E-GAME group) used online gamification. The same teacher taught all the classes.

Table 4
Groups and interventions

Item	Class A	Class B
Number of students	31	30
Type of gamification	Board games	Online gamification

The digital gamification used by class B was a free internet platform: *Kahoot!, Quizizz*, *Gamilab* and *Quiz Whizzer* (see Figure 6). The online gamification approaches include game challenges with clear goals and instant feedback, and the level of difficulty of the questions provided has the same cognitive level as activities provided in BioBoard-G.

Fig. 6. Free internet platform used for online gamification teaching method

The result of pre-post-tests for the BOARD-G group (N = 31) and E-GAME group (N = 30) were analysed to test the hypotheses. The four research hypotheses are:

i. H_{01}: There is no significant difference in the pre-test scores between the BOARD-G and E-GAME groups.
ii. H_{02}: There is no significant difference between pre-test and post-test scores in the BOARD-G group.
iii. H_{03}: There is no significant difference between pre-test and post-test scores in the E-GAME group.
iv. H_{04}: There is no significant difference in the post-test scores between the BOARD-G and E-GAME groups.

3. Results

The evaluation phase in the ADDIE model is discussed in detail in this section. The results of the pre-test mean scores for the BOARD-G and E-GAME groups are shown in Table 5.

Table 5
Pre-test mean scores for BOARD-G and E-GAME groups

Group	N	M	SD	t-value	Significance
BOARD-G	31	9.52	3.669	1.327	0.190
E-GAME	30	8.30	3.485		

The null hypothesis failed to be rejected because there were no significant differences in the pre-test scores between the BOARD-G group (M = 9.52, SD = 3.669) and E-GAME group (M = 8.30, SD = 3.485; t = 1.327, p = 0.190), where p-value was more significant than 0.05. Hence, there is no significant difference in pre-test achievement between the BOARD-G group and the E-GAME group students. Furthermore, although the sample selection for both groups was not conducted randomly, the initial level of achievement of the students in the subject of cell division for the study sample was equivalent and homogeneous.

Table 6 presents that the post-test score's mean value is higher than the pre-test score. There is a significant difference between the pre-test score (M=9.52, SD=3.669) and the post-test score (M=11.94, SD=3.540) with t (30) = -4.652, p = 0.00, where p-value was less than 0.05. This shows a significant improvement in the post-test scores compared to the pre-test scores of the group after using BioBoard-G board games. Therefore, the hypothesis that there is no significant difference in the pre-test and post-test mean scores for the BOARD-G group is rejected.

Table 6
BOARD-G group's mean scores for pre-test and post-test

BOARD-G	N	M	SD	t-value	Significance
Pre-test	31	9.52	3.669	-4.62	0.000
Post-test	31	11.94	3.540		

Based on Table 7, there is a significant difference between the pre-test score (M=8.30, SD=3.485) and the post-test score (M=9.97, SD=2.566) with t (30) = -3.808, p <.05. This demonstrates that there is a significant improvement in the post-test scores compared to the pre-test scores for the group after using online gamification. Thus, the hypothesis that no significant difference exists in the E-GAME group's pre-test and post-test mean scores are rejected.

Table 7
E-GAME group's mean scores for pre-test and post-test

E-GAME	N	M	SD	t-value	Significance
Pre-test	30	8.30	3.485	-3.808	0.001
Post-test	30	9.97	2.566		

Based on Table 8, the results exhibit a significant mean difference (t = 2.480, df = 59, p < 0.05) between the post-test scores of the BOARD-G group and the E-GAME group after conducting experiments. The null hypothesis is rejected because the p= 0.016 is smaller than 0.05. Therefore, there is a significant mean difference in the post-test scores between the BOARD-G group and the E-GAME group. Furthermore, the mean post-test score of the BOARD-G group was higher than that of the E-GAME group. Hence, the teaching approach using the BioBoard-G board game was more effective in improving students' understanding of cell division than online gamification.

Table 8
Post-test mean scores for BOARD-G and E-GAME groups

Groups	N	M	SD	t-value	Significance
BOARD-G	31	11.94	3.540	2.480	0.016
E-GAME	30	9.97	2.566		

Our findings demonstrated that students in the board game group outperformed those in the online gamification group regarding achievement in cell division topics. This indicates that employing board games as a learning strategy has a lot of potential for supporting the teaching of science information and enhancing students' learning. The results of this study corroborate Wang and Zheng [24], which demonstrate that non-digital approaches to teaching science produce superior student achievement than digital gamification. The study also shows the potential of board games in science instruction to enhance students' comprehension and mastery of scientific ideas [25,26]. This statement is also proven parallel by Bayeck [27] through a systematic highlight analysis of the use of board games to help students improve their understanding of complex science concepts. Using board games in learning might give students more implicit and direct feedback than digital gamification, making it easier for them to overcome the difficulty in accomplishing tasks and achieving goals.

The findings of this study are also consistent with the theory of constructivism that underlies the development of BioBoard-G, which is that student knowledge is built through communication and the exchange of opinions during game activities. Other than that, the application of cognitive constructivism theory occurs when the structure of cognitive skills such as remembering, understanding, analysing, applying, evaluating and creating in the topic of cell division will be taught to students in stages and according to the level of personal abilities of students. While the application of social constructivism theory is trained through interaction in pairs and allows students to reflect, listen actively, give feedback, ask questions, make suggestions, formulate, offer guidance, and advise [19,20]. The two learning theories have been used as a reference in the planning and production of appropriate gamification to obtain a practical learning impact.

Note that both approaches show improvement in terms of achievement. This is because both approaches use applying game elements. The teaching and learning process that adapts game activities creates active engagement among students and even increases students' understanding of abstract and complicated science concepts [28]. Therefore, the human brain more readily accepts information processing in a relaxed and fun environment [29]. Fantasy elements used in game design can increase the cognitive level, thus helping to improve students' understanding of science learning. In addition, maturity factors can affect the results of this decision; students become more skilled at a topic when they are always given reinforcement related to it [30]. Apart from that, game elements provided by online gamification increase motivation and are liked by students [31]. Even so, the online training and quiz method given to the students of the E-GAME group is one form of reinforcement that is shaped to the memorisation process rather than the mastery of the science concept itself. Their learning does not involve active involvement or interaction with their peers, and the class atmosphere is not as active as the group that uses board games. The quick hit of success also brought a problem in that students had no time to reflect on what kind of knowledge they had used during the task [24]. This is also supported by a study conducted by Nisa *et al*., [32] who found that online gamification does not encourage active communication and discussion among teachers and students. Thus, it does not meet the principles of good feedback learning. This is because the test is done quickly, and the answer is only displayed for a few seconds. Therefore, the discussion about the answer could not be carried out due to limited time constraints.

However, the findings of this study are contrary to the findings of a study conducted by Wang and Zheng [24], which showed no significant difference in science achievement using non-digital and digital gamification. The study's findings show that student science achievement is almost the same for students exposed to digital and non-digital gamification in science teaching. The findings of this study are also in line with the meta-analysis conducted by Talan, Doğan, and Batdı [33] over fifteen years, which found that teaching approaches using digital or non-digital gamification positively impact student achievement. The responsive environment through gamification encourages

students to know what they are doing in the game immediately. This will maintain the student's involvement and interest in following the learning process, and even more skills and knowledge that the student will acquire will help in solving problems related to cell division, increasing the student's achievement in the topic.

Our findings reinforce the findings of previous studies about the use of board games to help students improve their understanding of complex science concepts. We make two recommendations for researchers and educators interested in using board games for science learning based on our findings. First, because of the merits of educational board games, we recommend that researchers and developers design to develop more board games that can support teaching science knowledge. Nowadays, game mechanics or rules provided in board games are familiar among students, focusing on the content of game activities rather than studying complicated game rules. Other than that, our findings indicate that board games can benefit students' learning performance. Therefore, developing more board games for teaching science can enhance the quality of science education. For a quality board game, it is crucial to provide immediate feedback to students so that they can quickly reflect on their gameplay and learning.

Secondly, emphasis was placed on physical or tabletop games that do not require using technology equipment directly. Future researchers are encouraged to investigate the potential and effects of learning and instructions via hybrid board games, which combine physical and digital elements. In line with the digital era, traditional board games can now incorporate interactive digital features like augmented reality, video games, and quick response (QR) code scanning, all of which can be created using smartphones and tablets. With those features, digital elements in board games can better support teaching and learning in science classes.

4. Conclusions

This study was conducted to test the effectiveness of the gamification approach on secondary school biology students on cell division in Malaysia. We implemented an experiment to compare the effects of non-digital and digital gamification. Our results showed that students using board games performed significantly better in achievement in cell division topics than online gamification. This demonstrates that using board games as an approach to learning shows great potential to support teaching science knowledge and facilitating students' learning. Although board games are not as sophisticated as other digital designs, they offer a different and exciting pedagogy through playing activities. Moreover, board games play a unique role because they can solve learning problems simultaneously, and students can interact with learning materials directly that board games have the potential to improve problem-solving skills through active face-to-face discussions that certainly differentiate the experience with users who rely on digital gamification.

Acknowledgement

This study was supported by the scholarship and funding division of the Malaysian Ministry of Education.

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