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DESIGN, DEVELOPMENT, AND EVALUATION OF DIVTCELL APP: GAMIFYING EUKARYOTIC CELL DIVISION AND ITS EFFECTS ON ACADEMIC ACHIEVEMENT

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ABSTRACT

Due to the increasing popularity of digital games, educators worldwide have grown interested in designing and developing gamified learning systems to facilitate learning. The study utilized a design and development research design to develop a gamified learning app, DivTCell, to teach eukaryotic cell division to high school students. The application was designed based on suggestions from science teachers and emerging themes in the literature. It was then evaluated by science teachers using an application evaluation rubric. The DivTCell was implemented in one in-tact class to examine its effects in improving students' academic achievement. Results from the evaluation show that the application have accurate concepts, accessible, and functional. Similarly, improvements in academic achievement were also noted after the implementation of the app as shown in the significant difference in the scores for the pretest ($M=26.80$, $SD=2.32$) and posttest ($M=30.76$, $SD=2.44$) conditions; $t(45)= -8.49$, $p = 0.00$. Effect size was also calculated at $d=1.25$, indicating high practical significance. Game elements such as badges, leaderboards, challenges, and autonomy are essential in motivating students to learn. These results demonstrate that when end users are in mind in developing a gamified learning system that positively affects students' academic achievement.

Keywords: academic achievement; gamification; learning application; mobile application

INTRODUCTION

Gamification uses game design elements and aesthetics in non-game contexts (Zimmerling et al., 2019; Sailer & Homner, 2020). Moreover, in an increasingly digital world, many aspects of our lives rely on technology (Pusey & Pusey, 2015). Both gamification and digital technologies received increased attention and interest in academia and educational practice due to their hypothesized motivational power as a method in an instructional context (Grimalt-Álvaro et al., 2019; Sailer & Homner, 2020). Aside from its massive benefit on motivation, gamification learning contexts positively benefit user interaction and social effects. Due to these benefits, gamification has been increasingly accepted as a helpful learning tool for developing more engaging learning environments (Limbaco et al., 2021; Saleem et al., 2022). However, as gamification gains traction, so do the negative comments describing it as the "latest buzzword and the next fad" (Boulet, 2012) and "Pavlovication" (Klabbers, 2018). Several authors also identified issues and challenges in implementing gamification in the classroom (Domínguez et al., 2013; Gené et al., 2014; Sombrio et al., 2014).

Science education is essential to education in the 21st century, but there are several issues that need to be addressed (Bactong et al.,

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2021; Kalogiannakis et al., 2021; Walag et al., 2022). A critical problem science education faces is students' negative emotions and experiences towards the subject. Students find science challenging to understand, resulting in rejection and dropout rates (Mellado Jiménez et al., 2014; Vidakis et al., 2019; Hartono et al., 2023). Similarly, teachers' lack of interest, knowledge of content, pedagogy related to science teaching, and general negative experience towards science can be redirected to students (Costillo Borrego et al., 2013; Rubini et al., 2018; Walag et al., 2020; Bug-os et al., 2021b; Garcia et al., 2022). Teachers may also not be exposed to a wide variety of pedagogical strategies, resources, and game types that are known to improve and make digital game integration easier (Takeuchi & Vaala, 2014). For this reason, integrating gamification in science education is recently gaining traction in addressing students' engagement, joyfulness, and motivation to support curricular activities in science (Loganathan et al., 2019; Lasala Jr, 2022).

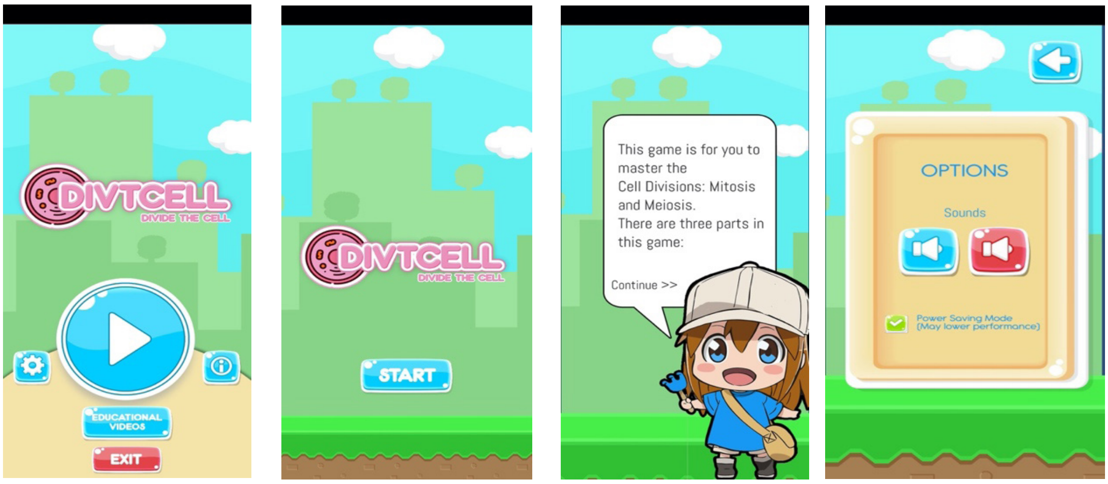
Several studies have integrated gamification into their science classrooms (Wilson et al., 2018). For example, digital games were integrated into teaching chemical reactions between metals and the reactivity of different metals, and it was found that gamification enhanced emotional and behavioral engagement (Khan et al., 2017). Similarly, when Kahoot was used in a biology class, students enjoyed and actively participated (Yapıcı & Karakoyun, 2017; Jones et al., 2019; Kalleny, 2020). In addition, augmented reality has also been used to teach cell biology topics and has shown high usability (Lam et al., 2023). Aside from developing engagement and motivation, students were also found to develop an increased understanding of plants when gamification is integrated into their elementary biology class (Borsos, 2019). These reports highlight that biology topics require innovative teaching pedagogies to help improve students' engagement, motivation, and understanding.

Due to the nature and complexity of biology topics, teachers often rely on visual-based activities as the main backbone of their teaching strategies. One lesson that requires significant visual resources to teach is cell division. For example, interactive courseware was developed to address misconceptions about cell division (Shamsudin et al., 2020). Another study utilized massive open online virtual reality courses to teach various biology topics, including cell division (Hewawalpita et al., 2018). Meanwhile, another study utilized computer-based multimedia instructional packages to teach cell division, addressing students' academic achievement (Akinbadewa, 2020). These studies demonstrate the efforts made by several researchers to address the gap in appropriate, contextualized, and visually appealing teaching strategies to teach cell division in a fun, motivating, and effective way. These studies only cover interactive and engaging elements but do not cover other significant predictors of learning which are integral to gamified learning environments. As such, this paper aims to design, develop, and evaluate a digital game that can be used to teach cell division to secondary school students. Further, the study will also examine the effects of digital games on students' academic achievement.

METHODS

The present study utilized a design and development research design (Limbaco et al., 2021) and a one-group pretest and posttest pre-experimental design (Bug-os et al., 2021a). A gamified app for teaching cell division was designed based on the initial qualitative data gathered from secondary school teachers combined with emerging themes from the literature. It was then developed, alpha- and beta-tested, and evaluated by science teachers as end users of this instructional material. The app was then implemented in one in-act class of senior high school students to examine its effects in improving academic achievement. Before the intervention, a pretest was administered to serve as baseline data for comparison of posttest scores collected after the intervention.

DivTCell is an educational app where learners can study cell division in eukaryotic cells in a gamified environment. The learners explore concepts and processes in mitosis and meiosis through concept notes, videos, challenges and questions, and other games in the app. The game primarily aims to complete all tasks and attain the highest score. Once the user opens the application, they will be directed to the welcome page (Figure 1A) and prompted to tap the start button. The user will be redirected to the play, settings, information, and educational videos selection page (Figure 1B). Once the user chooses the play icon, they will be redirected to Figure 1C, where "Cell-O," the in-game character, will greet them and explain the contents. Once Cell-O completes the orientations, the user will be redirected to Figure 1D to choose whether to play with or without sounds or use the power-saving mode.



(a) (b) (c) (d)

Figure 1. DivTCell Welcome Page Application Interface

Once the user taps the information icon in Figure 1A, they will be redirected to Figure 2A, which contains the information about the application, including the name of the developers, contributors, and references. Meanwhile, when the user taps the educational videos icon, they will be directed to Figure 2B, which contains additional learning materials to enhance learning on the topic. Users have the choice of which materials to interact with within this section

(a) (b)

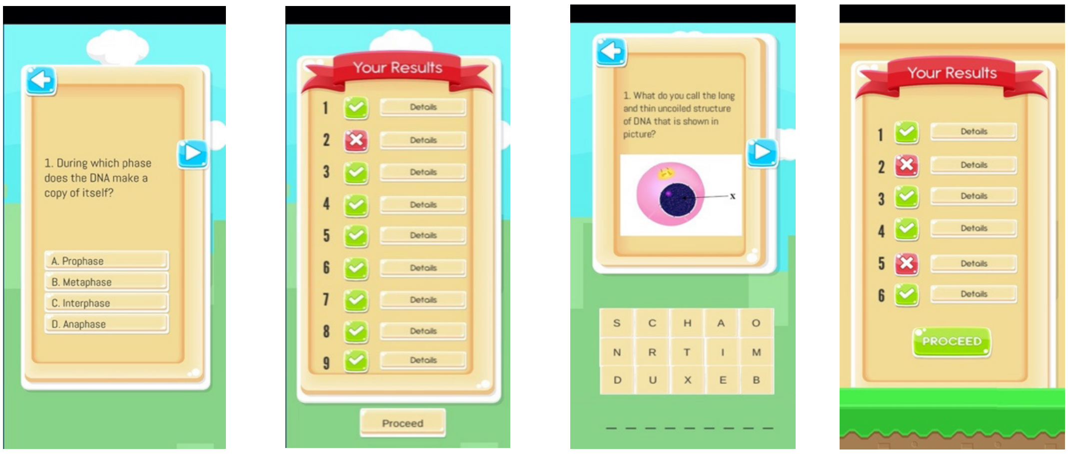
Figure 2. Information and Educational Video Pages of DivTCell

Once the user starts playing the game, they decide whether to play mitosis or meiosis first. These options are shown in Figure 3A, a continuation of Figure 1C. For example, if users choose mitosis, they will be redirected to Figure 3B, which reviews the concepts of mitosis. The user will then be prompted to tap the "go to mitosis map," leading them to Figure 3C. It contains a map with numbers that correspond to a mitotic phase. For example, if the user taps the number 1, corresponding to prophase, the app will redirect the user to the page explaining the prophase events, as shown in Figure 3D.

(a) (b) (c) (d)

Figure 3. Interface Showing the Contents of the DivTCell Application

Once the user completes all the stages in Figure 3C, they will be led to the game proper, shown in Figure 4. One game students can play in the application is a quiz game with a multiple-choice test, shown in Figure 4A. Students can interact with the questions on this page and gain points when getting the correct answer. Once the user completes the questions within a given timeframe, they will be redirected to Figure 4B, which shows the scoreboard. On this page, students can also interact with each item by getting an explanation for the right and wrong answers. Another game users can play is guess the word game shown in Figure 4C. In this game, the user answers the questions using the letters and clues provided. The user is only given three chances to choose the wrong letters, and once this runs out, a dialogue box will appear, providing the correct answer. Similar to the quiz game, a scoreboard with an explanation also appears after the game, as shown in Figure 4D.



(a) (b) (c) (d)

Figure 4. The Interface of the Game Proper of DivTCell

The present study utilized two instruments to seek answers to the research objectives. A revised Application Evaluation Rubric (Bactong et al., 2021; Garcia et al., 2022) was utilized to evaluate the application based on its accuracy, accessibility, functionality, and screen design. The revised rubric is presented in Table 1. The pilot-tested rubric yielded 0.81 Krippendorff's Alpha for interrater reliability, suggesting that the rubric has an acceptable interrater agreement (Saldo & Walag, 2021).

Table 1. Revised Application Evaluation Rubric based on Bactong et al. (2021) and Garcia et al. (2022)

Criteria	Very Good	Good	Fair	Poor
Accuracy	The presented contents are reliable and scientifically accurate.	The presented contents are reliable and scientifically accurate, although the scope is limited.	Some of the presented contents are not reliable and scientifically accurate.	The presented contents are not reliable and scientifically accurate.
Accessibility	The mobile application can be easily downloaded and does not require internet access to function.	The mobile application can be downloaded and requires internet access to function.	The mobile application requires internet access to operate	The mobile application cannot be downloaded and requires internet access to function.
Functionality	Users can use the application right away without any assistance.	Users can use the application right away with minimal assistance.	Users need guidance to show or model how to use the application.	The application is difficult to use, and users must be instructed each time.
Screen Design	The application's text, graphics, videos, and sounds are always organized to enhance the content.	The application's text, graphics, videos, and sounds are usually organized to enhance the content.	The application's text, graphics, videos, and sounds are poorly organized and may distract from the content.	The application's text, graphics, videos, and sounds are cluttered, confusing, and distracting.
Aesthetics	The application's graphics and interface most likely motivate users to engage with it.	The application's graphics and interface motivate users to engage with it.	The application's graphics and interface do not impact whether or not users are motivated to engage with it.	The application's graphics and interface will not likely deter users from engaging with it.

A researcher-made achievement test was also constructed based on the approved Table of Specifications and the procedures provided in the literature (Sarı et al., 2017). The items covered knowledge, comprehension, application, and analysis domains. The test was initially composed of 50 multiple-choice items and subjected to content and face validation by three science education and biology experts. The said test was also subjected to pilot testing at a nearby high school (Del Carmen National High School), yielding a 0.72 Cronbach's alpha which denotes acceptable internal consistency. After validation and reliability, one item was rejected, leaving only 49 items used in the experiment. The achievement test may be requested from the corresponding author.

Necessary permissions were acquired from the University of Science and Technology of Southern Philippines (USTP) and Siargao National Science High School before the conduct of the study. After approval was sought, participants were briefed before the experiment on the goals, potential risks, benefits, duration, procedures, and voluntary consent. Ethical clearance was also acquired from the USTP Research Ethics Review Committee. Only participants who voluntarily participated were considered part of the present study. A pretest for the achievement test was then given to 46 students of one-in-tact classes. Participants were then instructed to download the application installer from Google Drive and were asked to install it on their mobile phones. Ample time was given for the installation process. Once the app was installed, participants were given two occasions (one hour each) to explore and utilize the app for learning. After, a posttest was administered to measure the changes in their academic achievement.

Seven science teachers involved in the experiment and working in the school were tapped as expert evaluators to evaluate the developed application. They were asked to observe the class and then use the application once to develop a sound evaluation. They were then asked to rate the app using the revised application evaluation rubric.

Mean, standard deviation, and paired t-tests were utilized in the processing, analysis, and interpretation of the data. The application evaluation data were summarized using the mean and standard deviation. The paired t-test was used to see if the scores on the pretest and posttest were significantly different (Casino & Walag, 2020). Cohen's *d* was calculated, and Hedges' correction was done for each variable pair to determine the effect size. All statistical calculations were performed using R Statistical Package.

RESULTS AND DISCUSSION

The DivTCell mobile application was assessed regarding five criteria. Seven science teachers utilized the revised evaluation rubric to assess the application's overall performance and recognize the comments or suggestions to enhance the application. The evaluation results are summarized in Table 2. The application is very good in all criteria except the aesthetic standards. As shown, accuracy has scored the highest. It is vital since accuracy tells that the presented contents are reliable and scientifically accurate for the user to trust and use the mobile app. The user must believe in the accuracy and reliability of the data (Postolache et al., 2022). Other science education apps easily scored the highest accuracy (Bactong et al., 2021; Garcia et al., 2022), highlighting the importance of accurate concepts embedded in gamified applications. In addition, this extends the accuracy of concepts on the perceived usefulness notion of the Technology Acceptance Model. When users find concepts to be accurate, they see the application to be useful in their learning.

Accessibility and Functionality criteria cover the application is ability to download, install, and use. This high rating is not surprising as the application was developed with ease of use in mind. As suggested, ease of use or functionality is one of the main factors attracting learners to using games in class (Zhonggen, 2019; Limbaco et al., 2021). In addition, perceived ease of use is one of the most important considerations for a user to decide whether to accept or reject a technology system (van der Heijden, 2003).

Design aesthetics have long been reported to impact enjoyment strongly (van der Heijden, 2003), and players frequently give positive reviews to games with aesthetic designs (Merikivi et al., 2017a). As shown in Table 2, aesthetics received the least score. This low score might be due to the highly animated design of the application, which may no longer be appropriate for senior high school students (19 to 20 years old). It is vital as design aesthetics have positively affected users' perception of the mobile system's ease of use, usefulness, and enjoyability (Merikivi et al., 2017b). To positively influence the perceived usefulness and ease of use, applications must be designed with the end users in mind.

Table 2. Evaluation of the DivTCell Application

Criteria	Mean ± SD	Description
Accuracy	3.86 ± 0.38	Very Good
Accessibility	3.71 ± 0.49	Very Good
Functionality	3.57 ± 0.53	Very Good
Screen Design	3.57 ± 0.53	Very Good
Aesthetics	3.14 ± 0.69	Good

To compare senior high school students' pre- and post-test academic achievement scores, a paired-sample t-test was performed. There was a significant difference in the scores for the pretest (M=26.80, SD=2.32) and posttest (M=30.76, SD=2.44) conditions; t(45)= -8.49, p = 0.00. Therefore, we reject the null hypothesis that there is no difference in academic achievement between the pretest and posttest. Further, Cohen's effect size value (*d*=1.25) suggested a high practical significance. This result suggests improving students' academic achievement after using the gamified app.

The improvement in academic achievement as a result of utilizing the gamified app is consistent with various studies examining the effect of gamification on students' academic achievement (Yıldırım & Şen, 2021). As reported, game elements help change students' perspectives on learning with the help of technology. In addition, game elements incorporated into learning platforms help learn abstract and complex topics more desirable and manageable (Cameron & Bizo, 2019). Students consider badges a motivational push to strive harder in learning (Sanmugam et al., 2016). This could be one of the reasons for the improvement in academic achievement, as digital badges are mostly used as a game element to improve students' learning and engagement (Abdul Rahman et al., 2018).

Aside from digital badges, the game challenge has also positively affected academic achievement (Udeani & Akhigbe, 2020). The need for challenge in education setup is also reflected in the game's difficulty level. When students are not challenged, they are not motivated to use the app, while too much challenge discourages students from using it. As such, an appropriate level of difficulty must be considered in the design of gamified learning systems (van Roy & Zaman, 2017). This game element is exemplified through the increasing difficulty and variety of questions and games integrated into the developed app.

Aside from game elements like leaderboards, challenges, and badges, gamification can also help students learn based the theory-based gamification heuristics. In educational contexts, students with choices and teacher and parental support are more engaged in learning (van Roy & Zaman, 2017). When learning is gamified, van Roy and Zaman suggest that the design should avoid forcing users to use a part of the gamified system in order for them not to feel controlled and that users must be given a certain level of autonomy. Based on this argument, the positive results on students' academic achievement may be due to the level of autonomy provided by the DivTCell gamified app. Students can utilize the app more flexibly and based on their needs, not in a straightforward and controlled manner.

CONCLUSION

In this study, a gamified learning application, DivTCell, was designed, developed, and evaluated. The results show that the app was accurate, accessible, and functional. Meanwhile, the app was also evaluated as low in the aesthetic component as it was found inappropriate for the target users. These results demonstrate the importance of designing an application based on user needs. Moreover, the use of the application helped improve students. As such, gamified learning systems show considerable promise in improving students' academic achievement in science. There are some limitations in this study that may have implications for further studies. Firstly, the present design of the application was based on an informal qualitative interview and literature review conducted, which may not reflect the general perspective on gamified applications. Second, the examination of academic achievement was only implemented in one class and no control group. Since this study was exploratory, a more robust experiment could be used for further studies, and qualitative design may be integrated to have a more concise conclusion. Furthermore, other confounding variables (sex, game duration, learning styles, and others) may be explored. The study had limitations. However, the findings still have important and practical implications for teaching, learning, and science education curriculum.

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