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Online game-based learning: A strategy to enhance learning of the cell division among Grade 11 STEM students

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ABSTRACT

This study examined the effectiveness of game-based learning in students' mastery of Cell Division, specifically in competencies related to identifying the phases of mitosis and meiosis and describing their structural changes. Using a pretest–posttest control group design, 30 respondents were divided into two groups: a control group that received traditional instruction and an experimental group that received game-based learning. Results showed that both groups exhibited low initial mastery, with pretest means of 10.13 for the control group and 12.73 for the experimental group. After instruction, both groups improved significantly, as indicated by paired t-tests with substantial effect sizes ($d = 3.05$ and $d = 3.02$, respectively). However, the experimental group attained a significantly higher posttest mean (25.67) than the control group (21.20), with a very large between-group effect size ($d = 1.38$). Although gain scores did not significantly differ, the experimental group's mastery level was considerably higher. Findings demonstrate that game-based learning enhances students' conceptual understanding more effectively than traditional teaching. The study recommends integrating game-based tools in biology instruction to support active learning, engagement, and high-level mastery of complex scientific concepts.

Keywords: Game-based learning, cell division mastery, mitosis and meiosis, student performance, experimental research design.

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INTRODUCTION

Biology education is widely recognized as a discipline that poses challenges for learners due to its abstract concepts and complex procedures. Cell division, especially meiosis, has consistently been recognized as one of the most challenging subjects to teach and understand. International research studies have shown that students find it challenging to understand the unnoticed processes involved in mitosis and meiosis, distinguish between the two stages, and connect genetic concepts with observable events (Brown, 2005; Duncan et al., 2009; Oztap et al., 2013). These enduring misconceptions hinder students' understanding of increasingly complex biological concepts, despite repeated instruction in the classroom.

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Similar difficulties are evident in the Philippine circumstances. The Department of Education DepEd (2012) states that General Biology I was designated as a core topic in the Senior High School curriculum as part of the K–12 Basic Education Program, which was implemented in 2012 to enhance STEM (Science, Technology, Engineering, and Mathematics) education. Despite these changes, many common misconceptions persist. Garciano (2019) found that Grade 10 students in Zambales exhibited significant misconceptions in genetics, with a prevalence of 55%, making it the most misunderstood science area among those assessed.

Maligalig and Paño (2023) observed that numerous Senior High School Biology textbooks provide incomplete or inaccurate explanations of essential concepts, such as cell division, which may reinforce student misconceptions rather than clarifying them. The results presented highlight the urgent necessity for pedagogical approaches that go beyond conventional lecturing and address the specific issues faced by Filipino students. Most of the research on learning challenges in the Cell Division issue focuses on cognitive factors, including misconceptions. They frequently ignore more comprehensive viewpoints, though, such as social, affective, and motivational aspects, as well as teacher and student perspectives.

Researchers worldwide contend that traditional training alone is insufficient for addressing these conceptual challenges. According to Salleh et al. (2021), promoting a deeper understanding of abstract scientific material is crucial, and this can be achieved by implementing student-centered techniques that utilize interactive technologies and diverse representations. To increase learner motivation, engagement, and comprehension, one new strategy is Game-Based Learning (GBL), which combines gaming with educational goals (Prensky, 2001; Hashim et al., 2019).

Game-based learning develops immersive learning environments where play and material are genuinely related, in contrast to gamification, which merely adds surface-level game-like aspects, such as badges or points. However, a significant portion of current research on GBL has been conducted in foreign settings, raising concerns about its applicability in Philippine classrooms. Furthermore, research has identified obstacles to implementation, including limited resource availability and inadequate teacher preparation (Kirriemuir & McFarlane, 2004; Jääskä & Aaltonen, 2022). The limitations of conducting studies in the Philippines to determine the effectiveness of GBL in secondary schools are significant.

This study provides a unique contribution by being one of the first implementations of the Wisc-Online Game Builder platform in Philippine senior high school Biology, particularly regarding the intricate subject of cell division. The free, open-access platform Wisc-Online is especially well-suited for public schools with limited resources, as it enables teachers to create adaptable games aligned with curricular standards.

This study provides a unique contribution to the local literature on science education by directly comparing the effectiveness of Wisc-Online-based game-based learning to traditional lecture approaches. The results of this research are expected to be substantial for several stakeholders. The project aims to dispel misconceptions and foster a more comprehensive, engaging understanding of mitosis and meiosis among students. It provides educators with a valuable and free instructional resource that can enhance traditional techniques.

This study aims to provide significant insights by examining the effectiveness of game-based learning methods in teaching biology. This research will demonstrate how gamified learning enhances the performance of Grade 11 STEM students in General Biology I. The results will demonstrate how these game-based learning methodologies can be adapted to meet students' diverse learning needs. This study will also address gaps in existing research on the actual application of game-based methods in biology classes, potentially informing the development of improved teaching methodologies and curricula. This study may represent effective techniques for other schools aiming to enhance engagement and efficacy in scientific education.

Statement of the problem

This research will assess the effectiveness of game-based learning in teaching General Biology 1 to Grade 11 STEM students at Babag National High School Senior High, Babag 1, Lapu Lapu City, during the 2025 to 2026 school year, providing a basis for learning activities.

Specifically, this research sought to answer the following questions:

1. What are the pretest and posttest performances of the students in the control and experimental groups exposed to game-based learning in the specified learning competencies on the Cell Division topic, particularly in characterizing the phases of cell division and their central points and describing the shapes of mitosis and meiosis?
2. What is the level of students' perception regarding the effectiveness of game-based learning in achieving the intended learning competencies on Cell Division?
3. Is there a significant difference in the pretest and posttest scores between the control and experimental groups based on the specified learning competencies?
4. Is there a significant difference between the posttest performances of the students in the control group and the experimental group?
5. Is there a significant relationship between the students' perception and their posttest performance in the experimental group?
6. Based on the findings, what specific learning activities can be designed to enhance students' engagement and motivation?

METHODOLOGY

This methodology outlines the flow employed to evaluate, gather, analyze, and interpret the data for this study, which sought to perform a comprehensive analysis of the impact of game-based learning methodologies on the academic achievement of students in cell division. This study employed a quasi-experimental research method to collect comprehensive and reliable information on the effects of game-based learning. A quasi-experimental study design is a research methodology used to assess the efficacy of an intervention without random assignment, and it may provide significant insights into the utilization of naturally occurring groups and the measurement of changes over time (Reichardt, C.S., 2019). This design is suitable for evaluating interventions in natural classroom settings where random assignment is not feasible. The researchers employed an experimental Group Pretest-Posttest design and a Likert-scale survey to collect quantitative data before and after the implementation of the game-based learning, with the test questionnaire adapted from the Campbell Biology 10th Edition book and General Biology resources for Senior High School serving as the primary instrument, used for both the control and experimental groups on their pre- and post-tests. This methodology aimed to assess the effectiveness of the gamified learning approach in Cell Division for Grade 11 STEM students, specifically to evaluate any enhancement in their academic performance following the intervention.

The flow of the study, comprising input, process, and output, involved the study of two groups, one exposed to traditional learning and the other subjected to the same approach supplemented with game-based learning, with a pre-test and post-test design used on both groups. To select a sample from a diverse population, purposive random sampling was employed, and the sample was gathered from Grade 11 STEM students at Babag National High

School. In this study, the dependent variables were the students' pre-test and post-test scores, representing the material taught using game-based learning, and the pre-test and post-test were identical for both groups in terms of the number of items and questions, administered regardless of students' profiles. The process involved securing authorization from the school principal and parents to implement the game-based learning for Grade 11 STEM students. The experimental group employed game-based learning that catered to the identified learning competencies in General Biology 1, specifically in the Cell Division topic, such as characterizing the phases of the cell cycle and their control points and describing the stages of mitosis and meiosis, with activities designed to avoid interfering with the content of the indicated competencies.

This study was conducted at Babag National High School Senior High School, a secondary public school located in Babag I, Lapu-Lapu City, within the Division of Lapu-Lapu. Babag National High School Senior High School is a vibrant educational institution located in an urban area, serving as a key center for learning in its community. With a student population of one thousand four hundred ninety-seven (1,497), the school promotes a diverse and inclusive environment that caters to the educational needs of Senior High School students in the area, and it has seventy-five (75) dedicated teachers committed to fostering students' holistic growth and development. The school is equipped with a variety of facilities to support both academic and technical vocational courses, offering classrooms, computer laboratories, mini hotels, science laboratories, cookery laboratories, and clinics to enhance the students' learning experiences, and laboratory apparatuses such as microscopes are also available for use. Moreover, functional learning materials and equipment are sourced from the school's MOOE and donations from internal stakeholders, and the school is known for its emphasis on academic excellence and deep commitment to uphold the DepEd mission and vision. The research locale is situated within Lapu Lapu City.

The participants in this study were Grade 11 STEM students from Babag National High School Senior High School Academic's General Biology 1 class for the School Year 2025-2026. A purposive sampling strategy was employed to select study participants, ensuring the collection of complete and accurate data. This study focused on a single research group comprising one biology teacher and a group of students who received game-based learning instruction, composed of thirty (30) Grade 11 STEM students, ten (10) males and twenty (20) females, consisting of 15 students in the control group and another 15 in the experimental group. The experimental group received an intervention using Wisc-Online learning activities to assess the effectiveness of the educational content on students' performance, while the control group underwent the conventional strategy during instruction. Within the Controlled Group, there were 5 males, representing 33.33%, and 10 females, representing 66.67%, for a total of 15 respondents; within the Experimental Group, there were likewise 5 males, representing 33.33%, and 10 females, representing 66.67%, for a total of 15 respondents. Using a Likert-scale survey questionnaire and a one-group pretest-posttest design, the researchers collected quantitative data before and after the gamified learning intervention to assess its effectiveness for Grade 11 STEM students in General Biology I.

This study examined the integration of game-based learning (GBL) into cell division for Grade 11 STEM students at Babag National High School Senior High. To assess the effectiveness of this study, the researchers employed a Likert-scale survey and a pre-test and post-test design to evaluate the intervention's efficacy, with the pre-test assessing students' prior understanding and the post-test evaluating their learning progress following the intervention. The Likert-scale survey aimed to gather data on students' perceptions and experiences of the intervention. The test questionnaire used in this research was adapted from the Campbell Biology 10th Edition book and General Biology resources for Senior High School, serving as the primary instrument, and these questionnaires were used for both the control and experimental groups on their pre- and post-tests. This thorough methodology enabled a comprehensive evaluation of the intervention's impact on student learning and comprehension (Anwar, 2019). The researchers employed purposive sampling to choose the respondents, a method involving the collection of data from individuals who meet specific criteria, and the data collected suggest that incorporating game-based learning into Cell Division can effectively enhance student motivation and engagement.

The pre-test and post-test consisted of thirty (30) multiple choice questions with specific test items based on the two (2) learning competencies under the Cell Division topic, namely characterizing the phases of the cell cycle and their control points and describing the stages of mitosis and meiosis, with the test questions comprised of fifteen (15) items for each learning competency. To assess the effectiveness of game-based learning in terms of student engagement and motivation, the researchers used a structured Likert-scale survey, adapted from Piyayodilokchai et al. (2013) and revised to align with the study's objectives. Each construct was designed to capture specific aspects of students' experiences with the intervention. Engagement items focused on students' active participation, collaboration with peers, and attentiveness during the activities. Comprehension measured students' self-perceived understanding of the phases of the cell cycle, checkpoints, and the stages of mitosis and meiosis. Motivation was examined in terms of students' interest in learning, willingness to persist in challenging tasks, and enthusiasm for using game-based approaches in future lessons. This instrument provided valuable insights into the affective dimensions of learning, complementing the pre-test and post-test results, and enabled the researchers to draw a holistic evaluation of the effectiveness of game-based learning in the classroom.

This study was conducted during the 2025 to 2026 school year and lasted for a total period of four (4) weeks. To ensure systematic data collection and adherence to ethical standards, the research procedure proceeded through the following stages, each with specific time allotments: preliminary preparation, test administration, instructional implementation, survey administration, and data interpretation. During preliminary preparation, a formal letter was submitted to the Principal of Babag National High School Senior High School requesting permission to conduct the study, followed by a face to face meeting lasting approximately 30 to 45 minutes to explain the purpose of the research, discuss ethical considerations, and finalize the schedule for the pretest, instructional activities, posttest, and survey administration, with this preparatory phase completed during week one within three (3) days.

The pretest was planned and prepared prior to administration, including the formulation of objectives, construction of test items, and identification of evaluation criteria, and it was administered to the respondents through a written test to determine their prior knowledge of the lesson, with the administration taking one regular class period on week one, approximately 40 to 60 minutes. After the pretest, the researcher introduced and discussed the first topic using guided discussion, during which participants exchanged ideas, shared opinions, asked questions, and responded to one another's arguments, with the researcher facilitating the discussion and providing clarifications and additional explanations as needed; this instructional discussion was conducted for two (2) class periods on week 1, equivalent to 80 to 120 minutes. Following the discussion of the topic, game-based learning activities were implemented to assess their effectiveness in improving students' academic performance, carefully designed to reinforce the lesson content through structured games and interactive tasks, with the implementation spanning four (4) class periods on week 2, equivalent to 160 to 240 minutes, conducted over two weeks. After the completion of the game-based learning intervention, a posttest was administered to the respondents through a written questionnaire, containing items parallel to those in the pretest and designed to measure students' learning gains, assess the effectiveness of game-based learning, and determine its impact on academic performance, with the posttest administration taking one class period on week 4, approximately 40 to 60 minutes. Immediately after the posttest, a survey questionnaire using a 4-point Likert scale was administered to assess the participants' level of satisfaction with the game-based learning approach, with the survey administration on week 4 requiring 20 to 30 minutes to complete. After all the data were collected, the researchers organized, tabulated, and analyzed the results, including scoring the pretest and posttest, summarizing survey responses, and preparing the data for statistical analysis and interpretation, with the interpretation of the collected data completed on week 4 within two to three (2 to 3) days.

In conducting this study on the development, implementation, and evaluation phases of game-based learning, ethical principles were strictly observed to protect the dignity, autonomy, and well-being of all participants, with special emphasis placed on securing informed consent from all students and their parents and guardians, ensuring voluntary participation, maintaining confidentiality and anonymity, minimizing risks, managing data responsibly, and securing approval. In accordance with ethical study protocols, approval was obtained from the relevant researchers to ensure respect for the rules, and to obtain participant data and implement the study in the designated research setting, a communication letter and the research proposal describing the aims and protocols were presented to the School Principal for approval. All participants gave their informed consent in accordance with ethical research guidelines, and participants in the study population were provided with a comprehensive overview of the study's purpose, procedures, potential risks, and benefits, conveyed clearly and comprehensibly to allow participants to make educated decisions on their cooperation, with participation entirely voluntary and participants under no obligation to take part. In accordance with Republic Act No. 10173, the Data Privacy Act of 2012, the study highlighted the accountable and secure management of personal data to protect participants' rights to privacy, with participants' privacy rights carefully respected through the governing of the collection, processing, and transmission of personal data, and strict confidentiality measures employed, including anonymizing participant identities in research reports and safeguarding any personally identifiable information separately from the data. Cultural awareness was maintained by honoring the beliefs, behaviors, and norms of the research participants, involving refraining from imposing personal views and beliefs, fostering open discourse, and modifying research methodologies as needed to align with cultural norms.

Several statistical techniques were employed to evaluate and interpret the data accurately, with percentages used to determine the respondents' profiles, and a range of statistical tools and data analysis methods used to ensure a clear, valid, objective, and reliable presentation, analysis, and interpretation of the significant facts and information collected. Percentage was used as a simple statistical tool to provide precise distributions and proportions of respondents relative to the total population. Mean and standard deviation were calculated to represent students' performance on the pre- and post-tests. Cohen's d, a standardized effect size measure, was used to quantify the difference between two group means. A paired t-test was used to determine whether there was a significant difference between students' pre- and post-test scores in both the control and experimental groups, a test suitable for comparing two related score sets derived from the same group of students before and after the intervention. An independent samples t-test was used to compare post-test scores between the experimental and control groups, evaluating whether the performance differences between the two groups were statistically significant and thereby determining the effectiveness of the game-based learning intervention compared to the traditional teaching method. The weighted mean was used to evaluate survey responses regarding students' engagement, comprehension, and motivation, enabling the researchers to identify the overall average ratings of students for each Likert scale construct. A four-point Likert scale was utilized to collect and analyze students' evaluations of the game-based learning activities.

For students' feedback, the responses were categorized using the four-point Likert scale, with each response assigned a numerical value used to measure respondents' stance. A range of 3.25 to 4.00 corresponded to the verbal rating Strongly Agree, described as indicating that the students strongly agreed with the statement about the game-based activities. A range of 2.50 to 3.24 corresponded to the verbal rating Agree, described as indicating that the students agreed with the statement about the game-based activities. A range of 1.75 to 2.49 corresponded to the verbal rating Disagree, described as indicating that the students disagreed with the statement about the game-based activities. A range of 1.00 to 1.74 corresponded to the verbal rating Strongly Disagree, described as indicating that the students strongly disagreed with the statement about the game-based activities.

To avoid ambiguity, specific terms are defined as theoretically and operationally used in the study. General Biology 1 refers to the topics as reflected in the DepEd curriculum guide for General Biology 1, which the respondents are studying, including the postulates of cell theory, the structure and function of major and subcellular organelles, as well as prokaryotic and eukaryotic cells, various cell types, and cell modifications. Cell Division is a fundamental biological process in which a single parent cell divides to produce two or more daughter cells. Game-based activities are activities meant to actively engage students in the learning process through real-world, inquiry-based projects, and in this study, they were utilized to teach specific learning competencies during the first quarter of the 2025-2026 school year. Game-Based Learning is an active learning strategy that teaches and evaluates information, skills, and attitudes via the use of both digital and non-digital games, incorporating gaming mechanics, components, and principles into the educational process to enhance engagement, motivation, and enjoyment for learners, effectively transforming learning into a gamified experience. Pre-test refers to a test that assesses students' entry performance in the identified learning competencies. Post-test refers to the test that determines the students' performance level after the intervention has been implemented. Respondents refer to the subjects from Grade 11 Senior High School STEM students at Babag National High School who were exposed to game-based learning. Wisc-online is a platform that provides a variety of educational resources, such as interactive games, movies, and simulations, to assist both teachers and students.

RESULTS AND DISCUSSION

This chapter presents the results and discussion derived from data gathered from 30 Grade 11 STEM students at Babag National High School Senior High School, comprising 15 students in the control group and 15 students in the experimental group, who participated in a quasi-experimental Group Pretest-Posttest research design. Data were gathered through a 30-item pretest and posttest assessment adapted from the Campbell Biology 10th Edition book and General Biology resources for Senior High School, together with a 4-point Likert-scale survey adapted from Piyayodilokchai et al. (2013), and were analyzed using percentage, mean, standard deviation, Cohen's d, paired t-test, independent samples t-test, weighted mean, and Pearson r. The discussion that follows is grounded entirely in the data gathered from these 30 participants, and the results are interpreted in direct relation to the objectives of the study, namely to determine the pretest and posttest performance of the control and experimental groups, to assess students' perception of the effectiveness of game-based learning, to examine the significance of differences within and between groups, and to determine the relationship between perception scores and posttest performance.

The pretest and posttest performance of the control and experimental groups on the 30-item assessment in Cell Division revealed that the control group obtained a pretest mean of

10.13 (33.78%) with an SD of 2.56, a minimum score of 6, and a maximum score of 15, indicating low initial mastery, while the experimental group recorded a higher pretest mean of 12.73 (42.44%) with an SD of 3.28, a minimum score of 6, and a maximum score of 17. This means that both groups began the study with an inadequate understanding of mitosis and meiosis, consistent with earlier studies reporting that learners frequently struggle with abstract genetic processes, chromosome behavior, and the sequential phases of cell division (Smith, 2020; Kara & Yesilyurt, 2019). After the instructional intervention, both groups showed significant improvement. The control group achieved a posttest mean of 21.20 (70.67%) with an SD of 3.95, a minimum score of 15, and a maximum score of 28, indicating substantial learning gains, while the experimental group attained a posttest mean of 25.67 (85.56%) with an SD of 2.29, a minimum score of 22, and a maximum score of 29, reflecting high mastery of cell division concepts. The experimental group's superior performance suggests that game-based learning, characterized by interactivity, immediate feedback, and engagement, enhanced comprehension more effectively than the traditional approach. This result aligns with findings by Johnson (2018) and Torres and Santos (2021), who emphasized that digital and gamified learning experiences promote deeper conceptual understanding in science topics. The results imply that both instructional strategies improved student learning, but game-based learning had a greater impact, with the high mastery level of the experimental group suggesting that students benefit from active learning environments that enable them to visualize, manipulate, and apply biological processes, thereby supporting constructivist principles in science education and meaning that integrating game-based and interactive tools into biology instruction can significantly enhance mastery of complex topics such as cell division.

Students' perception of the effectiveness of game-based learning (GBL) in achieving the intended learning competencies on Cell Division revealed an overall weighted mean of 3.93, verbally interpreted as Strongly Agree, based on the legend wherein 3.25 to 4.00 corresponds to Strongly Agree, 2.50 to 3.24 to Agree, 1.75 to 2.49 to Disagree, and 1.00 to 1.74 to Strongly Disagree. Specifically, students strongly agreed that they preferred GBL to the traditional method of teaching in expressing their ideas (weighted mean = 3.93), that the GBL method provided enough scope to improve their understanding of basic principles (weighted mean = 3.93), that they were actively engaged in group discussions (weighted mean = 3.90), that GBL increased their interest in learning General Biology (weighted mean = 3.97), that the activity incorporated technology and catered to individual differences (weighted mean = 3.93), that GBL helped clear misconceptions and follow the procedure of the activity (weighted mean = 3.97), that the facts or concepts of the activity were essential to learning (weighted mean = 3.90), that the GBL approach suited the way they liked to learn (weighted mean = 3.93), that discussing with groupmates helped them understand better what they were learning (weighted mean = 3.93), and that there were enough opportunities to discuss, provide feedback, and incorporate practical work (weighted mean = 3.93). Table 4 reveals that students Strongly Agree, with an overall weighted mean of 3.93, that GBL is highly effective in achieving learning competencies in Cell Division, with high ratings across all indicators, namely interest, engagement, misconception correction, feedback, and suitability to learning styles, showing strong learner acceptance. This aligns with Gee (2017) and Prensky (2011), who argue that games enhance motivation, conceptual understanding, and active participation. Similarly, Qian and Clark (2016) found that GBL supports deeper learning through collaboration and feedback. These findings imply that GBL should be integrated into biology instruction to boost engagement, support diverse learners, and strengthen mastery of complex concepts.

The paired t-test results comparing pretest and posttest scores within each group show that, for the control group, the difference is highly significant ($t = 11.79$, $p < .001$) with a very large effect size ($d = 3.05$ within), based on the legend wherein 0.00 to 0.19 is Negligible Effect, 0.20 to 0.49 is Small Effect, 0.50 to 0.79 is Medium Effect, 0.80 to 1.19 is Large Effect, 1.20 to 1.99 is Very Large Effect, and 2.00 and above is Extensive Effect. This indicates that even traditional instruction produced substantial improvements. Similarly, the experimental group showed a highly significant increase (t = 11.69, p < .001) with a very large effect size (d = 3.02 within). These results demonstrate that learning occurred in both groups and that both forms of instruction were effective in increasing understanding of cell division. These gains support Mayer's (2019) assertion that structured instruction, whether traditional or technology-enhanced, can lead to significant learning improvements when learning objectives are clear and systematically delivered, and they also echo Artino's (2018) findings, which reported that consistent instructional scaffolding promotes meaningful improvement in scientific reasoning. The very large effect sizes in both groups signify that students responded strongly to structured instructional interventions, implying that teachers must deliver cell division topics through carefully planned lessons, clear explanations, and guided practice. However, the nearly equal effect sizes of both groups also show that students can learn cell division effectively when instruction is well-designed, regardless of approach, with what differentiates the experimental group being the higher end-level mastery, suggesting that how students engage with content, such as through games, simulations, and interactive tasks, influences the depth and retention of learning.

The comparison of the two groups' performance shows that at pretest, the experimental group scored significantly higher, with a control mean of 10.13 (SD = 2.56) versus an experimental mean of 12.73 (SD = 3.28), yielding t = negative 2.42, p = .023. This indicates a baseline advantage, suggesting that the experimental group may have had a slightly stronger prior science background, a pattern typical in educational research where intact classes may differ even before an intervention (Cohen, Manion, and Morrison, 2018). At posttest, the difference between the groups became more pronounced, with a control mean of 21.20 (SD = 3.95) versus an experimental mean of 25.67 (SD = 2.29), producing a significant difference (t = negative 3.79, p = .001) with a very large effect size (d = 1.38 very large). This shows that although both groups improved, the experimental group outperformed the control group by a wide margin, and therefore the game-based learning approach had a stronger effect on final achievement. The gain scores, however, comparing a control gain mean of 11.07 (SD = 3.63) versus an experimental gain mean of 12.93 (SD = 4.28), did not differ significantly (t = negative 1.29, p = .209). This means that although the experimental group achieved higher final scores, the amount of improvement was statistically similar in both groups, a valuable methodological reminder that interpreting posttest scores alone may overlook baseline differences, supporting the recommendations of Field (2020) and Fraenkel and Wallen (2019) to consider pretest differences when evaluating intervention effectiveness. The significant posttest difference confirms that game-based learning enhances mastery more effectively than the traditional approach, while the nonsignificant gain-score difference suggests that traditional instruction can still produce comparable improvement but may not be able to bring learners to the same high-level mastery achieved in game-based learning. This supports the findings of Bae and Kwon (2021) that game-based environments improve attention, engagement, and deeper processing, which are necessary for mastering complex biological processes.

The correlation analysis between students' perception scores and their posttest performance, based on a sample of 12, revealed a very weak negative relationship (Pearson r = negative 0.23), indicating that higher perception ratings toward the simulation did not correspond to higher achievement scores. The computed p-value of 0.4680 is well above the 0.05 significance level, indicating that the relationship is not statistically significant, and the statistical decision confirms that there is no meaningful linear relationship between perception and posttest performance. This means students' positive perceptions of the interactive simulation did not significantly influence their test outcomes. The results suggest that factors such as prior knowledge, cognitive ability, or study discipline may have played a larger role in determining performance than perception alone.

The study's findings suggest that various learner-centered and game-based learning activities can be developed to boost students' motivation and engagement in understanding Cell Division. The significantly increased posttest results and encouraging student attitudes towards the game-based learning method suggest that engaging, technology-enhanced activities are successful in maintaining interest and enhancing conceptual comprehension. Interactive sequencing games created with the Wisc-Online Game Builder can help students master the phases of meiosis and mitosis, requiring students to organize stages in a progressive order, pair images with their corresponding phase descriptions, and recognize significant events such as chromosome separation and alignment. The prompt feedback offered by Wisc-Online enhances accurate comprehension and addresses misconceptions, validating the study's conclusion that game-based learning facilitates superior mastery of complicated biological processes, a finding echoed by Qian and Clark (2016), who reported that rule-based digital games and sequencing encourage sustained engagement and conceptual clarity in science learning.

Wisc-Online can also be used to create timed review games and challenge-based quizzes that boost motivation through friendly competition, including multiple-choice questions, drag-and-drop checkpoints, and score-based progression assignments aligned with the learning skills. The study found that students consistently reported that game-based learning enhanced their interest and motivation in Biology, emphasizing that competitive and goal-directed components may further encourage engagement, a view supported by Plass et al. (2015), who asserted that challenges, feedback, and explicit objectives in digital games augment student motivation and perseverance. Cooperative group activities should likewise be included, where students finish Wisc-Online games in small groups and evaluate their responses before submitting them, and as evidenced by students' strong agreement that group discussions enhanced their comprehension, this promotes social interaction and peer learning grounded in social constructivist philosophy, consistent with research by Sung and Hwang (2013) showing that collaborative game-based learning settings greatly increase student engagement and conceptual understanding in science classes. Remedial and enrichment activities can further be developed using Wisc-Online's adaptable characteristics, with students facing difficulties utilizing simplified guided games featuring suggestions and visual aids, while experienced learners are presented with more complex problems necessitating the analysis of chromosomal counts or the comparison of mitosis and meiosis. This difference addresses the study's conclusion that although both groups made progress, the experimental group's mastery was higher, suggesting that flexible game-based activities can accommodate a range of learning requirements, a point emphasized by Gee (2005), who noted that effectively designed educational games inherently facilitate varied learning by enabling learners to advance at their own pace.

Taken as a whole, the findings drawn from the 30 participants demonstrate that both the control group and the experimental group achieved significant learning gains in Cell Division, with the control group improving from a pretest mean of 10.13 (33.78%) to a posttest mean of 21.20 (70.67%), and the experimental group improving from a pretest mean of 12.73 (42.44%) to a posttest mean of 25.67 (85.56%), each yielding highly significant within-group differences (control: $t = 11.79$, $p < .001$, $d = 3.05$; experimental: $t = 11.69$, $p < .001$, $d = 3.02$). The results directly address the study's objectives by revealing that although a baseline difference existed at pretest ($t =$ negative 2.42, $p = .023$), the experimental group significantly outperformed the control group at posttest ($t =$ negative 3.79, $p = .001$, $d = 1.38$), even though the gain scores between groups did not differ significantly ($t =$ negative 1.29, $p = .209$), and that students strongly agreed, with an overall weighted mean of 3.93, that game-based learning was effective in achieving the intended learning competencies, while perception scores showed no significant relationship with posttest performance (r = negative 0.23, p = 0.4680). These findings contribute to the field by providing empirical evidence, grounded in a quasi-experimental design with pretest-posttest comparisons and multiple inferential statistical tests, that game-based learning through Wisc-Online interactive sequencing games, timed review challenges, cooperative group activities, and adaptable remedial and enrichment tasks can produce higher-level mastery of complex biological concepts such as mitosis and meiosis than traditional instruction alone, while also demonstrating that structured instruction of any form can yield substantial learning gains and that student perception of an intervention does not necessarily predict actual achievement outcomes. Collectively, these results provide the empirical foundation for the conclusions, implications, and recommendations to be presented in the subsequent chapter, where the pedagogical and curricular applications of integrating game-based learning into General Biology instruction for Grade 11 STEM students are discussed in greater detail.

CONCLUSION

The findings of the study demonstrate that both the control and experimental groups began with a low level of understanding of Cell Division, as reflected in their pretest mean scores of 10.13 and 12.73, respectively. These results indicate that the learners initially had limited mastery of the phases and processes involved in mitosis and meiosis. Following the instructional interventions, both groups exhibited substantial improvement in their academic performance. The control group achieved a posttest mean score of 21.20, while the experimental group obtained a higher posttest mean score of 25.67. The paired t test analysis confirmed that the improvements in both groups were statistically significant and were accompanied by very large effect sizes, providing strong evidence that meaningful learning occurred under both instructional approaches.

Despite the significant improvement observed in both groups, further analysis revealed that the students who were exposed to game-based learning achieved significantly higher posttest performance than those who received traditional instruction. Although the gain score analysis indicated no significant difference in the magnitude of improvement between the two groups, the experimental group attained a higher final level of mastery. This finding suggests that while both instructional approaches were effective in promoting learning, game-based learning enabled students to achieve a greater level of conceptual understanding of Cell Division. The higher posttest performance and the very large between group effect size further establish the superiority of game-based learning as an instructional strategy for teaching the topic.

Overall, the findings support the conclusion that students initially possessed limited knowledge of Cell Division concepts, including mitotic stages, chromosomal behavior, and meiotic processes, but their understanding improved significantly after instruction regardless of the teaching approach employed. Nevertheless, the evidence consistently indicates that game-based learning provides a more effective pedagogical approach because it fosters greater mastery of scientific concepts through an engaging and interactive learning environment. By promoting visualization, immediate feedback, and active learner participation, game-based learning strengthens conceptual understanding and aligns with constructivist principles in science education.

In light of these findings, it is recommended that game-based learning be more widely integrated into the teaching of General Biology, particularly in topics that require learners to understand complex biological processes such as Cell Division. Science teachers are encouraged to incorporate well designed educational games and interactive learning activities alongside conventional instructional methods to improve student engagement, motivation, and conceptual mastery. School administrators should provide adequate support through instructional resources and professional development opportunities that enable teachers to implement game-based learning effectively. Future researchers are likewise encouraged to conduct similar studies involving larger and more diverse populations, longer intervention periods, and additional science topics to further validate and extend the effectiveness of game-based learning in enhancing students' academic performance and meaningful learning.

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