International Journal of Basic and Applied Sciences, 14 (7) (2025) 266-274

International Journal of Basic and Applied Sciences

Website: www.sciencepubco.com/index.php/IJBAS
https://doi.org/10.14419/4s6nz990
Research paper

Learning Mendelian Genetics Using A Game Based Learning Activities

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Received: October 8, 2025, Accepted: November 4, 2025, Published: November 9, 2025

Abstract

This study aimed to develop and evaluate a game-based learning activity on Mendelian Genetics to improve student engagement, understanding, and motivation. The activity was designed using the ASSURE model, a systematic approach to instructional planning. A mixed-methods design was used. The quantitative phase involved a one-group pre-test and post-test with 45 Grade 8 students from Ilat National High School to assess learning gains. The qualitative phase involved unstructured interviews to explore students' learning experiences. The game, titled "The Gene Quest: Mendelian Genetics," featured animations, interactive Punnett square tasks, and a leader-board to enhance participation. Six experts—four science teachers and two IT professionals—evaluated the game based on content accuracy, design, usefulness, and ease of use. Data collection tools included a 30-item multiple-choice test, expert evaluation sheets, and interview responses. Quantitative data were analyzed using weighted and composite means and the Hake gain score, while thematic analysis was used for qualitative data. The game received excellent ratings across all evaluation criteria. A Hake gain score of 0.96 indicated a high level of learning improvement. Students described the game as enjoyable and engaging. They reported better understanding of genetics concepts, improved confidence in learning, and acknowledged certain challenges during gameplay. The findings suggest that game-based learning is an effective strategy for teaching complex topics like Mendelian Genetics. It supports deeper understanding, boosts motivation, and enhances academic performance.

Keywords: *Game-Based Learning Activities; Mendelian Genetics; Gamification; Learning Gain; Grade 8 Science.*

1. Introduction

In today's era, the evolving field of education continues to generate efficient and engaging learning alternatives, remaining a priority for educators worldwide. As teaching adapts to diverse learners, teachers seek innovative strategies that promote deeper understanding and sustained interest. Traditional methods that rely on memorization often fall short, leading to disengagement and frustration. This highlights the need for creative approaches that support active participation and meaningful learning. Strategies such as discussions, problem-solving, and hands-on tasks help students grasp concepts more effectively, while technology integration provides dynamic and immersive experiences.

Biology, the study of life, has grown rapidly and now plays a key role in fields like healthcare, agriculture, and environmental science (Chu et al., 2018). Despite its relevance, many students struggle with biology, particularly in understanding abstract and complex topics like Genetics. Genetics explores how traits are inherited and involves technical terms and interdisciplinary concepts, making it especially difficult for students to master (Cimer, 2017). In the Philippines, this challenge is compounded by consistently low performance in science subjects, as reflected in national and international assessments (OECD, 2023). These concerns emphasize the need for improved science instruction, particularly in genetics education.

Given the digital nature of today's learners, technology has become essential in education. The rise of digital tools has led to educational games designed to boost motivation and interest (Nadeem et al., 2023). Game-based learning (GBL) incorporates gameplay elements—like points, challenges, and feedback—into learning environments. This method has shown potential in making abstract content like Genetics more accessible and engaging (Wallace, 2024). Initiatives by DepEd and Microsoft Philippines already support game-based platforms in schools (Labesig, 2022). According to Nisbet (2023), GBL helps reinforce learning objectives, while Falciani (2020) highlights its role in developing knowledge, skills, and values through game mechanics.

Recent studies further validate the effectiveness of GBL in science education. Situmorang et al. (2024) conducted a systematic review of digital game-based learning in biology and found that interactive games significantly improved students' conceptual understanding and retention, especially when aligned with curriculum standards. Chiotaki et al. (2023) emphasized the importance of adaptive GBL environments that respond to learner input, promoting autonomy and deeper engagement. Seow and Lee (2025) introduced "Geneblock," a gamified biotechnology tool for undergraduates, which improved comprehension but required high-end devices and lacked curriculum integration for secondary learners.

While Nisbet (2023) notes GBL's motivational benefits, this study addresses the gap in Mendelian-specific tools with interactive Punnett squares. Unlike Geneblock and other general biology games, "The Gene Quest" was designed specifically for Grade 8 students and integrates curriculum-based challenges, visual trait modeling, and real-time feedback. Its mobile accessibility and intuitive interface make it suitable for under-resourced classrooms, addressing the equity concerns raised by Coil et al. (2017). Moreover, the game's structured progression—from trait selection to Punnett square application—aligns with Bloom's Taxonomy and supports differentiated instruction.

Gamification in Genetics has been effective in enhancing engagement and comprehension (Yoshida et al., 2015), but many existing tools require advanced technology, limiting their use in under-resourced schools (Coil et al., 2017). To address this, researchers suggest using flexible and creative methods—such as visual aids, storytelling, and interactive tasks—that make learning more enjoyable and clearer (Dieser & Bogner, 2015; Beylefeld & Struwig, 2015). Studies show that well-designed games can improve academic performance and deepen understanding of genetic principles (Eisenkraft, 2018; Clark et al., 2015).

However, there remains a gap in the development of gamified tools specifically designed for teaching Mendelian Genetics. Many available resources, such as Punnett Farms (Low & Ellefson, 2024), offer general genetics simulations but often lack the low-resource requirements or the specialized features needed to fully engage students in the quantitative aspects of genetic prediction. The Gene Quest directly addresses this gap by offering a unique, tailored solution. While Nisbet (2023) notes GBL's general motivational benefits, this study's tool, "The Gene Quest," is distinguished by its integration of low-resource mobile technology, animated problem scenarios, and, most critically, interactive Punnett squares. This feature allows Grade 8 students to manually manipulate alleles and receive real-time feedback, which adopts a deeper, hands-on mastery of genetic cross prediction, a crucial skill often underdeveloped by simpler, older gamification tools. Educators emphasize that game-based activities can inspire curiosity, critical thinking, and inquiry-based learning.

Creating interactive classrooms is vital for improving learning outcomes. Passive instruction often leads to disinterest and low retention, while interactive learning—through games, projects, and group work—boosts focus and motivation. As gamified strategies gain momentum in education, especially for complex topics like Genetics, their integration into the curriculum becomes increasingly important. While GBL has shown benefits across subjects (Habib, 2021; Eltahir et al., 2021), its application in the Grade 8 science curriculum, particularly in Genetics, remains underexplored.

This study aimed to develop and evaluate a game-based learning activity on Mendelian Genetics tailored for Grade 8 students. The research involved designing gamified materials, evaluating them through expert feedback on content, design, usefulness, and ease of use, and assessing students' learning through pre- and post-tests, along with qualitative reflections. The study was conducted at Ilat National High School, Batangas, Philippines.

Further, the study aimed to develop a game-based learning activity in Mendelian Genetics, describe its features, assess students' learning gain, and identify their experiences in using the activity. To achieve this, the study sought to answer several key questions. First, it aimed to identify possible game-based learning activities that could be developed to teach Mendelian Genetics. It also aimed to describe the developed game-based learning activity in terms of its content, design, usefulness, and ease of use. In addition, the study examined the level of learning gain among students after engaging with the activity. Lastly, it explored the learners' experiences to understand how the game-based approach supported their learning process. Finally, based on the overall findings of the research, the study proposed learning activities designed to enhance student engagement, improve conceptual understanding, and make the teaching of Mendelian Genetics more effective and enjoyable.

2. Research Method

An explanatory sequential mixed methods design was employed in this study. The quantitative phase used a pre-experimental single-group design to evaluate the impact of the game-based learning activity on students' understanding of Mendelian Genetics. Learning gains among 45 Grade 8 students from Ilat National High School were measured by comparing baseline and post-intervention data, analyzed using descriptive statistics and the Hake factor test. Complementing this, qualitative data were gathered through unstructured interviews with the same students to explore how gamified features—such as animations, challenges, leaderboards, and interactive Punnett squares—affected their motivation, engagement, and conceptual understanding. Thematic analysis was used to identify patterns and enrich the interpretation of quantitative results. This design provided a comprehensive evaluation of the educational value of the gamified approach by integrating performance data with learner experiences in mastering Mendelian Genetics.

The educational game titled GeneQuest: Mendelian Explorer was developed using Unity 3D (version 2022.3 LTS) as the primary development platform due to its versatility in creating interactive, cross-platform educational applications. Game design and visual assets were produced using Adobe Illustrator and Blender, while C# served as the main scripting language for interactive features. The development followed an iterative design approach, integrating feedback from subject matter experts in genetics and educational technology after each prototype cycle. Game Structure and Content: The game consisted of three modules, each representing key concepts in Mendelian Genetics: Module 1: Basic Genetic Terminologies and Laws, Module 2: Monohybrid and Dihybrid Cross Simulations, Module 3: Problem-Solving and Genetic Prediction Scenarios. Each module incorporated problem-based challenges, interactive quizzes, and virtual simulations to reinforce understanding and application of genetic concepts. Gameplay Duration and Implementation: Each gameplay session lasted approximately 45–60 minutes, corresponding to one full class period. Participants engaged in the game twice per week over a two-week intervention period, resulting in a total of four gameplay sessions. The duration was determined based on cognitive load considerations and alignment with typical instructional time frames in the curriculum. Pilot Testing and Validation: Before implementation, the game underwent pilot testing with 10 students to assess usability, instructional clarity, and technical functionality. Revisions were made accordingly to enhance engagement and ensure accurate representation of Mendelian principles.

This study employed Braun and Clarke's (2006) six-phase framework for Thematic Analysis, a flexible yet systematic approach for identifying, analyzing, and reporting patterns (themes) within qualitative data. First, the researchers immersed themselves in the data by reading and re-reading interview transcripts and observation notes to gain a comprehensive understanding of participants' responses and contexts. Second, using inductive coding, meaningful data segments were highlighted and labeled with descriptive codes that captured essential ideas. Coding was conducted manually to ensure close engagement with the data. Third, related codes were clustered into potential themes that reflected broader patterns relevant to the research question, such as student engagement, conceptual understanding, or perceived learning enhancement through games.

Then, themes were reviewed and refined to ensure they accurately represented the coded data and the dataset as a whole. Some themes were merged, refined, or discarded based on internal homogeneity and external heterogeneity. Each theme was clearly defined, capturing the essence of what it represented. Subthemes were also identified where necessary to illustrate nuanced aspects of participants' experiences. Lastly, final themes were contextualized and supported by verbatim quotations from participants, providing evidence-based interpretations linked to existing literature and the study's research objectives.

Inductive (data-driven) coding was used, allowing themes to emerge naturally from participants' narratives rather than being imposed by pre-existing theoretical constructs. Each meaningful segment of text served as the coding unit. To enhance trustworthiness, inter-coder agreement was established through double-coding a subset of data and discussing discrepancies until consensus was reached. Reflexive journaling was also used to ensure transparency and mitigate researcher bias.

The participants of this study were purposively selected based on their roles in the development, evaluation, and implementation of the game-based learning activity in Mendelian Genetics. In the initial phase, the researchers collaborated with instructional designers to create a game aligned with the Grade 8 science curriculum, integrating core genetics concepts and gamification strategies to enhance engagement and learning. To evaluate the game's quality, a panel of six expert evaluators—comprising four science teachers specializing in Mendelian Genetics and two IT professionals in educational technology and instructional design—reviewed the activity using a structured evaluation sheet. They assessed the game in terms of content, design, usefulness, and ease of use, providing feedback that guided refinements. Additionally, 45 Grade 8 students from Ilat National High School, who were currently studying Mendelian Genetics, participated as end users. They completed pre- and post-tests to measure learning gains and took part in unstructured interviews to share their experiences. Their feedback offered valuable insights into how the game influenced their engagement, comprehension, and overall classroom learning experience. The student sample, while representative of the target grade level, was limited to a single school in Batangas province. This context-specific sample may affect generalizability. Future studies are encouraged to replicate the research across diverse educational settings, including rural and urban schools, to validate the tool's broader applicability.

The development of the game-based learning activities in Mendelian Genetics for Grade 8 Science followed the ASSURE Model: Analyze Learners, State Objectives, Select Methods, Media, and Materials, Utilize Media and Materials, Require Learner Participation, and Evaluate and Revise. The researchers began by analyzing learner needs through consultations with a Grade 8 science teacher at Ilat National High School. It was found that students struggled with abstract genetic concepts but responded well to interactive digital tools.

Based on these insights, the researchers stated clear learning objectives, focusing on the competency "Predict phenotypic expressions of traits following simple patterns of inheritance." The activities aimed to strengthen students' understanding of genetic terms, Punnett squares, and trait prediction through measurable outcomes.

Next, appropriate methods, media, and materials were selected. A custom-designed mobile application was developed with features like visual demonstrations, trait selection, and instant feedback. The team ensured proper utilization by preparing the learning environment with necessary devices and internet access, testing the app for usability, and conducting orientation sessions.

During implementation, students participated actively by solving Punnett square problems, exploring genetic traits, and engaging with gamified features such as leaderboards and badges.

Finally, the researchers conducted evaluation and revision through post-tests and student feedback. Results showed improved understanding, prompting minor interface updates and incorporation of teacher suggestions, ensuring the app remained effective, curriculum-aligned, and responsive to learners' needs.

To collect the necessary data, the researchers utilized three primary instruments: an evaluation tool, a researcher-made pre-test/post-test, and an interview guide.

The evaluation tool was specifically constructed by the researchers to assess the quality of the developed game-based learning activity, The Gene Quest: Mendelian Genetics. This tool focused on four key areas: content, design, usefulness, and ease of use. It was validated through expert review by the research adviser and panel members and finalized based on their recommendations. A 5-point Likert scale was used to rate each criterion, with interpretation ranging from "Unsatisfactory" to "Excellent." The tool was administered to six expert evaluators, consisting of four Science teachers and two IT professionals.

The pre-test/post-test was a 30-item multiple-choice examination designed to assess students' learning gains in Genetics. Items were aligned with the Most Essential Learning Competencies (MELCs) and guided by a Table of Specifications (TOS) based on Bloom's Taxonomy. The test emphasized concepts such as genotype-phenotype relationships and Punnett square analysis. It was validated by Science teachers, with pilot testing conducted among Grade 9 students to ensure clarity and internal consistency. Cronbach's alpha yielded a reliability score of 0.87. Pre-tests were administered prior to the implementation of the game, while the post-tests were conducted afterward. The Hake Gain Formula was used to interpret learning improvement, with gain scores categorized from "Low" to "High."

Data gathering was conducted from February 21, 20205 to March 13, 2025, after securing approval from the school principal of Ilat National High School. An orientation was held with the assigned Science teacher and selected Grade 8 students, where the researchers explained the study's purpose, procedures, and confidentiality terms. A consent form was distributed to ensure voluntary participation. The data collection began with a four-day classroom discussion on mitosis and meiosis, aligned with the MELCs, followed by a familiarization session on the fifth day, where students explored the mechanics and objectives of the game-based learning activity, The Gene Quest: Mendelian Genetics. A 30-item pre-test was administered to assess prior knowledge in Mendelian Genetics, followed by four days of direct instruction on the topic. Afterward, students engaged with the gamified learning activity, then completed the post-test using the same test items to measure learning gains. Individual unstructured interviews were also conducted to explore students' learning experiences, engagement, and challenges with the game. All test scores were submitted to a statistician for analysis using the Hake Gain Formula, while interview responses were transcribed and thematically analyzed. The combined results were used to assess the effectiveness and educational value of the gamified learning activity in teaching Genetics to Grade 8 students.

Upon completion of data collection, appropriate statistical procedures were employed. Weighted means were used to analyze evaluator ratings and student assessment scores. Composite means summarizes the overall evaluation of the game's content, design, usefulness, and ease of use. The Hake gain formula quantified the normalized learning gains between pre-test and post-test results. For qualitative responses, thematic analysis was conducted by coding significant statements, grouping them into key themes, and validating the findings through peer review to ensure accuracy and credibility.

While the findings of this study demonstrate promising outcomes, the validation process is limited by the use of a single-school sample composed of 45 Grade 8 students from Ilat National High School. Although the participants were representative of the target curriculum level, the homogeneity of the sample, both in geographic location and institutional context, may constrain the generalizability of the results. To strengthen external validity, future studies should replicate this research across a broader range of educational settings, including public and private institutions, urban and rural schools, and regions with varying levels of technological access. Expanding the sample size and diversity would allow for comparative analysis across demographic groups and instructional environments, offering deeper insights into the scalability and adaptability of game-based learning tools like "The Gene Quest." Additionally, longitudinal studies could explore the sustained impact of such interventions on student achievement, motivation, and retention in genetics and other science domains.

3. Results and Discussions

3.1. Developed game-based learning activity

The Gene Quest: Mendelian Genetics is a game-based learning mobile application developed using C # within the Unity Game Engine, a powerful platform for creating interactive educational tools. The use of Blender, an open-source 3D modeling software, enabled the creation of high-quality animations and visual models that bring abstract genetic concepts to life, supporting visual learning as suggested by Mahler and Mayer (2023). The app features a structured, user-friendly interface designed with clear navigation and an instructional layout, aligning with Singh's (2023) recommendation for enhanced student comprehension. It opens with a DNA-themed title screen and allows users to select from three roles—Student, Teacher, and Admin—each offering tailored features such as activity access, progress tracking, and user management.

The game incorporates multiple interactive elements, including animated problem scenarios with pre- and post-question animations that provide context and feedback, a method proven to improve engagement and retention (Lin et al., 2018). Students engage in trait-specific challenges following a stage-based model—Choose, Challenge, Apply—with traits such as eye color, flower color, dimples, and animal ear shapes. Learning is reinforced through drag-and-drop activities and text input tasks, allowing users to complete Punnett squares manually, which promotes deeper conceptual understanding (Karpicke & Blunt, 2019). A leaderboard system showcases student rankings, badges, and scores to motivate learners, aligning with gamification principles supported by Chou (2015) and Zichermann & Cunningham (2015).

Additionally, the game includes the Gene-ius Challenge, a timed, two-choice quiz that strengthens critical thinking and knowledge recall—an approach shown by Zhang & Crawford (2023) to enhance internalization of learning objectives. Altogether, this mobile application transforms genetics instruction into an engaging, personalized experience that blends scientific accuracy with interactive design, effectively supporting mastery of dominant and recessive inheritance patterns.

3.2. Evaluation of the developed game-based learning activity in genetics

This study presents the evaluation results of the game-based learning activity in terms of its content, design, usefulness, and ease of use. These components were assessed to determine the overall quality and effectiveness of the game, and to understand how well it aligns with educational objectives, engages learners, and supports meaningful learning experiences.

3.2.1. Content

This item presents the evaluation of the game-based learning activity in Genetics, specifically focusing on its content. This aspect refers to the accuracy, completeness, clarity, and application of problem-solving skills within the game.

Table 1: Evaluation of the Developed Game-Based Learning Activity in Genetics in Terms of Content

Content	WI	VI
The game keeps all hereditary concepts and problem-solving applications factually accurate, up-to-date, and verifiable from credible sources, free from errors or inconsistencies.	4.83	Excel-lent
It covers in full detail, from the various genes and the Punnett squares through genotypic and phenotypic ratios and traits, to the real-life application of the science.	5	Excel-lent
The design of the game makes learning about heredity fun and easy through clear definitions of concepts, with illustrations from real life, easy transitions between levels, and activities that foster problem-solving skills and motivation.	4.83	Excel-lent
The game provides comprehensive coverage of heredity concepts, using well-structured scenarios and examples to demonstrate strong problem-solving skills, accurate predictions with Punnett squares, and real-life applications.	5	Excel-lent
Composite Mean	4.92	Excel-lent

Table 1 presents the expert evaluation of the game-based learning activity in Genetics in terms of content. All six experts gave consistently high ratings across four indicators: accuracy, completeness, clarity, and application of problem-solving skills, showing strong agreement on its instructional quality. The game demonstrated excellent accuracy, presenting hereditary concepts in a factual, current, and reliable way, aligning with Duncan's (2024) view that scientific accuracy prevents misconceptions. Its completeness was also rated excellent, covering key Mendelian Genetics topics like genotypic and phenotypic ratios and Punnett squares, supporting Buckley and Doyle's (2016) emphasis on comprehensive content for deeper learning. Clarity of delivery was praised for the game's intuitive structure and clear instructions, which enhanced learner focus and engagement (Duncan, 2024). For problem-solving, the game effectively promoted analytical thinking through interactive tasks, as supported by Contente and Galvão (2022). In summary, the game's excellent performance across all indicators confirms its value as a high-quality, curriculum-aligned instructional tool for Genetics education.

3.2.2. Design

This item presents the evaluation of the game-based learning activity in Genetics, specifically focusing on its design. This aspect refers to the game's visual appeal, user flow, originality, and effectiveness, ensuring an engaging experience, smooth navigation, and increased learner involvement through creative and goal-oriented design.

Table 2: Evaluation of the Developed Game-Based Learning Activity in Genetics in Terms of Design

Design	WI	VI
The game is highly engaging and visually appealing, with a smart use of color, imagery, and layout complemented by sound pedagogical reasoning, facilitating understanding and problem-solving in the prediction of traits.	5	Excel-lent
Smooth interface encourages engagement for total concentration on heredity concepts, allowing participants to navigate the activity efficiently and apply genetic inheritance problem-solving skills.	4.83	Excel-lent
The game integrates innovative and original gamification components that greatly engage and motivate learners by adequately helping with problem-solving activities in predicting traits.	4.83	Excel-lent
The game mechanics integrate challenge, rewards, animations, and especially the Punnett squares, to create an effective format for engaging, motivating, and problem-solving in inheritance patterns.	4.83	Excel-lent

Composite Mean	4.87	Excel-lent

Table 2 presents the evaluators' feedback on the design of the game-based learning activity in Genetics, showing consistently high ratings across all indicators. This suggests that the game's visual appeal, interface, gamification components, and mechanics effectively support learner engagement, motivation, and problem-solving. The visual design was praised for its appealing layout, color, and imagery, aiding focus and comprehension (Deterding et al., 2011). The smooth interface enabled intuitive navigation, minimizing cognitive overload (Sooegaard, 2024). The game's innovative features—such as challenges and missions—boosted motivation and sustained interest. Lastly, the game mechanics, including rewards and Punnett square tasks, provided feedback and reinforced genetic concepts (Gillis & Barney, 2025). Overall, the excellent ratings confirm that the game's design promotes both engaging and effective learning.

3.2.3. Usefulness

This item under the evaluation criteria is needed in the study to determine how effectively the game-based activity supports student understanding of genetics through engaging and relevant learning experiences.

Table 3: Evaluation of the Developed Game-Based Learning Activity in Genetics in Terms of Usefulness

Usefulness	WI	VI
The activities offer great opportunities for students to develop their problem-solving skills in heredity, allow for accurate predictions of phenotypic expressions, and improve assessment performance.	5	Excel-lent
The activity is directly and completely aligned with the learning objectives and engages students in critical learning of how to use problem-solving strategies in predicting genetic traits.	5	Excel-lent
Problem-solving skills are related to real-world application through activities involving games, such as computing with Punnett squares, that deal with the topic of genetic inheritance.	5	Excel-lent
The game effectively suits and engages Grade 8 students in learning inheritance through real-world applications, probabilities of heredity, and interactive problem-solving that enhance their skillful predicting of phenotypic expressions.	5	Excel-lent
Composite Mean	5	Excel-lent

Table 3 presents the evaluation of the game-based learning activity in Genetics in terms of its usefulness. The results show excellence across all the indicators. These results imply that the game-based activity strongly supports the development of critical thinking and conceptual understanding in genetics by actively engaging students in problem-solving experiences. The uniform excellence highlights the effectiveness of the game-based learning activity in aligning instructional design with intended learning outcomes, especially in reinforcing key genetics concepts such as phenotypic prediction and inheritance patterns. Furthermore, the use of real-world applications, such as Punnett square problems, ensures that students find the lessons meaningful and relevant to everyday life. These features are supported by Zou et al. (2021), who demonstrated that interactive, goal-oriented game-based learning fosters greater academic performance and motivation. Additionally, the activity's structure and content were seen as highly suitable for the developmental level of Grade 8 learners. The design elements, such as appropriate language, interactive feedback, and paced content, made the experience accessible and engaging for the students. This supports the findings of Acosta-Medina et al. (2021), who emphasized the importance of age-appropriate educational tools in fostering participation and learning outcomes. Overall, consistent excellence across all evaluated aspects underscores the strength of this game-based learning approach in delivering a meaningful and effective Genetics education experience.

3.2.4. Ease of use

This item presents the evaluation of the game-based learning activity in Genetics, specifically focusing on its ease of use. This aspect refers to how intuitively students can navigate and interact with the game without needing extensive guidance, which is crucial in determining if the game provides a smooth, efficient, and user-friendly learning experience.

Table 4: Evaluation of the Developed Game-Based Learning Activity in Genetics in Terms of Ease of Use

Ease of use	WI	VI
The activity is highly efficient, providing seamless and quick tools for inputting and analyzing genetic traits to support problem-solving in predicting phenotypic expressions.	4.83	Excel-lent
The game effectively handles errors by providing clear feedback on incorrect Punnett square predictions, guiding students toward the correct answer, and reinforcing their understanding of genetic inheritance.	4.83	Excel-lent
The game allows for very easy navigation, creating a smooth path without the need to close out and log in again to access the problem-solving tools and practice.	5	Excel-lent
A highly positive and engaging learning experience is offered by the game, which is easy to navigate so that transitions between concepts of heredity and levels can flow smoothly while promoting motivation and a sense of achievement.	5	Excel-lent
Composite Mean	4.92	Excel-lent

Table 4 shows that the gamified learning activity received consistently excellent ratings across all usability indicators: efficiency, error management, navigation, and overall user experience. These results indicate that the tool is educationally purposeful, user-friendly, and engaging for Grade 8 students studying heredity. The game's intuitive navigation—with clearly labeled buttons and smooth transitions—helped reduce cognitive load and supported learner autonomy, echoing Liu II (2022). The user experience was praised for being visually clean, interactive, and immersive, aligning with Wouters and Van Oostendorp (2022), who highlight the importance of emotional engagement in learning games. In terms of efficiency, the game performed smoothly with quick feedback and responsive mechanics, which maintained learner motivation and momentum (Stiller, 2019). Its error management system offered constructive, explanatory feedback that promoted resilience and reflection, supporting Buschang et al.'s (2019) findings on the value of error-based learning.

3.3. Learning gain in students engaged in a game-based learning activity

The study measured students' learning gains using pre- and post-tests, with the average improvement calculated through Hake's normalized gain (g). As shown in Table 7, the results indicate a significant increase in performance and conceptual understanding after using the game-based learning activity.

Table 5: Students' Pre- and Post-Test Scores and Hake Gain

Test	Mean	Hake Gain (g)	Interpretation
Pre-Test	7.58	0.96	High
Post-Test	29.29		

Table 5 presents the pre- and post-test results of students who participated in a game-based learning activity on Genetics. The low pre-test mean score of 7.58 indicates limited prior knowledge, while the post-test mean of 29.29 shows substantial improvement in understanding after the intervention. This increase highlights the effectiveness of the game's interactive and engaging design in supporting learning. The high Hake Gain of 0.96 reflects significant conceptual learning, confirming the game's educational impact based on Hake's (1998) criteria. These findings align with Boctor (2013) and Padmanabha et al. (2017), who emphasized the value of game-based learning in promoting motivation, engagement, and deeper comprehension in science education.

3.4. Students' experiences in the use of game-based learning activities in genetics

Table 6 presents the feedback from students regarding their experiences with the game-based learning activity in Genetics. This feedback provides insights into how the students perceived the activity in terms of its engagement, effectiveness, and overall learning impact.

Table 6: Student Feedback on the Use of Game-Based Learning Activity in Genetics Education

Theme	Subtheme	Description	Sample Quote
Engagement and enjoyment	Features the students enjoyed	The elements really make learning enjoyable and interactive, keeping the students focused and motivated throughout the activity.	"Yung design po ng punnett square ang maganda, natulungan din po kaming makita ang pagkakaiba po nung nilalagay na trait sa loob." P-18
	Leaderboard ranking	Learners reported that the presence of the Leaderboard helped them to be motivated.	"Exciting po yung game lalo na po yung leaderboard, parang nakikipag-unahan po sa kaklase dahil nakikita yung scores." P-2
Learning and Understanding	Students' Learning in Mendelian Genetics and their understanding of the topic	As of the student's statements, they easily grasp the lesson of heredity, specifically the use of the Punnett square.	"Mas natuto din po kami doon sa mga natanong po na nasa dulo noong mga Punnett square." P-1
	Difficulty of Levels	Some levels posed enough difficulty that students viewed these challenges as positive for critical thought and handling of the content.	"Madali lang po yung Level 1, yung level 2 po ay mas nachallenge po kami, pero okay naman po dahil para may challenge po sa game." P-6
	Animated features and Punnett square	The students highlighted the help of the animated features in the game, as this helps them in solving the Punnett square given.	"Isa po sa pinakamagandang features ay yung animation, dahil natutulungan po kaming mas maintindihan yung sasagutan." P-14
Challenges and Difficulties	Punnett square difficulty	Some students encountered challenges in applying Punnett squares, often due to confusion in inputting correct alleles or forgetting a step, which affected their performance.	"Madali pong gamitin ang game, pero ang Punnett square ay medyo complicated, lalo na po kapag nakalimutan kong ilagay ang isang letter, possible pong maging zero ang score." P-28
	Confusing genetic traits	Learners reported confusion in identifying specific genetic traits, particularly in scenarios involving plant characteristics like leaf types.	"Madali po para sa akin ang level 1, pero nahirapan ako sa level 2 dahil ang mga tanong at traits sa scenario ay naging mas complicated." P-4
	Time limit pressure	The imposed time limits created a sense of pressure for some students, leading to rushed decisions or incomplete answers.	"Ang time po ay isa sa mga challenge para sa akin dahil nakakadagdag po ng pressure, at nag-aalala ako na baka hindi ko masagot ang mga tanong sa tamang oras." P-3
	Technical issues	Several students experienced technical barriers such as slow loading times and unstable internet connections.	"Ang challenge na aking naranasan ay ang internet connection dahil nakaapekto po ito sa oras ko sa pagsagot kaya hindi ko nasagot ang ilang mga tanong." P-22
Confidence in Learning	Improved learning confidence	Many students reported increased confidence in their understanding of Mendelian Genetics after participating in the game-based activity.	"Ngayon po, ako ay confident sa aking pag-unawa sa Mendelian Genetics pagkatapos gumamit ng game." P-29
	Uncertainty for some learners	While several students expressed improved confidence, others remained uncertain about their learning, citing confusion with some concepts or the need for more careful reading of the questions.	"Ni-rate ko po ang aking confidence sa pagkatuto mula sa game ng 75 out of 100 dahil medyo nalilito pa rin ako, pero nauunawaan ko ito kapag binabasa ko nang mabuti ang mga tanong." P-32

	Confusing visuals and pacing	Some students experienced difficulty due to unclear or overwhelming visual elements and the pacing of the activity.	"Ang confidence ko po sa pag-aaral ng genetics ay 90/100, kahit na ang ilang mga picture ay nakakalito." P-28

3.4.1. Engagement and enjoyment

The participants found the game-based learning activity in Genetics enjoyable, engaging, and effective, with interactive elements like animations, scoring, and leaderboards enhancing their motivation and comprehension of complex concepts. While some experienced challenges, such as time limits and drag-and-drop mechanics, these were perceived positively as they promoted critical thinking and problem-solving. As López-Jiménez et al. (2021) noted, balancing challenge and enjoyment in gamified learning fosters greater student engagement and makes difficult topics more accessible and memorable.

3.4.2. Learning and understanding

Game-based learning significantly enhanced the teaching and understanding of Mendelian Genetics by using interactive features such as animations, color coding, and Punnett square exercises to simplify complex concepts and support knowledge retention. Participants reported that the game's progressive difficulty, real-time feedback, and hands-on tasks made learning more engaging, meaningful, and easier to apply. As Lampropoulos and Sidiropoulos (2024) noted, gamified environments effectively bridge theory and practice, improving both comprehension and academic performance.

3.4.3. Challenges and difficulties

Participant feedback revealed several challenges encountered during the use of the game-based learning activity in Mendelian Genetics. While the game was appreciated for being engaging and interactive, difficulties emerged—particularly with understanding and using the Punnett square and navigating the game interface. To enhance effectiveness, suggestions included adding a tutorial and using dynamic visual aids, as supported by Hughes and O'Reilly (2021), who emphasized that interactive tools improve comprehension of complex biology topics. Other issues included the increasing complexity of scenarios, which made it harder for some students to follow, highlighting the need for gradual difficulty progression (Koidl et al., 2022). Time limits also caused pressure for some, impacting decision-making and enjoyment (Wu et al., 2019), and a few experienced technical problems like phone lag and internet issues, echoing concerns raised by Perrin and Duggan (2021) on digital learning barriers.

3.4.4. Confidence in learning

Despite challenges, participants generally felt more confident in learning Mendelian Genetics after using the game. Interactive features, visual aids, and immediate feedback helped students better understand and retain the content, consistent with findings from Sage (2024) and Smith (2020), who reported improved confidence and motivation through game-based learning. Active engagement and simplified visual presentation made abstract concepts more accessible, aligning with constructivist principles (Jones & Clark, 2020). While most participants reported increased confidence, a few expressed uncertainties due to factors like prior knowledge or unclear visuals. Overall, the game-based activity supported improved understanding and academic confidence, suggesting its value in science education.

4. Conclusion

This study underscored the transformative potential of technology-enhanced pedagogy in Genetics education, particularly through game-based learning modalities. Central to the study was a purposefully designed digital activity that harnessed interactive technology to interpret Mendelian Genetics, an area traditionally regarded as abstract and cognitively demanding. By integrating genetic principles within a gamified digital framework, the activity bridged theoretical constructs with experiential engagement, which developed deeper conceptual understanding.

Evaluation results affirmed the activity's strength across multiple dimensions: its design was pedagogically sound, its content accurate and relevant, and its interface both useful and user-friendly. More importantly, the learning experience adopted went beyond comprehension. Students reported a deeper understanding of Mendelian principles, expressed enjoyment in the challenge it posed, and gained confidence in their ability to grasp scientific concepts.

The majority of participants described the activity as both engaging and enjoyable. They appreciated its capacity to clarify key ideas, stimulate curiosity, and enhance their overall learning experience. The game-based format supported cognitive development and nurtured a sense of empowerment and enthusiasm toward the subject.

While the results of this study affirm the effectiveness of game-based learning in teaching Mendelian Genetics, several limitations must be acknowledged. First, the implementation relied on access to mobile devices and stable internet connectivity, which may not be available in all educational settings, particularly in rural or under-resourced schools. This technological dependency could hinder the scalability of the intervention unless alternative offline or low-bandwidth versions of the game are developed. Second, the study was conducted within a single school context, which limits the diversity of learner backgrounds and instructional environments. Although the sample was appropriate for the Grade 8 curriculum, broader validation across varied geographic regions, socioeconomic groups, and school types is necessary to enable generalizability. Third, the intervention focused solely on Mendelian Genetics. While this topic is foundational, future research could explore scalability to other biology topics such as molecular genetics, evolution, or cell biology.

Adapting the game-based framework to interdisciplinary subjects, like environmental science or health education, may also yield valuable insights into its versatility. Longitudinal studies are recommended to assess the sustained impact of game-based learning on student retention, motivation, and academic performance. Moreover, teacher training and curriculum integration strategies should be explored to support widespread adoption. Future research could also investigate how gamified tools influence collaborative learning, critical thinking, and self-efficacy in science education.

In light of these findings, several recommendations emerged:

a) For Science Educators: Teachers are encouraged to integrate game-based learning into their instruction on Mendelian Genetics. Doing so can make abstract concepts more relatable and adoptive of a dynamic, student-centered learning environment.

b) For School Administrators: Institutional support is vital. Administrators should provide educators with the necessary training, technological infrastructure, and policy backing to implement gamified strategies effectively.
c) For Curriculum Developers: The inclusion of gamified instructional materials in school programs is advised to boost student engagement, deepen conceptual understanding, and improve performance in Science subjects.
d) For Future Researchers: Expanding the scope of this study is essential. Future investigations may explore the tool's effectiveness across different grade levels and subject areas, assess its long-term impact, and develop similar resources for other topics in Genetics or broader Science education. Engaging larger and more diverse participant groups will also enhance the generalizability of future findings.

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