Development and Evaluation of Mamaxgenius as Teaching and Learning Tool to Understand Maternal Effects

Nur Ain Faiqah Zamri, Adibah Abu Bakar, Syazwan Saidin*

Department of Biology, Faculty of Science and Mathematics, University Pendidikan Sultan Idris, 35900 Tanjong Malim, Perak, Malaysia

***Corresponding author**

DOI: https://dx.doi.org/10.47772/IJRISS.2025.9010401

Received: 20 January 2025; Accepted: 27 January 2025; Published: 25 February 2025

ABSTRACT

Studying maternal effect can be challenging for undergraduate biology students. Game-based learning, such as educational card games, offers a potential solution to enhance understanding of the complex concept. This study aims to develop and evaluate the MamaXGenius card game to aid in teaching maternal effect, a subtopic in genetics. The development phase employed the analyze, design, develop, implement, and evaluate (ADDIE) model and involved 170 biology students from semesters 3 to 7 at Sultan Idris Education University (UPSI). The study utilized a usability questionnaire for the MamaXGenius card game, administered via survey forms. A quantitative approach was used to analyze the data, employing descriptive statistics to calculate mean values, frequency percentages, and standard deviations. Results revealed mean scores of 3.73 (σ=0.480) for content, 3.74 (σ=0.468) for usability and playability, and 3.78 (σ=0.439) for satisfaction, indicating positive perceptions among respondents. The MamaXGenius card game was found to be interesting, usable, and playable, and it received high satisfaction scores from biology students. Thus, novel educational methods for teaching maternal effect should be developed, with educational card games being a viable and cost-effective approach.

Keywords: Game-based learning, Teaching tool, Genetics, Maternal effect, MamaXGenius card game

INTRODUCTION

Understanding genetics is fundamental for biology students, as it provides the basis for many areas of biological science. However, research indicates that genetics is often perceived as a difficult subject to learn (Duncan et al., 2009; Osman et al., 2016). Students frequently struggle with complex concepts, and educators face challenges in effectively teaching topics such as molecular genetics and genomics (Banet & Ayuso, 2000). Furthermore, the specialized and unfamiliar terminology in genetics often leads to misunderstandings and misconceptions that deviate from accepted theoretical frameworks (Machová & Ehler, 2021; Oja, 2024). The extensive use of domain-specific vocabulary, including terms like DNA polymerase, homozygous, codominance, non-Mendelian inheritance, extranuclear inheritance, and maternal effect, adds to the difficulty. Although considerable research has focused on students' perceptions of genetics (Adelana et al., 2024; French et al., 2022; Barry et al., 2022; Kim & Castelli, 2021), there remains a significant gap in studies that provide effective strategies to help students overcome these complexities.

To address these challenges, educators are increasingly adopting innovative teaching methods aimed at enhancing student comprehension and engagement. One promising approach is gamification, which integrates game-like elements into educational environments to create more engaging learning experiences (Putz et al. 2020; Saari, 2023; Kapp, 2012). In recent years, educational games have been used to complement traditional teaching methods, increasing student interest and fostering active learning. Examples of gamification in the classroom include awarding points for positive behavior or assignment completion and conducting competition-based quizzes during lectures, making learning more interactive and enjoyable (Landers et al.,

2018; Wen et al., 2018, Rapp, 2017; Cooper, 2014). Research suggests that gamification can positively affect both cognitive and emotional outcomes, and has been found to improve problem-solving and spatial skills (Granic et al., 2014; Green & Bavelier, 2012; Li & Tsai, 2013, Li & Tsai, 2013). Although the use of games to promote active learning is not new, there are relatively few studies on games specifically designed to enhance learning and develop competencies in genetics. Previous efforts to gamify genetics education have focused on areas such as plant genotyping, cancer biology, and molecular genetics, including gene expression, over-expression, under-expression, and mutations (Flute et al., 2019; Nosek et al, 2007; Low & Ellefson, 2024; Seow & Wen, 2024). While these initiatives are commendable, they do not specifically address foundational concepts in non-Mendelian genetics, such as the maternal effect.

At Sultan Idris Education University (UPSI), the genetics curriculum includes the topic of maternal effect, which explains how traits in offspring are influenced by the mother's genotype rather than the offspring's own genotype (Bernardo, 1996; Schwabl & Groothuis, 2010). Preliminary surveys suggest that students often find this concept difficult to understand and remember due to its abstract nature and complex terminology (unpublished data). In response to these challenges, we developed MamaXGenius, an educational card game designed to teach undergraduate students the concept of maternal effect. The game was created with several objectives in mind: a) to serve as a practical exercise that enables students to integrate knowledge; b) to introduce essential terminologies related to maternal effect through a follow-up activity after the lecture; and c) to facilitate face-to-face communication between students, encouraging discussion and questioning. While previous studies have explored the impact of gamification and educational games on student engagement and learning in various scientific disciplines, few have specifically examined their influence on understanding complex genetic concepts. Most existing research has focused on general genetics education without addressing the specific challenges posed by abstract topics such as maternal effect. Our study seeks to bridge this gap by evaluating student perceptions of using the MamaXGenius card game to learn about maternal effect and its impact on student learning satisfaction. We hypothesize that students will demonstrate a positive improvement in understanding after completing the card game.

METHOD

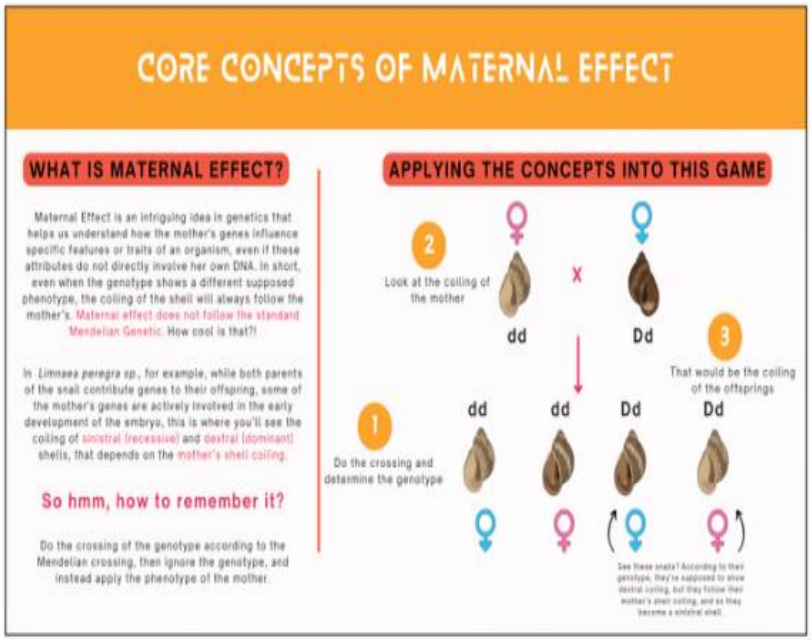
Research design

This study employs developmental design to create MamaXGenius, a card game aimed at enhancing biology students' understanding of maternal effect. The study proceeded in two main phases: the development of the educational tool and the evaluation of students' perceptions towards the tool. The ADDIE model was used as instructional model. Consequently, this research explored students' perception on content, usability, playability, and overall satisfaction after using this card game for learning.

Development of MamaXGenius

The development of the MamaXGenius card game followed a structured process, starting with the conceptualization phase, where the need for a tool to address the abstract and challenging concept of maternal effect in genetics was identified. The game mechanics were carefully selected, with a card-based format chosen to promote active learning and engagement through interactive question-and-answer gameplay. The game features a total of 73 cards, including 20 question cards and 53 answer cards. The question cards display multiple pairs of snail shells with dextral and sinistral coiling patterns, along with their respective genotypes, while the answer cards illustrate the offspring's coiling and genotypes. In the content development stage, key genetic concepts such as non-Mendelian inheritance and maternal effect were incorporated to ensure alignment with the curriculum (Figure 1).

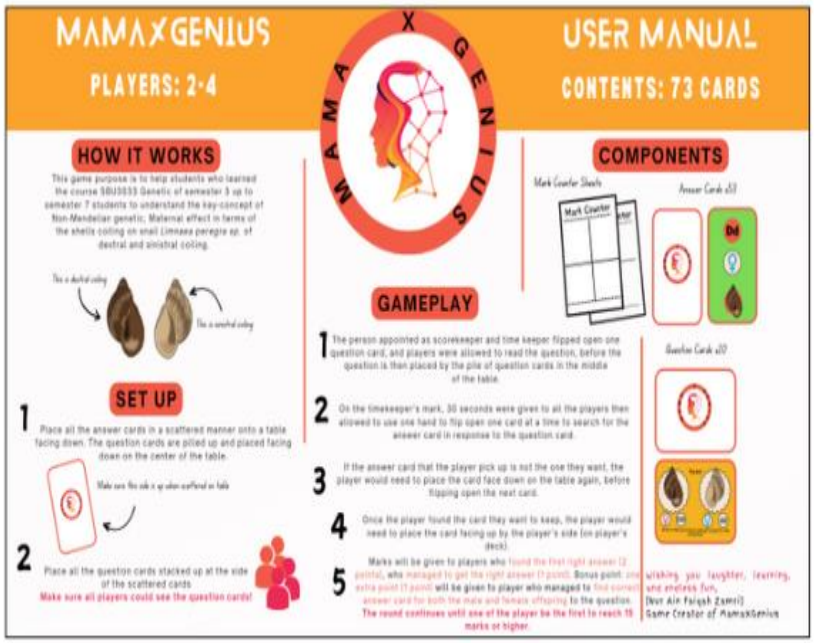
ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue I January 2025



MamaXGenius note card

MamaXGenius question card

MamaXGenius Answer card



MamaXGenius user manual

Figure 1. Features of MamaXGenius educational tool for learning maternal effects in genetics

Design elements were informed by the multimedia learning theory, which emphasizes the integration of both visual and textual information to reduce cognitive load and improve retention. The card interface, with its vibrant colors of green, blue, and yellow, combined with diagrams of snail shell coiling patterns, was specifically designed to enhance learning by presenting complementary graphics and text. This approach ensures that students can better grasp the genetic concepts by storing information in long-term memory through a balance of visual aids and textual explanations. Cognitive theory further informed the game's design by encouraging students to actively engage with the material. As students interact with the game, they apply prior knowledge of maternal effect, either assimilating new information or accommodating it to reinforce their

understanding of the topic. This development process, guided by both multimedia learning and cognitive theories, ensured that the game effectively enhances student learning and engagement.

Development of MamaXGenius

The study population consisted of biology students enrolled at UPSI, Perak. A sample of 170 students majoring in Bachelor of Education (BEd) Biology from semesters three to seven was selected, as these students had completed the genetics course in semester 2. First and second-semester students were excluded from the study. For the pilot study, 35 semester seven biology students were chosen and excluded from the main study. A simple random sampling technique was used to represent the entire population. Informed consent was obtained from all participants.

Research Instruments

The study used two types of research instruments, namely expert validation forms and usability questionnaires. Two experts from the Department of Biology were used to examine the face and content validity of the MamaXGenius and the questionnaire, respectively. The evaluation of the MamaXGenius card game included a comprehensive assessment of several criteria through specific items adopted from Gutierrez (2014) using a four-point Likert scale. For content, the items evaluated included the appropriateness of game content to learning outcomes, the ability of the game to help students connect with learned material, the effectiveness of graphics in distinguishing dextral and sinistral coiling, the readability and simplicity of the text, and the appropriateness of the gameplay difficulty level. In terms of usability and playability, the evaluation focused on the flexibility of using the game, ease of use, the game's ability to improve understanding, usability of the game manual, sturdiness of the cards, ease of maintaining the overall design, clarity and documentation of the game rules, encouragement of engagement and interaction, and the visual appeal of the game's colors and icons. For satisfaction, the criteria included overall satisfaction with the game, likelihood of recommending the game to peers, the fun factor of using the game, whether the game functioned as intended, and the overall pleasantness of the game experience.

Data analysis

The data collected from the questionnaire were subjected to quantitative analysis to ensure a rigorous evaluation of the educational card game. Validity was assessed using the Content Validity Index (CVI) through expert evaluation, ensuring that the questionnaire accurately measured the constructs it was intended to assess. Reliability of the data was measured with Cronbach's alpha, which evaluates the internal consistency of the questionnaire. Descriptive statistical methods were applied to analyse the data, including calculations of frequency, frequency percentage, mean, and standard deviation.

RESULTS AND DISCUSSION

Validity and Reliability

The validity of the face and content of MamaXGenius card game was measured using the game content validity assessment form and analysed using CVI. For the face and content validity, the score of CVI obtained is 0.989, which is above the required acceptable value for two experts which is 0.80 (Yusoff, 2019). Cronbach’s alpha value obtained in this study was 0.854, which is higher than the targeted value, 0.7, in return could be interpreted as good (Tavakol, & Dennick, 2011; Ibáñez Usach et al., 2015). This result indicates that the instrument was well received and is effective for measuring respondents' opinions on the practices of learning organizations in actual studies.

Evaluation of MamaXGenius Card Game

A survey was conducted to assess students' perceptions of the game, focusing on its content, usability andplayability, and also satisfaction. We found that respondents agreed the materials presented in MamaXGenius helped them better understand the concept of maternal effect and effectively connected to their

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue I January 2025

prior learning. Table 1 presents the frequency distribution of agreement for each item under the Content construct.

Table 1. Content descriptive evaluation of MamaXGenius card game

No	Items	Frequency of Agreement (%)				Mean Score	Standard Deviation
	Content	SD	D	A	SA		
1.	Game content is appropriate to the learning outcomes to be achieved which is to distinguish non-Mendelian genetics according to the Genetics Proforma.	1 (0.6)	0 (0.0)	46 (27.1)	123 (75.0)	3.71	0.492
2.	Playing games that contain contents related to the topic of Maternal Effect can help me connect what I have learned.	0 (0.0)	2 (1.2)	40 (23.5)	128 (75.3)	3.74	0.465
3.	I can distinguish dextral and sinistral coiling of shells with the help of graphics in the game cards.	0 (0.0)	3 (1.8)	41 (24.1)	126 (74.1)	3.72	0.487
4.	The text used is easy to read, simple, and precise.	1 (0.6)	1 (0.6)	36 (21.2)	132 (77.6)	3.76	0.481
5.	The difficulty level of the gameplay is appropriate.	0 (0.0)	2 (1.2)	44 (25.9)	124 (72.9)	3.72	0.477
	Average mean and standard deviation					**3.73**	**0.480**

Specifically, 77.6% of participants strongly agreed that ‘The text used is easy to read, simple, and precise, highlighting the effectiveness of the game in conveying complex genetic concepts. The content of the MamaXGenius card game, including illustrations of dextral and sinistral shell coiling, the genotype of parents and offspring, and key terminologies such as 'dextral' and 'sinistral,' played a crucial role in enhancing students’ comprehension. This aligns with previous studies (Franco Mariscal et al., 2012; Bell et al., 2020) which indicate that well-designed educational card games significantly aid in learning complex scientific topics. Our study suggests that, the illustrations and questions effectively reinforced the principle that the offspring’s shell coiling is determined by the mother's phenotype. This interactive application of the concept helped students solidify their understanding of the maternal effect, as evidenced by their ability to correctly pair offspring with the mother based on shell coiling.

Table 2 presents the frequency distribution of agreement for each item in the usability and playability construct. The usability construct assesses how user-friendly and accessible the MamaXGenius card game is, with aspects such as ease of navigation, clarity of instructions, and overall user experience during gameplay. Playability, on the other hand, evaluates how engaging, enjoyable, and interactive the game is, focusing on game mechanics and entertainment value. Our findings show a high mean value of 3.74 with a low standard deviation of 0.468 for this construct, indicating that respondents found the game both user-friendly and enjoyable. This positive response aligns with previous research, which suggests that active learner engagement through participation in educational activities leads to successful outcomes among students (Rield et al., 2021). Moreover, the playability of MamaXGenius promotes healthy competition and cooperation, sharpening students' social skills while enhancing their understanding of the topic (Gutierrez, 2014). Additionally, the game instructions and rules are clearly presented using simple language, allowing for easy understanding. The short rounds of gameplay keep the experience focused and contribute to higher levels of student engagement. The game's design, with bright colors and appropriately sized text, further supports usability and playability,

contributing to an enjoyable learning experience. As can be seen from our result, the high usability of the card game is evidenced by students' ability to easily understand the instructions and mechanics, thus enhancing their overall learning experience. Moreover, the game's short playtime allows for post-game debriefing, offering students an opportunity to clarify

any misconceptions and further deepen their understanding (Cosimini & Collins, 2023). Overall, the MamaXGenius card game demonstrates high playability, fostering both healthy competition and cooperative learning. By engaging in small group discussions after each round, students expand their understanding of the maternal effect, supporting cognitive development through assimilation and accommodation, as proposed by Piaget's theory (Piaget, 1975).

Table 2. Usability and playability descriptive evaluation of MamaXGenius card game

No	Items	Frequency of Agreement (%)				Mean Score	Standard Deviation
	Usability and Playability	SD	D	A	SA		
1.	I can use the card games at a flexible time.	0 (0.0)	3 (1.8)	46 (27.1)	121 (71.2)	3.69	0.499
2.	The game is easy to use.	0 (0.0)	1 (0.6)	39 (22.9)	130 (76.5)	3.76	0.443
3.	I can improve my understanding through the use of MamaXGenius.	1 (0.6)	0 (0.0)	39 (22.9)	130 (76.5)	3.75	0.472
4.	The game can be played using the manual.	1 (0.6)	0 (0.0)	37 (21.8)	132 (77.6)	3.76	0.465
5.	The cards are sturdy and well-made.	0 (0.0)	1 (0.6)	50 (29.4)	119 (70.0)	3.69	0.475
6.	The overall box design of MamaXGenius is easy to keep and maintain.	0 (0.0)	1 (0.6)	43 (25.3)	126 (74.1)	3.74	0.456
7.	The rules of the game are easy to understand and well-documented.	1 (0.6)	0 (0.0)	39 (22.9)	130 (76.5)	3.75	0.472
8.	I feel encouraged to interact and engage in the game through competing in a friendly manner.	1 (0.6)	0 (0.0)	39 (22.9)	130 (76.5)	3.76	0.443
9.	The visuals, colors, and icons used in MamaXGenius are visually stimulating and relevant to the topic Maternal Effect.	1 (0.6)	3 (1.8)	27 (15.9)	139 (81.8)	3.79	0.489
	Average mean and standard deviation					**3.74**	**0.648**

Table 3 presents the frequency distribution of agreement for each item under the Satisfaction construct, which revealed highly positive feedback from students regarding the MamaXGenius card game. A majority of respondents (71.2%) expressed overall satisfaction with the game, resulting in a mean score of 3.80 (σ = 0.443). Notably, 76.5% of students indicated they would recommend the game to their peers, with a mean score of 3.78 (σ = 0.458), while the same proportion (76.5%) found the game enjoyable to use ($\bar{x}$ = 3.80, σ = 0.416). Additionally, 77.6% agreed that the game functioned as intended ($\bar{x}$ = 3.71, σ = 0.467). The pleasantness of the game was also rated highly, with 70.0% of respondents agreeing ($\bar{x}$ = 3.81, σ = 0.411). Our

findings align with previous research, such as that by Gutierrez (2014), which demonstrated that educational card games generally receive positive responses from students, with engagement positively influencing satisfaction. This study also supports prior work highlighting the educational benefits of card games on student learning and engagement. For example, Rajashekar and Bellad (2016) found that card games improved first-year medical students'

understanding and retention of nerve muscle physiology, leading to better exam performance. Similarly, Piyawattanaviroj et al. (2019) reported enhanced conceptual understanding and attitudes towards chemistry through the use of periodic table card games. Furthermore, the interactive and competitive nature of educational card games has been associated with higher levels of student satisfaction. Hidayat et al. (2023) emphasized that such games make learning more engaging, while Kordaki and Gousiou (2017) noted the positive impact on motivation and enjoyment. This is further supported by Kim et al. (2017) and Yu et al. (2021), who demonstrated that the perceived educational value and enjoyment of games enhance student engagement and satisfaction. These findings collectively support the positive response to the MamaXGenius card game, showing that it fosters engagement, improves learning, and enhances student satisfaction with their educational experience.

Table 3. Satisfaction descriptive evaluation of MamaXGenius card game

No	Items	Frequency of Agreement (%)				Mean Score	Standard Deviation
	Satisfaction						
1.	I am satisfied with MamaXGenius.	0 (0.0)	3 (1.8)	46 (27.1)	121 (71.2)	3.80	0.443
2.	I would recommend MamaXGenius to my friends.	0 (0.0)	1 (0.6)	39 (22.9)	130 (76.5)	3.78	0.458
3.	MamaXGenius is fun to use.	1 (0.6)	0 (0.0)	39 (22.9)	130 (76.5)	3.80	0.416
4.	MamaXGenius works the way I wanted it to work.	1 (0.6)	0 (0.0)	37 (21.8)	132 (77.6)	3.71	0.467
5.	MamaXGenius is pleasant to use.	0 (0.0)	1 (0.6)	50 (29.4)	119 (70.0)	3.81	0.411
	Average mean and standard deviation					**3.78**	**0.439**

The overall results from this study shows that MamaXGenius has been positively perceived by students as a valuable learning tool. This is consistent with the findings of Castillo et al. (2022), who noted that activities promoting active student participation led to successful outcomes among college students. Additionally, game-based learning methods are increasingly being used as key components in science education, as supported by game-oriented teaching studies (Zhou et al., 2018). MamaXGenius in this study demonstrates how its engaging design and interactive features provide a more immersive and effective learning experience compared to traditional educational methods. For instance, the game's interactive nature-requiring discussions and decision-making, thus enhances learning by making the process more engaging and less monotonous. The competitive elements of the game, such as its rules and objectives, also contribute to increased motivation among students, a factor often lacking in conventional classroom settings. Furthermore, the use of visual elements, such as illustrated and colourful cards, makes abstract concepts more tangible and memorable, which has been shown to improve student engagement and learning outcomes. The social interactions fostered by the game encourage collaboration and discussion, leading to deeper understanding and better retention of the material, as students benefit from each other's perspectives and knowledge.

This study highlights the potential benefits of the MamaXGenius educational game in enhancing genetics learning, however it also has limitations that should be addressed in future research. The primary limitation of this study is the relatively small, demographically homogeneous participant pool, which may affect the generalizability of the findings. To address this, future studies should involve a larger and more diverse group of participants to better evaluate MamaXGenius. Additionally, we did not assess the effectiveness of MamaXGenius on participants in this study, leaving the impact of the card game uncertain. Therefore, further research is required to explore the effectiveness of MamaXGenius in enhancing the understanding of the maternal effect, especially when compared to traditional educational methods.

CONCLUSION

Our findings demonstrate that the MamaXGenius card game is an effective tool for reviewing and mastering the concept of maternal effect in genetics. To our knowledge, this is the first study to develop a card game specifically for teaching this topic in genetics classes. The game is highly recommended as a supplemental pedagogical tool due to its ability to engage students and enhance their understanding of complex genetic topics. The result of this study reaffirms the value of integrating educational games into learning curriculums and demonstrates the specific contributions of MamaXGenius in simplifying abstract genetics, specifically maternal effect concepts for biology students. By strategically developing and implementing this innovative teaching tool, we have made a significant advancement in fostering student engagement, improving comprehension, and promoting an active learning environment.

REFERENCES

1. Adelana, O. P., Ayanwale, M. A., & Sanusi, I. T. (2024). Exploring pre-service biology teachers' intention to teach genetics using an AI intelligent tutoring-based system. Cogent Education, 11(1). https://doi.org/10.1080/2331186X.2024.2310976
2. Banet, E., & Ayuso, E. (2000). Teaching genetics at secondary school: A strategy for teaching about the location of inheritance information. Science Education, 84(3), 313–351. https://doi.org/10.1002/(sici)1098-237x(200005)84:3%3C313::aid-sce2%3E3.0.co;2-n
3. Barry, S., Stofer, K. A., Loizzo, J., & DiGennaro, P. (2022). High school students' perceptions of science and scientists improve following university-based online DNA Day. Journal of Biological Education, 57(5), 1170–1185. https://doi.org/10.1080/00219266.2021.2012228
4. Bell, P. T., Martinez-Ortega, B. A., & Birkenfeld, A. (2020). Organic Chemistry I Cassino: A card game for learning functional group transformations for first-semester students. Journal of Chemical Education, 97(6), 1625–1628. https://doi.org/10.1021/acs.jchemed.9b00995
5. Bernardo, J. (1996). Maternal effects in animal ecology. American Zoologist, 36(2), 83–105. https://doi.org/10.1093/icb/36.2.83
6. Castillo, A. I., Roos, B. H., Rosenberg, M. S., Cartwright, R. A., & Wilson, M. A. (2022). Genie: An interactive real-time simulation for teaching genetic drift. Evolution: Education and Outreach, 15(1), 3. https://doi.org/10.1186/s12052-022-00161-7
7. Cooper, S. (2014). A framework for scientific discovery through video games. Morgan & Claypool Publishers.
8. Cosimini, M. J., & Collins, J. (2023). Card and board game design for medical education: Length and complexity considerations. Korean Journal of Medical Education, 35(3), 291–296. https://doi.org/10.3946/kjme.2023.267
9. Duncan, R. G., Freidenreich, H. B., Chinn, C. A., & Bausch, A. (2009). Promoting middle school students' understandings of molecular genetics. Research in Science Education, 41(2), 147–167. https://doi.org/10.1007/s11165-009-9150-0
10. Flutre, T., Diot, J., & David, J. (2019). PlantBreedGame: A serious game that puts students in the breeder's seat. Crop Science, 59(4), 1374–1375. https://doi.org/10.2135/cropsci2019.03.0183le
11. Franco Mariscal, A. J., Oliva Martínez, J. M., & Bernal Márquez, S. (2012). An educational card game for learning families of chemical elements. Journal of Chemical Education, 89(8), 1044–1046. https://doi.org/10.1021/ed200542x

12. French, E. L., Kader, L., Young, E. E., & Fontes, J. D. (2022). Physician perception of the importance of medical genetics and genomics in medical education and clinical practice. Medical Education Online, 28(1). https://doi.org/10.1080/10872981.2022.2143920
13. Granic, I., Lobel, A., & Engels, R. C. M. E. (2014). The benefits of playing video games. American Psychologist, 69(1), 66–78. https://doi.org/10.1037/a0034857
14. Green, C. S., & Bavelier, D. (2012). Learning, attentional control, and action video games. Current Biology, 22(6), R197–R206. https://doi.org/10.1016/j.cub.2012.02.012
15. Gutierrez, A. F. (2014). Development and effectiveness of an educational card game as supplementary material in understanding selected topics in biology. CBE Life Sciences Education, 13(1), 76–82. https://doi.org/10.1187/cbe.13-05-0093
16. Hidayat, I., Arizal, F., & Sutrisno, A. (2023). Primary student and teacher game-based learning engagement: The problem and the challenge. KnE Social Sciences. https://doi.org/10.18502/kss.v8i15.13928
17. Ibáñez Usach, C., Palma Guerrero, R., & Hernández Figueirido, D. (2015). Game boards as a review tool: An experience with undergraduate engineering students. In HEAd'15. Conference on Higher Education Advances (pp. 607–612). Universität Politècnica de València. https://doi.org/10.4995/HEAd15.2015.402
18. Jones, S. M., et al. (2019). A 'KAHOOT!' approach: The effectiveness of game-based learning for an advanced placement biology class. Simulation & Gaming, 50(6), 832–847. https://doi.org/10.1177/1046878119882048
19. Kapp, K. (2012). The gamification of learning and instruction: Game-based methods and strategies for training and education. San Francisco: Wiley.
20. Kim, J., & Castelli, D. (2021). Effects of gamification on behavioural change in education: A meta-analysis. International Journal of Environmental Research and Public Health, 18. https://doi.org/10.3390/ijerph18073550
21. Kim, S., Chang, M., Deater-Deckard, K., Evans, M., Norton, A., & Samur, Y. (2017). Educational games and students' game engagement in elementary school classrooms. Journal of Computers in Education, 4, 395–418. https://doi.org/10.1007/s40692-017-0095-4
22. Kordaki, M., & Gousiou, A. (2017). Digital card games in education: A ten-year systematic review. Computers & Education, 109, 122–161. https://doi.org/10.1016/j.compedu.2017.02.011
23. Landers, R. N., Auer, E. M., Collmus, A. B., & Armstrong, M. B. (2018). Gamification science, its history and future: Definitions and a research agenda. Simulation & Gaming, 49(3), 315–337. https://doi.org/10.1177/1046878118774385
24. Li, M.-C., & Tsai, C.-C. (2013). Game-based learning in science education: A review of relevant research. Journal of Science Education and Technology, 22(6), 877–898. https://doi.org/10.1007/s10956-013-9436-x
25. Low, H. G. H., & Ellefson, M. (2024). Punnett Farms: Developing an immersive educational game-based platform for learning genetics. Simulation & Gaming, 55(2), 302–322. https://doi.org/10.1177/10468781231220728
26. Machová, M., & Ehler, E. (2021). Secondary school students' misconceptions in genetics: Origins and solutions. Journal of Biological Education, 57(3), 1–14. https://doi.org/10.1080/00219266.2021.1933136
27. Nosek, T. M., et al. (2007). Pilot test of a serious gaming/immersion environment to teach clinical cancer genetics. The FASEB Journal, 21(5). https://doi.org/10.1096/fasebj.21.5.a213
28. Ojo, A. T. (2024). Examination of secondary school students' conceptual understanding, perceptions, and misconceptions about genetics concepts. Pedagogical Research, 9(1), em0185. https://doi.org/10.29333/pr/14095
29. Osman, E., BouJaoude, S., & Hamdan, H. (2016). An investigation of Lebanese G7-12 students' misconceptions and difficulties in genetics and their genetics literacy. International Journal of Science and Mathematics Education, 15(7), 1257–1280. https://doi.org/10.1007/s10763-016-9743-9
30. Piaget, J. (1976). Piaget and his school: A reader in developmental psychology. In B. Inhelder, H. H. Chipman, & C. Zwingmann (Eds.), Piaget and His School (pp. 11–23). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-46323-5_2

31. Piyawattanaviroj, P., Maleesut, T., & Yasri, P. (2019). An educational card game for enhancing students' learning of the periodic table. In Proceedings of the 3rd International Conference on Education and Multimedia Technology. https://doi.org/10.1145/3345120.3345165
32. Putz, L., Hofbauer, F., & Treiblmaier, H. (2020). Can gamification help to improve education? Findings from a longitudinal study. Computers in Human Behavior, 110, 106392. https://doi.org/10.1016/j.chb.2020.106392
33. Rajashekar, R., & Bellad, A. (2016). Effectiveness of educational card games as a supplementary educational tool in academic performance. Indian Journal of Clinical Anatomy and Physiology, 3, 4–7. https://doi.org/10.5958/2394-2126.2016.00002.5
34. Rapp, S. (2017). From games to gamification: A classification of rewards in World of Warcraft for the design of gamified systems. Simulation & Gaming, 48(3), 381–401. https://doi.org/10.1177/1046878117697147
35. Riedl, A., Yeung, F., & Burke, T. (2021). Implementation of a flipped active-learning approach in a community college general biology course improves student performance in subsequent biology courses and increases graduation rate. CBE Life Sciences Education, 20(2), ar30. https://doi.org/10.1187/cbe.20-07-0156
36. Saari, E., Ibrahim, N., Azmi, N., Isa, N. (2023). Awareness on the energy-saving behaviour among students: Gamification approach. Jurnal Teknologi Informasi dan Pendidikan. https://doi.org/10.24036/jtip.v16i2.813
37. Schwabl, H., & Groothuis, T. G. G. (2010). Maternal effects on behavior. In Encyclopaedia of Animal Behavior (pp. 399–411). Elsevier. https://doi.org/10.1016/B978-0-08-045337-8.00239-4
38. Seow Mun Hue, & Wen, S. (2024). Learning genetics through an innovative game: Geneblock. Journal of Biological Education, 1–11. https://doi.org/10.1080/00219266.2024.2365671
39. Tavakol, M., & Dennick, R. (2011). Making sense of Cronbach's alpha. International Journal of Medical Education, 2, 53–55. https://doi.org/10.5116/ijme.4dfb.8dfd
40. Wen, S., Lee, H., & Saw, P. (2021). The use of building blocks to teach communication and social skills to first-year pharmacy students. American Journal of Pharmaceutical Education, 85(8), 8464. https://doi.org/10.5688/ajpe8464
41. Yu, Z., Gao, M., & Wang, L. (2021). The effect of educational games on learning outcomes, student motivation, engagement and satisfaction. Journal of Educational Computing Research, 59(3), 522–546. https://doi.org/10.1177/0735633120969214
42. Yusoff, M. S. B. (2019). ABC of content validation and content validity index calculation. Education in Medicine Journal, 11(2), 49–54. https://doi.org/10.21315/eimj2019.11.2.6
43. Zhou, Y., Xu, T., Zhu, Z., & Wang, Z. (2018). Learning in doing: A model of design and assessment for using new interaction in educational games. In P. Zaphiris & A. Ioannou (Eds.), Learning and Collaboration Technologies. Learning and Teaching (pp. 225–236). Springer International Publishing. https://doi.org/10.1007/978-3-319-91152-6_18