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Research Article

Utilization of Pusdic Board Game in Increasing Level of Mastery of Grade 8 Learners in Predicting Phenotypic Expressions of Traits

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ABSTRACT

This study investigated the effectiveness of the Punnet Square Dihybrid Cross (PUSDIC) board game in enhancing Grade 8 students' mastery of predicting phenotypic expressions of traits. Using a quasi-experimental design with 40 students from Cauayan City National High School, the research compared an experimental group using the PUSDIC board game to a control group receiving traditional instruction. Results showed significantly higher post-test scores in the experimental group, with a mean increase of 28.10 points ($p < .001$) from pre- to post-test. The PUSDIC board game demonstrated a very large effect size, indicating its substantial impact on students' mastery of the subject. This interactive approach addresses challenges in teaching genetics by promoting active learning, critical thinking, and collaboration. The study supports the use of educational board games as an effective, accessible, and low-cost strategy for teaching complex scientific concepts to secondary school students, offering an engaging approach to improve science education outcomes.

Keywords: *Board games, Mastery level, Mendelian Genetics, Phenotypic expressions of traits, Punnet Square Dihybrid Cross (PUSDIC) board game*

Introduction

The issue of global competence and international assessments is crucial in both the global and local educational contexts. On a global scale, 193 nations have pledged to the Sustainable Development Goals (SDGs), with education being pivotal to achieving all other SDGs (Chandir and Gorur, 2021). Specifically, SDG 4.7 emphasises 'sustainable development and global citizenship,' advocating for the integration of these concepts into curricula, policies, and teacher education programs worldwide (Chandir & Gorur, 2021). In the Philippines, the introduction of the K to 12 Program in 2013 aimed to foster the holistic development and global competitiveness of Filipino

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learners (Balagtas et al., 2019). However, the country's performance in international assessments, such as PISA 2018, exposed significant challenges, with Filipino students ranking second to last among 78 countries in science literacy (Bernardo et al., 2023). This underscores the critical gap between the nation's educational reform efforts and international benchmarks. Interestingly, the effectiveness of international assessments in driving educational improvement is a subject of debate. While some studies suggest that participation in assessments boosts net secondary enrollment rates (Kijima & Lipscy, 2023), others argue that the PISA assessment of global competence may not be well-suited to inform policy or practice in promoting SDG 4.7 (Chandir & Gorur, 2021

Learners face significant challenges in understanding complex scientific concepts, particularly in the fields of genetics and environmental science. The intricate nature and conceptualisation of genetics pose difficulties for students, leading to challenges in their comprehension (Safitri et al., 2024). Studies have shown that students struggle to understand Mendelian genetics, often relying on descriptions of observable traits rather than integrating processes or using models (Calderón-Canales et al., 2021). The COVID-19 pandemic exposed shortcomings in traditional educational systems and their ability to adapt to crises, revealing limitations in Emergency Remote Teaching (ERT) strategies (Šinko et al., 2024),

Game-based learning (GBL) has emerged as an innovative strategy to address the challenges of teaching complex skills, such as research and project management, in a meaningful way. It offers an experiential and constructivist approach that promotes active learning and a deep understanding (Abbott, 2019). GBL aligns with constructivist theories, which emphasise that individuals develop knowledge through their own experiences and reflections, particularly in visual arts education (Tomljenović and Vorkapić, 2020). The effectiveness of GBL is supported by several learning theories. Constructivism and experiential learning are frequently cited as the theoretical foundations of GBL (Marougkas et al., 2023). These approaches encourage students' active participation through exploratory, problem-based learning, allowing them to reach more of their potential compared to traditional teaching methods (Tomljenović & Vorkapić, 2020). The experiential learning theory suggests that higher education should use student-centred, interactive, and collaborative teaching methodologies to promote initiative and autonomy in learning (Urquidi-Martín et al., 2019). This highlights the potential of innovative educational approaches in developing contexts. The PUSDIC Board Game, being a low-cost, interactive, and localised solution, could be particularly appropriate for settings where digital resources may be limited. This study supports the DepEd's educational goal of fostering mastery of genetics concepts through interactive, learner-centred strategies. The board game enables students to visualise and apply Mendelian principles, enhancing not only content retention but also critical thinking and problem-solving skills—core components of the K to 12 science framework that promotes enquiry-based and constructivist learning approaches.

While several studies have explored game-based learning interventions in science education, there is a notable lack of empirical research specifically examining board game interventions in Philippine science classrooms (Jimenez and Errabo, 2024). The existing literature predominantly focuses on digital educational games and their effectiveness in various contexts, such as primary schools in China (Chen et al., 2021) and high school citizenship studies in Taiwan (Kuo et al., 2023). However, these studies do not address the unique cultural and educational contexts of the Philippines. Interestingly, most research on game-based learning in science education has centred on digital games or computer-based interventions (Fuster-Guilló et al., 2019; Huang et al., 2023; Hussein et al., 2019). This trend highlights a gap in the literature on traditional board games, particularly in the Philippine context. Furthermore, while some studies have employed quasi-experimental designs to test the effectiveness of game-based interventions (Chen et al., 2021; Hussein et al., 2019; Kuo et al., 2023), experimental or quasi-experimental research specifically examining board game interventions in actual Philippine science classrooms is scarce. The limited empirical studies

on board game interventions in Philippine science classes and the lack of experimental research testing their effectiveness in actual classrooms represent significant gaps in the literature. This underscores the need for more rigorous, context-specific research to evaluate the potential benefits of board game interventions in Philippine science education, particularly through experimental or quasi-experimental designs in authentic classroom settings.

Research Questions

This Study aimed to investigate the effects of using the Punnet Square Dihybrid Cross (PUSDIC) Board game as a tool in improving the mastery level of Grade 8 students in predicting the phenotypic expressions of traits.

This study specifically answered the following questions:

- What were the pretest and posttest mean scores of the two groups of subjects before and after the implementation of the Punnet Square Dihybrid Cross (PUSDIC) Board game?;
- Is there a significant difference in the pre- and post-test scores of the experimental group?
- Was there a significant difference on the pretest and posttest mean scores of the group exposed to the intervention?;
- What was the effect size of the PUSDIC Board game on the participants' level of mastery in predicting phenotypic expressions of traits among the subjects?

Methods

Research Design

This study employed a quasi-experimental research design, specifically a pretest-posttest control group design, to evaluate the effectiveness of the Punnett Square Dihybrid Cross (PUSDIC) board game in improving students' mastery of predicting phenotypic expressions of traits. This design allowed the comparison between an experimental group exposed to the board game intervention and a control group receiving traditional instruction.

Participants and Sampling

A total of 40 Grade 8 students enrolled in the Basic Education Curriculum at Cauayan City National High School during School Year 2023–2024 were selected through purposive sampling, based on comparable academic profiles and timetable availability. After obtaining parental consent and administrative approval, these 40 students constituted the sampling frame. Within this purposively selected pool, individual learners were then randomly assigned—using a simple lottery method—to either the experimental group (n = 20), which received the PUSDIC board-game intervention, or the control group (n = 20), which received conventional lecture-discussion instruction

Data Gathering Instruments

- Test Construction and Content Validity
  The researcher-made 40-item multiple-choice test was meticulously crafted to align with the Grade 8 Science curriculum's learning competency on predicting phenotypic expressions of traits. Each item was mapped to specific curriculum standards and designed to progressively assess students' conceptual understanding of Mendelian genetics. To ensure content validity, the draft instrument underwent expert review by a master teacher and the department head, who evaluated item clarity, relevance, and coverage of key genetic principles; their feedback was incorporated to refine wording, eliminate redundancies, and confirm that the test fully represented the intended construct.
- Pilot Testing and Psychometric Analysis
  Prior to its use in the main study, the test was pilot-tested with 15 Grade 8 students from a comparable cohort to conduct a thorough item analysis. Difficulty indices for the retained items ranged from 0.32 to 0.77 (M = 0.54), indicating an appropriate spread of item challenge, while all discrimination indices exceeded 0.28, demonstrating each item's effectiveness in distinguishing higher- and lower-ability students. Ambiguous or poorly performing items were subsequently revised or replaced based on these analyses. Finally, the instrument's internal consistency was confirmed with a Kuder–Richardson Formula 20 reliability coefficient of 0.86, affirming that the test consistently measures students' mastery of

Mendelian-genetics concepts across administrations.

Data Collection Procedures

Data collection proceeded in three sequential phases. First, in the pretest phase, both the experimental and control groups were administered the researcher-made 40-item multiple-choice test under standardized conditions to establish baseline equivalence. Next, during the intervention phase, the experimental group participated in five 40-minute PUSDIC board-game sessions (totaling 200 minutes) spread over one week, during which students worked in pairs to apply Mendelian-genetics concepts through dice rolls, tile placement, and outcome prediction under teacher supervision; concurrently, the control group received five equivalent 40-minute lecture-discussion sessions on Mendelian genetics using traditional instructional materials. Finally, in the posttest phase, both groups immediately retook the identical 40-item test to measure learning gains and improvements in conceptual mastery.

Intervention Procedure

The PUSDIC Board Game, grounded in game-based and experiential learning theories, was developed as the instructional tool. The intervention was carried out in the sixth week of the fourth quarter, aligned with the learning competency *S8LT-IVf-18* — "Predict the phenotypic expressions of traits following simple patterns of inheritance."

The experimental group engaged in gameplay involving:

- Dice rolling, tile placement, and bowl-based genetic outcome drawing.
- Phenotypic ratio predictions based on the game's simulated dihybrid crosses.
- Immediate feedback and collaborative discussions during and after gameplay.

The control group was taught using traditional methods (e.g., textbook exercises and teacher-led discussions).

Data Analysis

The data analysis in this study involved both descriptive and inferential statistical methods to evaluate the effectiveness of the PUSDIC board game intervention.

Descriptive statistics, including mean and standard deviation, were used to summarize the pretest and posttest scores of both the experimental and control groups. To determine significant differences in student performance, independent samples t-tests were employed to compare the posttest scores between the two groups, while paired samples t-tests assessed the improvement within each group from pretest to posttest. Additionally, the effect size of the intervention was computed using Cohen's d and Hedges' g to measure the magnitude of the board game's impact on students' mastery of predicting phenotypic expressions of traits. All statistical computations were performed using a student-version statistical software package, with the significance level set at $p < 0.05$.

Ethical Considerations

All study procedures adhered to ethical research standards: written informed consent was obtained from parents or guardians (with student assent), and formal approval was secured from school authorities; participation was entirely voluntary, with students free to withdraw at any point without penalty; personal identifiers were replaced with codes to protect anonymity, and all data were stored securely and accessed only by the research team; moreover, the study complied with institutional guidelines and national regulations governing research with minor participants.

Result and Discussion

This section contains the answers to the research questions and their implications for the entire research study and the teaching and learning procedures.

Descriptive Statistics				
	GROUP	Mean	Std. Deviation	N
PRETEST	CONTROL	8.05	1.79	20
	EXPERIMENTAL	8.05	1.79	20
	Total	8.05	1.77	40
POSTTEST	CONTROL	15.00	2.13	20
	EXPERIMENTAL	36.15	1.84	20
	Total	25.58	10.89	40

Table 1 shows the descriptive statistics of the control and experimental groups using their mean scores, standard deviation, and N for the pre- and post-tests.

Studies have shown that innovative teaching methods, including game-based learning, can lead to improved learning outcomes. Egara and Mosimege (2023) reported that students taught mathematics using a flipped classroom approach had higher achievement scores than those taught using conventional methods (Egara & Mosimege, 2023). Similarly, Lemos et al. (2023) demonstrated significant improvement in knowledge between pre- and post-tests ($p < 0.05$) for both game-based and paper-based learning groups (Lemos et al., 2023). Interestingly, while some studies show the clear advantages of innovative methods, others find comparable results between experimental and control groups. For example, Lemos et al. (2023) found no significant difference between the game application and paper script groups in terms of post-test scores and learning success (Lemos et al., 2023). The trend across similar studies suggests that innovative teaching methods, including game-based learning, often lead to improved learning outcomes.

Paired Samples Test										
		Levene's Test for Equality of Variances		T-Test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Pretest	Equal variances assumed	7.8 1E-030	1.000	.00 .00	38.00 38.00 38.00	1.000 1.000	.00 .00	.57 .57	-1.15 -1.15	1.15 1.15
	Equal variances not assumed									
Posttest	Equal variances assumed	.10	.755	-33.60 -33.60	38.00 37.24	.000 .000	-21.15 -21.15	.63 .63	-22.42 -22.43	-19.88 -19.87
	Equal variances not assumed									

Table 2. Paired Sample Test of the Pretest and Posttest Mean Scores of the Control Group Shows the Levene's test results for the pre-board game activity and post-board game activity mean scores. The paired-sample t-test results showed a significant difference between the pre- and post-test mean scores of the control group (Egara & Mosimege, 2024). The t-value for the posttest was -33.60, with a p-

value of 0.000, indicating a statistically significant difference. This suggests that the control group experienced a significant change in their scores from the pretest to the posttest. Interestingly, while the control group showed improvement, several studies found that experimental groups using innovative teaching methods outperformed the control groups.

For instance, a study on blended learning in mathematics showed that students taught using this method had higher achievement and retention scores than those taught conventionally (Egara & Mosimege, 2024). Similarly, research on simulation-based training for nursing students (Oanh et al., 2024) and virtual laboratory use in science education (Lestari et al., 2023) demonstrated significant improvements in various skills in experimental groups. In conclusion, while the control group in this study showed significant improvement from pre-to post-test, the broader literature suggests that innovative teaching methods often lead to greater gains than conventional approaches. This highlights the potential benefits of incorporating new educational technologies and strategies to enhance student learning outcomes in various disciplines.

	Paired Differences					t	df	Sig. (2- tailed)
	Mean	Std. Deviation	S.E. Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pair 1 PRETEST_CTRL - POSTTEST_CTRL	-6.95	1.99	.44	-7.88	-6.02	-15.65	19	.000
Pair 2 PRETEST_EXP - POSTTEST_EXP	-28.10	3.16	.71	-29.58	-26.62	-39.76	19	.000

Table 3. Paired Samples Test of the Pretest and Posttest Mean Scores of Control and Experimental Group shows the paired samples t-test results of both the control and experimental groups for the pre-board game activity and post-board game activity.

The paired-samples test results indicated significant improvements in both the control and experimental groups from pre-to post-test, with the experimental group showing a larger increase in scores. For the control group, there was a statistically significant mean increase of 6.95 points from the pretest to the posttest ($t(19) = -15.65$, $p < .001$). The experimental group demonstrated an even larger statistically significant mean increase of 28.10 points from pre-test to post-test ($t(19) = -39.76$, $p < .001$). These results align with the findings of other studies on educational interventions. Egara and Mosimege (2024) found that students taught using a blended learning approach showed greater improvements in mathematics achievement than those taught conventionally (Egara & Mosimege, 2024). Similarly, Lestari et al. (2023) reported that combining virtual laboratories with demonstration methods was the most effective in improving students' scientific literacy ability (Lestari et al., 2023). In conclusion, while both groups improved, the substantially larger gain for the experimental group (28.10 vs. 6.95 points) suggests that the PUSDIC board game was highly effective in increasing Grade 8 learners' mastery of predicting phenotypic expressions of traits. This aligns with the general trend across studies that innovative, interactive teaching methods tend to produce greater learning gains than conventional approaches

	Effect Size	Description
Cohen's d	10.626598	Large Effect
Glass's delta	9.929577	Large Effect
Hedges' g	10.626598	Large Effect

Table 4. The effect Size of the Intervention on the Experimental Group shows the magnitude of the effect the intervention had on the level of mastery of grade 8 learners of Cauayan City National High School-Main Campus. The utilisation of the Pusdic board game had a very large positive effect on increasing the level of mastery of Grade 8 learners in predicting the phenotypic expressions of traits. The Cohen's d and Hedges' g values of 10.63 indicate an extremely large effect size, far exceeding the conventional threshold of 0.8 for a large effect size (Mao et al., 2021; Talan et al., 2020). This exceptionally large effect size is notably higher than those reported in most meta-analyses of game-based learning interventions to date. For instance, a meta-analysis on game-based learning for STEM education found a moderate overall effect size of 0.667 (Wang et al., 2022), while another on computational thinking reported an upper-middle-level effect of 0.600 (Ma et al., 2023). The effect size for the Pusdic board game was also substantially larger than the effects reported for digital games on nursing education, which ranged from 0.49 to 0.75 for various outcomes (Lee et al., 2024).

Summary

This quasi-experimental study investigated the effectiveness of the Punnet Square Dihybrid Cross (PUSDIC) board game in improving Grade 8 students' mastery of predicting phenotypic expressions of traits. The study compared an experimental group using the PUSDIC board game to a control group receiving traditional instruction. Results showed significantly higher post-test scores in the experimental group, with a mean increase of 28.10 points from pre- to post-test. The PUSDIC board game demonstrated a very large effect size, indicating its substantial impact on students' mastery of the subject. The study supports the use of educational board games as an effective, accessible, and low-cost strategy for teaching complex scientific concepts to secondary school students.

Implications for Teaching Practice

The implications for teaching practice based on this study—and bolstered by Anselmo's (2024) meta-analysis of physics learning kits—are both multifaceted and significant. Educational board games, such as PUSDIC, demonstrate high effectiveness in teaching complex scientific concepts—mirroring the consistent positive effects on conceptual understanding and retention reported for hands-on physics kits (Anselmo, 2024). This convergence of evidence suggests that teachers should consider incorporating interactive, tangible learning tools—whether board games or learning kits—to enhance student engagement and learning outcomes. The active nature of these materials promotes critical thinking, problem solving, collaboration, and deeper conceptual mastery, skills that extend beyond content recall. As accessible, low-cost pedagogical resources, both board games and physics kits are especially valuable in contexts with limited digital infrastructure. The large effect sizes observed in meta-analytic studies and significant gains in test scores in the PUSDIC pilot indicate that game-based and kit-based learning can substantially improve student mastery of abstract topics. Educators can therefore employ these resources alongside traditional instruction—reinforcing key concepts through hands-on, learner-centred experiences—and even develop subject-specific games or kits aligned with curriculum objectives. Overall, this body of research supports a shift toward more interactive, student-centred approaches in science education that make abstract principles concrete and engaging.

Conclusion

This study demonstrates the effectiveness of the PUSDIC board game in enhancing Grade 8 students' mastery of predicting phenotypic expressions of traits. The quasi-experimental design involving 40 students showed significantly higher post-test scores in the experimental group than in the control group. The experimental group exhibited a substantial mean increase of 28.10 points from the pre-to post-test, indicating a significant improvement in their understanding of the subject matter. The PUSDIC board game demonstrated a very large effect size, suggesting its substantial impact on student mastery of the subject. The interactive nature of the board game addresses the challenges of teaching genetics by promoting active

learning, critical thinking, problem-solving, and collaboration among students. This study supports the use of educational board games as an effective, accessible, and low-cost pedagogical strategy for teaching complex scientific concepts to secondary school students. These findings have important implications for teaching practice, suggesting that incorporating game-based learning approaches can lead to significant improvements in student understanding and engagement, particularly in challenging subjects such as genetics.

Recommendation

Key recommendations include incorporating educational board games like PUSDIC as supplementary tools in science classrooms, particularly for teaching complex topics like genetics, given the significant improvement in test scores and large effect size. Developing more subject-specific educational games tailored to curriculum objectives is suggested, as the success of PUSDIC indicates the potential benefits for student learning. A shift towards more interactive, learner-centered teaching approaches in science education is recommended, as the board game promotes active learning, critical thinking, problem-solving, and collaboration among students. Using board games as an accessible and low-cost pedagogical strategy is advised, especially in settings with limited digital resources. Providing teacher training to effectively integrate game-based learning approaches into existing curricula and lesson plans is crucial. Further research is encouraged to explore the long-term retention of knowledge gained through educational board games and their effectiveness in different subject areas. Finally, collaboration between educators and game designers is recommended to create more educational board games aligned with specific learning objectives.

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References

A. (2014b, March 27). *The National Achievement Test in the Philippines*. https://www.philippinesbasiceducation.us/2013/07/the-national-achievement-test-in.html?m=1

Anderson-Levitt, K., & Gardinier, M. P. (2021). Introduction contextualising global flows of competency-based education: polysemy, hybridity and silences. *Comparative Education*, *57*(1), 1–18. https://doi.org/10.1080/03050068.2020.1852719

Anselmo, C. T. (2024). USE OF LEARNING KITS IN PHYSICS EDUCATION AND ITS EFFECTIVENESS: A META-ANALYSIS. Ignatian International Journal for Multidisciplinary Research, 2(6), 307–323. https://doi.org/10.5281/zenodo.11474556

Balagtas, M. U., Garcia, D. C. B., & Ngo, D. C. (2019). Looking through Philippine's K to 12 Curriculum in Mathematics and Science vis-a-vis TIMSS 2015 Assessment Framework. *EURASIA Journal of Mathematics, Science and Technology Education*, *15*(12). https://doi.org/10.29333/ejmste/108494

Bayeck, R. Y. (2020). Examining Board Gameplay and Learning: A Multidisciplinary Review of Recent Research. *Simulation & Gaming*, *51*(4), 411–431. https://doi.org/10.1177/1046878119901286

Benefits of Using Board Games in the Classroom. (2022, January 31). User Generated Education. https://usergeneratededucation.wordpress.com/2022/01/31/benefits-of-using-board-games-in-the-classroom/#:~:text=They%20encourage%20critical%20thinking%20and,%2C%20inquiry%2C%20and%20critical%20thinking

Bernardo, A. B. I., Calleja, M. O., Chua, U. C., Cordel, M. O., Teves, J. M. M., & Yap, S. A. (2023). Profiling low-proficiency science students in the Philippines using machine learning. *Humanities and Social Sciences Communications*, *10*(1).

https://doi.org/10.1057/s41599-023-01705-y

Chandir, H., & Gorur, R. (2021). Unsustainable measures? Assessing global competence in PISA 2018. *Education Policy Analysis Archives*, *29*(August-December), 122. https://doi.org/10.14507/epaa.29.4716

Chen, J., Mei, B., & Yang, S. (2021). Towards the Sustainable Development of Digital Educational Games for Primary School Students in China. *Sustainability*, *13*(14), 7919. https://doi.org/10.3390/su13147919

Egara, F. O., & Mosimege, M. (2024). Effect of blended learning approach on secondary school learners' mathematics achievement and retention. *Education and Information Technologies*, *29*(15), 19863–19888. https://doi.org/10.1007/s10639-024-12651-w

Egara, F. O., & Mosimege, M. (2023). Effect of flipped classroom learning approach on mathematics achievement and interest among secondary school students. *Education and Information Technologies*, *29*(7), 8131–8150. https://doi.org/10.1007/s10639-023-12145-1

Flores-Camacho, F., Calderón-Canales, E., García-Rivera, B., Báez-Islas, A., & Gallegos-Cázares, L. (2021). Representational Trajectories in the Understanding of Mendelian Genetics. *Eurasia Journal of Mathematics, Science and Technology Education*, *17*(8), em1988. https://doi.org/10.29333/ejmste/10998

Fuster-Guilló, A., Jimeno-Morenilla, A., Rico-Soliveres, M. L., Restrepo-Calle, F., Azorín-López, J., & Pertegal-Felices, M. L. (2019). Evaluating Impact on Motivation and Academic Performance of a Game-Based Learning Experience Using Kahoot. *Frontiers in Psychology*, *10*(9). https://doi.org/10.3389/fpsyg.2019.02843

Hussein, M. H., Ow, S. H., Cheong, L. S., & Thong, M.-K. (2019). A Digital Game-Based Learning Method to Improve Students' Critical Thinking Skills in Elementary Science. *IEEE Access*, *7*, 96309–96318. https://doi.org/10.1109/access.2019.2929089

Jimenez, J., & Errabo, D. D. (2024). Cross-Cultural Biology Teaching Using Next-Generation Science Standards. *Education Sciences*, *14*(11), 1243. https://doi.org/10.3390/educsci14111243

Kijima, R., & Lipscy, P. Y. (2023). The politics of international testing. *The Review of International Organizations*, *19*(1), 1–31. https://doi.org/10.1007/s11558-023-09494-4

Kuo, H.-C., Chang, C.-Y., Weng, T.-L., & Chang, C.-C. (2023). Designing Our Own Board Games in the Playful Space: Improving High School Student's Citizenship Competencies and Creativity through Game-Based Learning. *Sustainability*, *15*(4), 2968. https://doi.org/10.3390/su15042968

Lee, M., Shin, S., Lee, M., & Hong, E. (2024). Educational outcomes of digital serious games in nursing education: a systematic review and meta-analysis of randomized controlled trials. *BMC Medical Education*, *24*(1). https://doi.org/10.1186/s12909-024-06464-1

Lemos, M., Wolfart, S., & Rittich, A. B. (2023). Assessment and evaluation of a serious game for teaching factual knowledge in dental education. *BMC Medical Education*, *23*(1). https://doi.org/10.1186/s12909-023-04498-5

Lestari, D. P., Herianto, H., Paidi, P., Supahar, S., & Suwarjo, S. (2023). Effect of science virtual laboratory combination with demonstration methods on lower-secondary school students' scientific literacy ability in a science course. *Education and Information Technologies*, *28*(12), 16153–16175. https://doi.org/10.1007/s10639-023-11857-8

M. (2018, October 20). *Cytogenetics Questions and Answers – Numerical Problems*. Sanfoundry. https://www.sanfoundry.com/cytogenetics-questions-answers-numerical-problems/

Mao, W., Lei, H., Cui, Y., & Chiu, M. M. (2021). Effects of Game-Based Learning on

Students' Critical Thinking: A Meta-Analysis. *Journal of Educational Computing Research*, *59*(8), 1682–1708. https://doi.org/10.1177/07356331211007098

Oanh, T. T. H., Thuy, L. T., & Huyen, N. T. T. (2024). The effect of simulation-based training on problem-solving skills, critical thinking skills, and self-efficacy among nursing students in Vietnam: a before-and-after study. *Journal of Educational Evaluation for Health Professions*, *21*, 24. https://doi.org/10.3352/jeehp.2024.21.24

Safitri, D., Zubaidah, S., Gofur, A., & Lestari, S. R. (2024). Mobile Augmented Reality Genetics to Improve Students' Mastery of Genetic Concepts. TEM Journal, 1399–1412. Portico. https://doi.org/10.18421/tem132-54

Flores-Camacho, F., Calderón-Canales, E., García-Rivera, B., Báez-Islas, A., & Gallegos-Cázares, L. (2021). Representational Trajectories in the Understanding of Mendelian Genetics. *Eurasia Journal of Mathematics, Science and Technology Education*, *17*(8), em1988. https://doi.org/10.29333/ejmste/10998

Talan, T., Doğan, Y., & Batdı, V. (2020). Efficiency of digital and non-digital educational games: A comparative meta-analysis and a meta-thematic analysis. *Journal of Research on Technology in Education*, *52*(4), 474–514. https://doi.org/10.1080/15391523.2020.1743798

Wang, L.-H., Guan, J.-Q., Chen, B., Hwang, G.-J., & Wang, Y.-Q. (2022). Effects of digital game-based STEM education on students\u2019 learning achievement: a meta-analysis. *International Journal of STEM Education*, *9*(1). https://doi.org/10.1186/s40594-022-00344-0