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Tectonic Clash: An Interactive Game-Based Learning Intervention for Mastering Earth Science Concepts

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ABSTRACT

This study investigates the effectiveness and acceptability of Tectonic Clash, a game-based learning intervention designed to improve science students' mastery of earth science concepts. In response to persistent challenges in Earth Science education in the Philippines, as evidenced by low international assessment scores, the study aims to explore innovative teaching strategies that enhance student engagement and concept mastery. The card game was evaluated by fifty pre-service and ten teachers using an evaluation form. Findings show that the game has the potential to stimulate critical discussion and encourage deeper engagement with scientific content. Both teacher groups rated the game highly across dimensions, including rules, design, color/graphics, fonts, artwork, and conceptual accuracy. Mean scores across all categories ranged from 4.23 to 4.9, indicating strong agreement on the game's educational value and design quality. The results confirm that Tectonic Clash effectively reinforces key Earth Science concepts and is well-received as a pedagogical tool. The study demonstrates the potential of game-based Learning to address persistent educational gaps and foster long-term retention in science education.

Keywords: *game-based learning, plate tectonics, science education, conceptual understanding, card game.*

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INTRODUCTION

Filipino students face significant challenges in Earth science, highlighted by their poor performance in the 2018 PISA assessment, where the Philippines ranked second to last among 78 countries.[1] This struggle reflects the broader ongoing challenge of building science literacy, as the government continues efforts to connect teachers, schools, and curricula better.[2] Multiple factors contribute to these difficulties, including teacher quality, social experiences, family background, and aspirations. Future science educators themselves face problems with subject knowledge, teaching methods, classroom settings, and lesson planning.[3] Teachers had to adapt to flexible Learning while maintaining core learning outcomes.[4] Additionally, teachers and secondary school students often view Earth science as less important than other science subjects, while cultural factors influence student science literacy. To address these challenges, experts recommend comprehensive strategies using evidence-based actions and new policies to tackle various contributing factors.[5] Innovative teaching approaches, such as educational video clips, promise to develop essential 21st-century skills and improve students' understanding of science concepts.[6] For example, the Computer Simulation Supported Predict-Observe-Explain (CSSPOE) method has shown promise in improving students' conceptual understanding and scientific reasoning.[7] These developments highlight the ongoing efforts to enhance science education in the Philippines through teacher training, curriculum alignment, and the integration of technology-enhanced learning approaches.

Among the innovative approaches gaining traction, game-based learning (GBL) has emerged as an effective tool for enhancing student engagement and learning outcomes across various subjects. This pedagogical approach is grounded in several educational theories, including constructivism, experiential Learning, and flow theory.[8] The theoretical foundation of GBL emphasizes the importance of flow experience integrated with game

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[3] Antipolo, Ace Mark R., and Danilo V. Jr Rogayan. "Filipino Prospective Teachers' Experiences in Teaching in K12 Science Curriculum: A Cross-sectional Research." *JPBI (Jurnal Pendidikan Biologi Indonesia)* 7, no. 1 (March 30, 2021): 1–10. https://doi.org/10.22219/jpbi.v7i1.15468.

[4] Lansangan, Ryan V., and Antriman V. Orleans. "Experiences of Filipino Secondary Science Teachers in Assessing Students in Flexible Learning During the COVID-19 Pandemic." *European Journal of Education and Pedagogy* 4, no. 2 (April 10, 2023): 182–93. https://doi.org/10.24018/ejedu.2023.4.2.630.

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[7] Pacala, Frank Angelo A. "Combining Active Learning Strategies: Performances and Experiences of Grade School Filipino Students." *International Journal of Social Learning (IJSL)* 2, no. 1 (December 13, 2021): 84–104. https://doi.org/10.47134/ijsl.v2i1.85.

[8] Barr, Matthew. "Video Games and Learning." In *Digital Education and Learning*, 1–31, 2019. https://doi.org/10.1007/978-3-030-27786-4_1.

elements for effective Learning.[9] Immersion and flow are essential components of the player experience, with immersion focusing on sensory engagement and flow emphasizing cognitive aspects such as the balance between challenge and skill. When well-designed, GBL can simulate authentic problem-solving tasks, combining instruction, Learning, and assessment.[10]

According to Morales et al. (2022), multiple game-based approaches can lead to better academic outcomes and increased student involvement in Grade 10 Science.[11] Comparably, engaging students in activity-based strategies has been shown to improve the motivation and performance of grade 7 students in earth science.[12] For instance, the Earth Layer Game (LABU) is a specific game base that has garnered positive feedback from students and specialists.[13] Furthermore, traditional Filipino games have been shown to enhance motivation, interest, and achievement in science among grade 7 students.[14]

Research has demonstrated that GBL has positively affected Filipino students' academic performance across various subjects. Fourth-grade pupils exposed to GBL strategies in mathematics education demonstrated significantly higher scores than those taught traditional methods.[15] Similarly, in language arts, GBL improved the grammar skills of grade 9 students, progressing them from developing proficiency to proficient levels.[16]

The benefits extend to reading pedagogy, where GBL has been identified as an innovative approach to address low reading proficiency among Filipino learners, offering interactive and engaging learning experiences.[17] Game-based Learning can actively involve students in their educational journey and create possibilities for continuous Learning that spans multiple subject areas.[18] A specific example of successful implementation comes from

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[9] Elsattar, Hussein Karam Hussein Abd. 2017. "Designing for Game-Based Learning Model: The Effective Integration of Flow Experience and Game Elements to Support Learning." In *Proceedings of the 2017 14th International Conference on Computer Graphics, Imaging and Visualization (CGIV)*, May 23–25, 2017. IEEE. https://doi.org/10.1109/CGIV.2017.31.

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[13] Hapsari, Dini, Agus Wedi, and Sulthoni Sulthoni. "Pengembangan Game Labu Siswa Kelas VII." *JKTP Jurnal Kajian Teknologi Pendidikan* 4, no. 3 (August 10, 2021): 242–50. https://doi.org/10.17977/um038v4i32021p242.

[14] Capinding, Andie Tangonan, and Remelie Dacumos Salazar. "Revitalizing Science Education: Harnessing the Power of Traditional Filipino Games in the Classroom." *TEM Journal*, November 27, (2023), 2241–50. https://doi.org/10.18421/tem124-35.

[15] Cayang, Juzzel Amor, and Eziel Mae Ursabia. "https://www.jippublication.com/leveling-up-mathematical-skills-the-effectiveness-of-game-based-learning." *Journal of Interdisciplinary Perspectives* 2, no. 7 January 1, 2024. https://doi.org/10.69569/jip.2024.0087a.

[16] Aratea, Marko L., and Mark Anthony C. Pasubillo. "Effects of Game-Based Learning on Improving Grammar Skills of Grade 9 Students." *Journal of English as a Foreign Language Teaching and Research* 4, no. 2 (September 30, 2024): 43–60. https://doi.org/10.31098/jefltr.v4i2.2445.

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[18] Adipat, Surattana, Kittisak Laksana, Kanrawee Busayanon, Alongkorn Ausawasowan, and Boonlit Adipat. "Engaging Students in the Learning Process With Game-Based Learning: The Fundamental Concepts." *International Journal of Technology in Education* 4, no. 3 (July 20, 2021): 542–52. https://doi.org/10.46328/ijte.169.

Philippine history education, where a GBL approach demonstrated high usability and student satisfaction.

These findings align with international research, which indicates that GBL positively impacts both cognitive and affective aspects of Learning.[19] Studies have shown that GBL can improve motivation, metacognition, and self-regulated Learning in higher education.[20] Additionally, GBL has been found to positively influence the acquisition of soft skills and basic competencies in computer science education, with students perceiving these tools as helpful and easy to use.[21]

Game-based learning approaches have demonstrated effectiveness in teaching scientific concepts, particularly in areas of practical application and learner feedback.[22] Research has shown that GBL has auspicious results in improving science education outcomes for high school students. Meta-analyses have revealed that GBL interventions have a statistically significant positive effect on students' learning outcomes, with a medium effect size. Research suggests that GBL is particularly effective in secondary schools compared to elementary schools.[23] Game-based Learning generates increased immersive engagement and reduces unnecessary mental burden compared to traditional non-gaming education.[24]To maximize these benefits, educational games should develop learners' identity, ensure applicability beyond classroom settings, and establish connections to authentic scientific practices.[25] Furthermore, incorporating collaborative multiplayer features can enhance student engagement and cultivate a sustained user community for educational gaming platforms.[26]

Specific subject areas have shown notable improvements. In Earth and Life Science classes, GBL led to higher post-test scores among grade 11 students than traditional instruction.[27] Multiple game-based strategies resulted in better academic performance for

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[19] Pratama, L. D., and W. Setyaningrum. "Game-Based Learning: The Effects on Student Cognitive and Affective Aspects." *Journal of Physics: Conference Series* 1097 (2018): 012123. https://doi.org/10.1088/1742-6596/1097/1/012123.

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[26] Asadi, Yahya M H I, C Gagan Babu, Poojary Shubham, and Savitha A Shenov. "Innovative Game-Based Educational Application for Learning." *2022 13th International Conference on Computing Communication and Networking Technologies (ICCCNT)* 21 (July 6, 2021): 1–6. https://doi.org/10.1109/icccnt51525.2021.9579868.

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Grade 10 learners than conventional teaching methods. GBL approaches in science education are often rooted in constructivist learning theories and primarily focus on knowledge attainment.[28] This theoretical grounding provides a solid foundation for understanding why GBL is effective in science contexts, where hands-on exploration and discovery are fundamental to Learning. The success of GBL depends on several critical factors. Key elements include game goals, mechanisms, fantasy, interaction, challenges, and mystery.[29] The effectiveness of online GBL is influenced by game-task fit, flow, and perceived usefulness, with utilitarian factors having a more substantial impact on knowledge improvement than hedonic motivations.[30] Integrating established learning theories with game design elements is crucial for effective GBL implementation.

Practical implementation involves systematic stages such as identifying learning objectives, creating scenarios, and applying game dynamics. The integration of GBL in Philippine education shows promise in enhancing student engagement, motivation, and academic performance across different subject areas and grade levels. When properly designed and implemented, GBL can increase student motivation, literacy, and learning outcomes.[31] Games can also improve concentration and create positive mental responses while motivating students to engage in classroom activities.[32] Making it a valuable tool for educators seeking innovative teaching methods. In mathematics education games, design factors are crucial in supporting learning outcomes and interests.[33] Research on young children's route-planning abilities revealed that scenario-based digital games can improve learning performance and strategy development while garnering high technology acceptance.[34]

While game-based Learning has garnered increasing attention as a pedagogical approach, there remains a notable gap in the literature, particularly within Alfonso Lista, Ifugao, Philippines, regarding its direct and measurable impact on Earth science conceptual understanding and academic performance. Crucially, whether these innovative approaches can directly correlate with improving PISA-relevant Earth science competencies among local learners is unexplored.

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[34] Lin, Yi-Hui, and Huei-Tse Hou. "Exploring Young Children's Performance on and Acceptance of an Educational Scenario-based Digital Game for Teaching Route-planning Strategies: A Case Study." *Interactive Learning Environments* 24, no. 8 August 27, 2015: 1967–80. https://doi.org/10.1080/10494820.2015.1073745.

A notable challenge for teachers at Sta. Maria National High School effectively conveys complex Earth science concepts, especially those concerning tectonic plates. Students frequently struggle to grasp these abstract ideas without proper visualization. Consequently, educators often rely heavily on traditional visual aids such as PowerPoint presentations, hand-drawn diagrams, and static physical models to illustrate geological processes and landform development. While these tools are essential for introducing key concepts, they often have inherent limitations in fostering deep understanding and sustained student engagement. The problem is that these necessary approaches often are not interactive enough, making students bored and tuning out. This lack of engagement stops them from understanding the concepts well and prevents them from building vital critical thinking and problem-solving skills for Earth science. These issues are compounded by typical challenges in science teaching, such as large class sizes, weak student foundations, insufficient instructional time, and a lack of essential teaching resources.[35] Furthermore, teachers often struggle to apply constructivist strategies effectively and require regular professional training to improve their science instruction and content knowledge. These difficulties can significantly harm the quality of science education and cause students to lose interest in the subject.[36] Adapting game-based Learning offers opportunities for collaborative Learning, skill development, and engagement through immersive experiences.[37] Students learn better with games because they get instant feedback on their mistakes.[38] Moreover, game-based Learning helps students lead their Learning, acquire needed knowledge, and develop self-management abilities.[39]

According to Moeller et al. (2020), the adaptability of game-based Learning means it can offer personalized learning experiences, adjusting to suit everyone's needs and preferences.[40] Game-Based Learning can create fair educational settings and promote successful results for learners across diverse gender and ethnic backgrounds.[41] This makes it particularly suitable for the diverse educational landscape in the Philippines, where schools may have varying technological infrastructure and resources. It can internally motivate minority learners with multimedia components, pedagogical guidelines, and constructive feedback systems.[42] Both digital and non-digital games can be effectively implemented,

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[42] Misra, Rupanada, Leo Eyombo, and Floyd T. Phillips. "How Game-Based Learning Can Effectively Engage Minority Students." In *IGI Global eBooks*, 1230–41, 2021. https://doi.org/10.4018/978-1-6684-3710-0.ch057.

ensuring that the benefits of this approach can reach students across different socioeconomic contexts in teaching science.

However, while GBL shows promise in various educational contexts, including language learning and science education, it requires careful design and consideration of learning theories and game elements to maximize its potential.[43] It should complement rather than replace traditional teaching methods, and its effectiveness may be limited by factors such as time constraints and potential anxiety in students. The successful implementation of GBL requires careful consideration of age-appropriateness, game types, and integration with emerging technologies like Augmented Reality.[44] While GBL shows promise in enhancing education, particularly in subjects requiring increased knowledge retention and critical thinking, its long-term effects and widespread applicability in specific fields, such as nursing education, may be limited.[45] As Philippine educators continue to adapt to post-pandemic educational realities, GBL represents a significant opportunity to transform traditional teaching approaches and better engage students in meaningful learning experiences.

These findings collectively suggest that integrating game-based strategies into science education can enhance students' motivation, engagement, and academic performance, making it an auspicious approach for teaching Filipino high school students. Given the documented challenges in earth science education within the Philippine context, game-based Learning offers a potential solution that addresses multiple contributing factors simultaneously: it can compensate for resource limitations, engage students regardless of varying family backgrounds, and provide innovative teaching tools that support professional development for educators. Specifically, Physical games offer significant benefits, providing easy access, low cost, and the ability to be modified for learning goals.[46] These interactive games also encourage teamwork, communication, and analytical thinking skills, allowing students to practice and strengthen their understanding.[47]

The study of Gutierrez (2014) discovered that the use of educational card game-based approaches in learning science has improved students' performance to a greater extent than traditional methods.[48] Learning through playing educational card games helps the student's concept of Learning, especially in understanding complicated processes and

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[43] Nguyen, Thanh Nam, None Phan Thanh Tuan, and None Nguyen Thi Ha Phuong. "Engaging Students in the Learning Process With Game-Based Learning." *International Journal of English Language Studies* 6, no. 1 (January 18, 2024): 54–60. https://doi.org/10.32996/ijels.2024.6.1.5.

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mechanisms that the game structure can directly reinforce.[49] The study of Levy et al. (2024) found that phys-card games help enhance the students' conceptual understanding and knowledge of physics processes and concepts.[50]

METHOD

Research Design This study will employ a quantitative research design, specifically a quantitative-descriptive design, to investigate the effectiveness and acceptability of "Tectonic Clash." This design will systematically measure the game's impact on science students' mastery of plate tectonic concepts, determined through experienced teachers and pre-service teacher evaluation.

Table 1. Evaluation Scale Description

Mean	Interpretation
4.21-5.00	Strongly Agree
3.41-4.20	Agree
2.61-3.40	Neutral
1.81-2.60	Disagree
1.00-1.80	Strongly disagree

Table 1 presents the quantitative-descriptive design employed to examine the effectiveness and acceptability of Tectonic Clash as an instructional tool for plate tectonics. The study utilizes a 5-point Likert scale to quantify respondents' judgments of the game's features, design quality, content accuracy, and perceived difficulty. The scale ranges from 1.00 (Strongly Disagree) to 5.00 (Strongly Agree), providing a systematic framework for interpreting the mean scores derived from the evaluations of fifty pre-service teachers and ten experienced teachers from four secondary schools in Ifugao.

A diverse group of educators will be involved in the card game evaluation. This study's respondents will be fifty pre-service teachers and ten experienced teachers from Ifugao, specifically at Aguinaldo National High School, Rufino I. Chungalao Science High School, Potia National High School, and Sta. Maria National High School. This approach aims to gather comprehensive feedback from individuals with varying teaching experience and theoretical knowledge levels.

[49] Su, T., M. Cheng, and S. Lin. "Investigating the Effectiveness of an Educational Card Game for Learning How Human Immunology Is Regulated." *CBE—Life Sciences Education* 13, no. 3 (2014): 504–515. https://doi.org/10.1187/cbe.13-10-0197.

[50] Levy, Smadar, David Perl-Nussbaum, and Edit Yerushalmi. "Physics Card Games to Support Knowledge Organization: Design Considerations and Teachers' Attitudes." *Physics Education* 59, no. 5 (July 30, 2024): 055010. https://doi.org/10.1088/1361-6552/ad61b2.

Data collection was facilitated through an evaluation form. The instrument employs a 5-point Likert scale and is designed to quantitatively assess the game's features, design, content accuracy, and perceived difficulties.

RESULTS AND DISCUSSION

Results

1. Teachers

Table 1. Rules of the Game

	Mean Score	Interpretation
The purpose and rationale for the game were fully explained.	4.7	Strongly Agree
The game's goals and objectives were clearly defined.	4.6	Strongly Agree
The directions were clear, concise, and easily understood.	4.5	Strongly Agree
The rules of the game provide players with equal conditions for fair play.	4.5	Strongly Agree
The game's rules provide a set of options for flexibility in making decisions when playing.	4.6	Strongly Agree
Overall	**4.6**	**Strongly Agree**

Teachers strongly agree on the game's rules, with a mean score of 4.6. The excellent mark shows that the game's rules are easily understood and explained, and the player fully grasps the objectives the game wants to impart. They slightly struggled with the game's directions on their first try, but understood it as the game continued, and with the help of a printed guide, the players played with ease.

2. Design of the game

Table 2. Card Size/Durability

	Mean Score	Interpretation
The card size is appropriate.	4.7	Strongly Agree
The deck of cards is compact and can be easily carried around.	4.7	Strongly Agree
The card thickness is appropriate.	4.8	Strongly Agree
The card fits nicely in my hand during gameplay.	4.8	Strongly Agree
The cards are easy to shuffle without getting gamed.	4.8	Strongly Agree
Overall	**4.8**	**Strongly Agree**

Teachers strongly agree on the game's design, with a mean of 4.8. This excellent rating shows that the respondents agreed that the card size is appropriate and easy. The second item in this criterion, which is about the compactness and handling of the card game (Strongly Agree), has a mean of 4.7 from the respondents.

Table 3. Color/Graphics

	Mean Score	Interpretation
Are the colors used on the cards visually appealing and appropriate for the theme of plate tectonics?	4.5	Strongly Agree
The text color contrasts nicely with the background, making it readable.	4.5	Strongly Agree

	Mean Score	Interpretation
The graphics accurately represent the tectonic plate concept.	4.8	Strongly Agree
The use of diagrams or images aids in understanding the concepts.	4.7	Strongly Agree
The overall design enhances enjoyment and interest in the game.	4.6	Strongly Agree
Overall	**4.6**	**Strongly Agree**

The color and graphics of the card game show a good response to the criteria. The colors used are appealing and help the players identify the different diagrams and icons involved in the concept of the plate tectonic clash. In this criterion, the respondents gave a mean of 4.6 (strongly agree). Although items one and two have the lowest rating of 4.5 due to the color contrast of the background and the text color, which needs to be improved. Overall, the color and graphics used in this card game enhance the enjoyment and interest of the game.

Table 4. Fonts

	Mean Score	Interpretation
Is the text (titles, descriptions, trigger conditions, and card type) on the cards clear, legible, and easy to read, especially regarding font size and contrast?	4.6	Strongly Agree
The font supports the theme or concept of the game.	4.7	Strongly Agree
The font size is appropriate for quick reading during gameplay.	4.7	Strongly Agree
The fonts are clearly distinguished from other text.	4.6	Strongly Agree
The alignment and placement of text on the card are visually balanced.	4.6	Strongly Agree
Overall	**4.6**	**Strongly Agree**

The font size of the card game shows a good response on the criteria, with a mean score of 4.6 (strongly agree). The respondents believe the font used for the card game's description, titles, and overall text is clear, legible, and easy to read. The size is appropriate and has a good contrast with the background. Additionally, the font choices support the game's thematic elements, and the text is easily distinguishable from other card text, facilitating quick comprehension during gameplay. The balanced alignment and placement enhance visual clarity, contributing to a positive perception of readability and design.

Table 5. Artwork/ Illustration

	Mean Score	Interpretation
The pictures printed on the card represent the topic. (Plate Tectonics)	4.8	Strongly Agree
Beyond being representative, does the card artwork effectively convey specific concepts, actions, or processes related to plate tectonics?	4.8	Strongly Agree
Is the information layout on each card well-organized and intuitive, allowing for quick comprehension?	4.8	Strongly Agree
Is the design on the back of the cards visually appealing, and does it provide a consistent look for the deck?	4.8	Strongly Agree
I can easily understand the game just by looking at its picture.	4.6	Strongly Agree
Overall	**4.8**	**Strongly Agree**

The data shows a good result on the artwork and illustration of the card game, which effectively supports the game's overall educational content. With an average score of 4.8 (strongly agree), respondents of the game strongly agree that the images accurately represent the topic and effectively convey the concepts, actions, and processes involved in the game. The well-organized information layout enables a quick understanding of the game concept. Additionally, the imagery helps players easily grasp the game's concepts and processes.

Table 6. Conceptual Accuracy

	Mean Score	Interpretation
The game promoted discussion of key topics related to plate tectonics.	4.9	Strongly Agree
The game emphasizes key points of the topic being played.	4.9	Strongly Agree
The terms used were appropriate to my level of knowledge.	4.9	Strongly Agree
The number of cards was appropriate to my level of knowledge.	4.8	Strongly Agree
The game was thought-provoking.	4.8	Strongly Agree
The card game helped me recall concepts/terms related to plate tectonics.	4.9	Strongly Agree
The game was effective in reviewing the material on plate tectonics.	4.9	Strongly Agree
The game encouraged the players to dig deeper into the subject matter.	4.9	Strongly Agree
The game's approach is innovative and effective.	4.9	Strongly Agree
Overall	**4.9**	**Strongly Agree**

The teachers agreed that the card game effectively promotes discussion and emphasizes key concepts of plate tectonics, with a mean of 4.9 (strongly agree). Respondents found the terminology used in the card game appropriate to their knowledge level. The game was viewed as thought-provoking, aiding recall and review of related concepts, while also encouraging more profound understanding and exploration of the subject. The game's innovative approach is appreciated. The positive response supports the game's conceptual accuracy and educational effectiveness.

3. Pre-service teachers

Table 7. Rules of the Game

	Mean Score	Interpretation
The purpose and rationale for the game were fully explained.	4.38	Strongly Agree
The game's goals and objectives were clearly defined.	4.46	Strongly Agree
The directions were clear, concise, and easily understood.	4.32	Strongly Agree
The rules of the game provide players with equal conditions for fair play.	4.38	Strongly Agree
The game's rules provide a set of options for flexibility in making decisions when playing.	4.40	Strongly Agree
Overall	**4.39**	**Strongly Agree**

The pre-service teacher strongly agreed that the game was well-explained, clearly structured, and fair to play, with an overall mean score of 4.39. The purpose and rationale of

the game were effectively communicated 4.38, and its goals and objectives were clearly defined 4.46, ensuring that players understood the intent and expected outcomes. Directions were considered clear, concise, and easy to follow, 4.32, which can contribute to the smooth flow of the gameplay. Respondents also agreed that the rules promoted fairness by providing equal conditions for all players (4.38) while allowing flexibility for decision-making during play 4.40, adding structure and strategic variety. These consistently high scores indicate that the game's instructions and rule design balanced clarity and fairness, and provided players with equal conditions for fair play, creating an engaging and well-organized gaming experience.

4. Design of the game

Table 8. Card Size/Durability

	Mean Score	Interpretation
The card size is appropriate.	4.70	Strongly Agree
The deck of cards is compact and can be easily carried around.	4.68	Strongly Agree
The card thickness is appropriate.	4.76	Strongly Agree
The card fits nicely in my hand during gameplay.	4.74	Strongly Agree
The cards are easy to shuffle without getting gamed.	4.68	Strongly Agree
Overall	**4.71**	**Strongly Agree**

With an overall mean score of 4.71, the results show that participants strongly agreed that the card size and durability were highly satisfactory. Also confirmed that the deck was small and portable (mean 4.6), making it convenient for storage and transportation, and that the card size was appropriate for gameplay (mean 4.70. The card thickness received a very positive rating of 4.76, indicating that it provided a premium and durable feel. Players also reported that the cards fit comfortably in their hands during gameplay, with a mean of 4.74, increasing handling ease, and that they were easy to shuffle without breaking, having a mean of 4.68, indicating both long-lasting quality and practical usability. These consistently high ratings indicate that the card design balances functionality, comfort, and durability, contributing to a positive gaming experience.

Table 9. Color/Graphics

	Mean Score	Interpretation
Are the colors used on the cards visually appealing and appropriate for the theme of plate tectonics?	4.38	Strongly Agree
The text color contrasts nicely with the background, making it readable.	4.24	Strongly Agree
The graphics accurately represent the tectonic plate concept.	4.42	Strongly Agree
The use of diagrams or images aids in understanding the concepts.	4.44	Strongly Agree
The overall design enhances enjoyment and interest in the game.	4.46	Strongly Agree
Overall	**4.39**	**Strongly Agree**

With an overall mean score of 4.39, the results demonstrate that the pre-service teacher strongly agreed that the cards' color scheme and graphics were visually effective and appropriate for the plate tectonics theme. The text color has enough contrast with the

background to guarantee reading, and respondents thought the colors were appealing and thematically appropriate, with a mean of 4.38. Diagrams and pictures greatly facilitated comprehension of the content, with a mean of 4.44, and the graphics were thought to accurately depict tectonic plate principles, with a mean of 4.42. Moreover, it was seen that the game's general design increased player interest and enjoyment, with a mean of 4.46. These consistently strong evaluations show that the card graphics enhance the game's instructional value in promoting clarity and comprehension.

Table 10. Fonts

	Mean Score	Interpretation
Is the text (titles, descriptions, trigger conditions, and card type) on the cards clear, legible, and easy to read, especially regarding font size and contrast?	3.98	Agree
The font supports the theme or concept of the game.	4.34	Strongly Agree
The font size is appropriate for quick reading during gameplay.	4.08	Strongly Agree
The fonts are clearly distinguished from other text.	4.34	Strongly Agree
The alignment and placement of text on the card are visually balanced.	4.42	Strongly Agree
Overall	**4.23**	**Strongly Agree**

The evaluation results show that participants thought the card text design was effective overall, with a mean score of 4.23, which is considered Strongly Agree. Respondents rated the titles, descriptions, trigger conditions, and card type as clear, readable, and easy to understand. However, this feature obtained the lowest grade, with a mean of 3.98, indicating that font clarity or contrast may need to be improved. The font style was regarded as supportive to the game's theme, having a mean of 4.34; the font size was deemed appropriate for reading quickly, with a mean of 4.08; and it was easy to tell one font or style from another, with a mean of 4.34. This positive rating of 4.42 was given to the text's alignment and positioning, indicating a neat and aesthetically pleasing layout. These results reflect strong approval of the card text design while highlighting a minor opportunity to enhance readability further.

Table 11. Artwork/ Illustration

	Mean Score	Interpretation
The pictures printed on the card represent the topic. (Plate Tectonics)	4.68	Strongly Agree
Beyond being representative, does the card artwork effectively convey specific concepts, actions, or processes related to plate tectonics?	4.60	Strongly Agree
Is the information layout on each card well-organized and intuitive, allowing for quick comprehension?	4.50	Strongly Agree
Is the design on the back of the cards visually appealing, and does it provide a consistent look for the deck?	4.58	Strongly Agree
I can easily understand the game just by looking at its picture.	4.30	Strongly Agree
Overall	**4.53**	**Strongly Agree**

With an overall mean score of 4.53, the results show that the pre-service participants strongly agreed that the cards' artwork and drawings were efficient and visually appealing. The respondents confirmed that the images went beyond mere representation by successfully communicating specific ideas, behaviors, or processes (4.60) and were highly representative of the subject of plate tectonics (4.68). The information was viewed as well laid out and easy to understand (4.50), which helped players quickly understand the substance of the cards while they were playing. The card backs received a rating of 4.58 for being aesthetically pleasing and in line with the deck's overall design, which helped to create a polished and unified look. Although this was ranked lower than other parts, indicating improvement opportunities, players also agreed that the graphics helped them grasp the game (4.30). These findings highlight that the card artwork supports comprehension of plate tectonics and enriches the game's aesthetic appeal and usability.

Table 12. Conceptual Accuracy

	Mean Score	Interpretation
The game promoted discussion of key topics related to plate tectonics.	4.56	Strongly Agree
The game emphasizes key points of the topic being played.	4.52	Strongly Agree
The terms used were appropriate to my level of knowledge.	4.52	Strongly Agree
The number of cards was appropriate to my level of knowledge.	4.60	Strongly Agree
The game was thought-provoking.	4.46	Strongly Agree
The card game helped me recall concepts/terms related to plate tectonics.	4.58	Strongly Agree
The game was effective in reviewing the material on plate tectonics.	4.54	Strongly Agree
The game encouraged the players to dig deeper into the subject matter.	4.52	Strongly Agree
The game’s approach is innovative and effective.	4.52	Strongly Agree
Overall	**4.54**	**Strongly Agree**

With an overall mean score of 4.54, the results show that participants strongly agreed on the game's high conceptual accuracy and educational value. Also reported that the game effectively promoted discussion of key topics related to plate tectonics, with a mean of 4.56, and emphasized essential points of the subject matter, with a mean of 4.52. The terms and number of cards were deemed appropriate for the players' level of knowledge, with a mean of 4.52 and 4.60, ensuring accessibility. The game was also thought-provoking (4.46) and highly effective in aiding recall of concepts and terms, with a mean of 4.58, and in reviewing the material (4.54). Finally, participants agreed that the game encouraged deeper engagement with the topic (4.52) and adopted an innovative, practical approach to Learning (4.52). These consistently high ratings show that the game not only reinforced understanding of plate tectonics but also stimulated interest, critical thinking, and active Learning.

Discussion

The data obtained from the teachers and pre-service teachers regarding the rules and the concept of the "Tectonic Clash" reveals a high level of comprehension and clarity.

Teachers strongly agreed that the game's purpose, goals, and directions were well-explained and easy to understand, with a mean score of 4.6. This indicates that the instructional design effectively facilitates smooth gameplay and minimizes confusion among players. The study of Garris et al. emphasizes that clear instructions are crucial for the successful implementation of educational games. The Fair and flexible rules further contribute to an inclusive gaming environment, fostering a creative way of Learning and improving critical thinking and decision-making.

The design of the card game garnered an overall mean of 4.8, indicating excellent acceptability of the card's size and durability. The compactness of the card and ease of handling support the notion that educational games should be compact and thus easily stored and carried around.[51] The graphic and color schemes also garnered a favorable outcome with a mean of 4.38-4.6. The visual appeal positively influences student motivation and comprehension. Using warm, happy, lively, transparent, and bright colors and appropriate logotypes will benefit organizational identity.[52]

The ratings for conceptual accuracy and educational effectiveness, with an overall mean score of 4.9-4.54 from teachers and pre-service teachers, show "Tectonic Clash" effectively promotes discussion of key plate tectonic concepts. The game emphasizes essential points and uses appropriate terminology. In the Learning of science, mastering scientific terminology is a crucial step for understanding concepts and processes, and fosters scientific literacy.[53] The positive feedback on the game's ability to reinforce recall and review is supported by the findings of Gutierrez, Piyawattanaviroj et al., and Lukas et al,[54,55,56] Who noted that educational card games enhance conceptual understanding and long-term retention. Furthermore, the game's design encourages deeper engagement with the concepts and processes involved in the subject matter, as evidenced by the mean scores across all evaluative items. The game's innovative approach has been perceived as effective in reviewing content and promoting active Learning, supporting the theoretical underpinning of constructivism and experiential Learning.[57] Learning through playing educational card games helps the student's concept of Learning, especially in understanding complicated processes

[51] Garris, Rosemary, Robert Ahlers, and James E. Driskell. "Games, Motivation, and Learning: A Research and Practice Model." *Simulation & Gaming* 33, no. 4 (December 2002): 441–67. https://doi.org/10.1177/1046878102238607

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[55] Piyawattanaviroj, P., T. Maleesut, and P. Yasri. "An Educational Card Game for Enhancing Students' Learning of the Periodic Table." *ResearchGate*. 2019. https://doi.org/10.1145/3345120.3345165.

[56] Lukas, Brenda Ak, Finola Iba Ak Patrick, Gloria Chong, Nursuriati Binti Jaino, and Melor Md Yunus. "Using U-NO-ME Card Game to Enhance Primary One Pupils' Vocabulary." *International Journal of Learning Teaching and Educational Research* 19, no. 5 (May 30, 2020): 304–17. https://doi.org/10.26803/ijlter.19.5.19.

[57] Barr, Matthew. "Video Games and Learning." In *Digital Education and Learning*, 1–31, 2019. https://doi.org/10.1007/978-3-030-27786-4_1.

and mechanisms that the game structure can directly reinforce.[58] The findings concluded that game-based interventions significantly improve students' performance and conceptual grasp in science.

The favorable evaluations indicate that "tectonic clash" can potentially address the challenges faced in earth science education in the Philippines. It is engaging, visually appealing, and content-accurate. The game's design can motivate students, enhance comprehension, and foster critical thinking about complex tectonic processes. Given the Philippine context, where traditional teaching methods often fall short in capturing students' interest,[59] integrating such game-based approaches can be a strategic move toward improving science literacy. Moreover, the positive feedback from both pre-service teachers and teachers suggests that "Tectonic Clash" is adaptable for classroom implementation and can serve as a supplementary instructional resource. The card game's portability and adaptability support its use across diverse educational settings, particularly in environments with limited resources. The findings align with Septianing et al,[60] Who advocates for innovative, technology-enhanced, and game-based approaches to elevate science education standards in developing countries.

While the overall findings are promising, some areas for improvement were identified. For example, slight concerns about the color contrast and font clarity suggest the need for further refinement to optimize comfort in the readability and visual impact of the game. Additionally, further research is recommended to assess the game's impact on actual student learning outcomes and engagement levels over time by doing a pre-test and post-test to evaluate the effectiveness of the card game in an actual educational setting.

CONCLUSION

The card game "Tectonic Clash" is an effective and acceptable innovative teaching tool for enhancing understanding plate tectonics. The ratings from teachers and pre-service teachers across various evaluation areas highlight the game's strength in fostering engagement and deepening comprehension of the concept and processes of the subject matter. The findings reveal that the game significantly promotes discussion, reinforces key concepts, and facilitates recall, supporting its potential to address persistent challenges in Earth Science education in the Philippines. The positive feedback on the game shows the game's suitability as a supplementary resource that can motivate students by providing an interactive and portable learning experience.

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[58] Su, T., M. Cheng, and S. Lin. "Investigating the Effectiveness of an Educational Card Game for Learning How Human Immunology Is Regulated." *CBE—Life Sciences Education* 13, no. 3 (2014): 504–515. https://doi.org/10.1187/cbe.13-10-0197.

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[60] Septianing, N. I., N. L. Melati, N. N. D. Cantika, and N. W. Destiani. "Pengaruh Penerapan Game Based Learning terhadap Motivasi Belajar Siswa Sekolah Dasar." *Khatulistiwa Jurnal Pendidikan dan Sosial Humaniora* 4, no. 1 (2024): 94–103. https://doi.org/10.55606/khatulistiwa.v4i1.2722.

This study implies the integration of game-based approaches as a strategic means to improve science literacy, critical thinking, and motivation among Filipino learners. The adaptability of the card game allows flexible implementation across various educational settings. The continued development and validation of such educational games will be essential to ensure that learners' needs are met and aligned with curriculum standards. However, some limitations were identified, notably regarding the printing process of the card game, in which the color contrast and font clarity are affected. Additionally, while the evaluative results are promising, further research is necessary to establish the game's impact. Future researchers could incorporate pre-test and post-test designs to quantitatively measure learning gains and engagement levels over time quantitatively, thereby providing a more comprehensive assessment of effectiveness in a classroom setting.

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