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Research Article

Strengthening Higher-Order Thinking in Science Through Collaborative Gameplay: A Quasi-Experimental Study

Cheryl P. Oro[1], Peter G. Narsico[2], Janine Napoles[1], Heart Love S. Reyes[1]

[1]College of Arts, Sciences, and Education, Cebu Institute of Technology- University, Cebu City, 6000, Philippines
[2]College of Management, Business, and Accountancy, Cebu Institute of Technology- University, Cebu City, 6000, Philippines

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**Corresponding author:*
E-mail:
cheryl.oro@cit.edu

ABSTRACT

The K–12 science curriculum emphasizes the development of essential 21st-century skills such as critical problem-solving, environmental literacy, innovation, and effective communication. Despite these curricular priorities, traditional lecture-based instruction often fails to cultivate higher-order thinking—particularly logical reasoning, which is foundational in science learning. This study investigates the effectiveness of Collaborative Game-Based Activities (CGBAs) as an instructional strategy to enhance students' logical reasoning skills in science. Employing a quasi-experimental research design, the study assessed the quality of CGBA implementation, students' baseline competency in logical reasoning, their progress across successive CGBA sessions, and overall improvement after the intervention. Grade 9 students participated in a series of CGBA sessions, with their logical reasoning abilities evaluated through pre-test and post-test assessments. Teacher rubric-based evaluations of CGBA quality revealed consistently high implementation fidelity, aligning well with instructional objectives. The findings indicated a significant improvement in students' logical reasoning scores following CGBA exposure, with the majority advancing from "Satisfactory" to "Good" and "Very Good" performance levels. A paired-samples t-test confirmed this difference to be statistically significant ($p < .001$), supporting the intervention's impact on academic performance. The study also affirmed that the assumptions required for parametric testing were met, enhancing the reliability of the findings. Overall, the study underscores the pedagogical value of integrating collaborative and game-based approaches to foster critical thinking, teamwork, and deep engagement with scientific concepts. By transforming passive instruction into active, inquiry-driven learning, CGBA offers a compelling model for strengthening logical reasoning and promoting meaningful science education.

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Introduction

Logical reasoning encompasses essential cognitive skills such as evaluating arguments, verifying information, and forming sound judgments (Dowhen, 2023). It is foundational across disciplines including language, science, computer science, and mathematics (Liu et al., 2025), and plays a vital role in hypothesis development and data interpretation in scientific inquiry (Morris, 2025). Researchers emphasize its importance in critical thinking (Cornell, 2024), higher-order cognitive development (Borge et al., 2024), and both formal and informal reasoning processes (Halpern, 2022; Helmenstine, 2025). Despite its significance, many students exhibit limited proficiency, particularly in applying these skills to scientific problems (Nugroho et al., 2025).

Educational policies, such as the Philippine K to 12 Science Curriculum, promote inquiry-based learning to foster scientific literacy and informed decision-making. International and regional perspectives (UNESCO, 2019; Arifin et al., 2025) highlight logical reasoning as a core skill in developing conceptual understanding and problem-solving. Through competencies like data analysis and hypothesis testing, science education aims to nurture critical thinkers capable of navigating real-world issues.

In professional domains, logical reasoning underpins success in STEM careers where problem-solving, collaboration, and adaptability are crucial (Lutkevich, n.d.). Studies affirm that it enhances innovation and decision-making, making it a transferable asset across diverse academic and workplace contexts (Great Learning Team, 2022; Indeed, 2023).

To bridge the gap in students' reasoning skills, the researchers introduced collaborative game-based learning (CGBL)—a learner-centered approach designed to promote active engagement through problem-solving. Early implementation of logic tasks (PM Publisher, 2022) and alternatives to exam-centric systems (Yasmin et al., 2023) are seen as vital in fostering analytical thinking.

UNESCO (2019) stresses that early development of reasoning is crucial for cultivating scientific and critical thinking. However, only 19% of Grade 9 students at a university in Cebu City answered logic-based science questions correctly during a preliminary assessment, prompting targeted intervention.

To assess the intervention's effectiveness, the following null hypothesis was posed: The implementation of Collaborative Game-Based Activities (CGBA) does not lead to a significant improvement in the ability of the Grade 9 students included in the study at a university in Cebu City to answer science questions requiring logical reasoning. Specifically, this study explores: (1) the characteristics of the collaborative game-based activities; (2) students' baseline competency in logic-based science questions; (3) progress after each activity; (4) overall post-intervention competency; and (5) the overall effectiveness of CGBA in enhancing logical reasoning skills.

Methods

Research Design. This study adopts a quasi-experimental research design to evaluate the impact of collaborative game-based activities on enhancing students' logical reasoning skills in the context of science-related questions. Quantitative methods serve as the primary analytical approach to examine the data collected during the intervention. The participants of this study came from a Grade 9 section of junior high school students of a university in Cebu City, comprising a total of 47 enrolled learners. This class was selected due to the high number of reported difficulties in logical reasoning compared to other observed sections.

Diagnosis. This study addresses a significant deficiency in students' logical reasoning skills, particularly in their ability to respond to science questions that require analytical thinking. Observations revealed substantial learning gaps, with students correctly answering only a small fraction of reasoning-based questions—

highlighting the urgency for intervention. Analysis pointed to several contributing factors, including conventional teaching methods, negative learning environments, language challenges, and insufficient development of foundational thinking skills. To respond to these issues, the researchers identified structured activities that promote logical thinking as the most effective strategy to enhance student performance in science-related reasoning tasks.

Accordingly, the focus of this study is on improving students' ability to answer science questions that require logical reasoning, based on three core rationales. First, such questions serve as diagnostic tools that help educators assess students' depth of understanding and identify misconceptions, thereby informing targeted instruction (Huseynova, 2023). Second, they provide opportunities for immediate feedback, which enhances student engagement and supports formative learning processes (Williams, 2024). Third, strengthening reasoning skills through structured questioning prepares students for standardized assessments, which often rely on well-designed question formats to evaluate higher-order thinking (Jimenez & Modaffari, 2021).

Specific Intervention. To address students' limited proficiency in answering science questions that require logical reasoning, this study introduces a pedagogical strategy that integrates collaborative learning with game-based elements. Collaborative Game-Based Activities (CGBAs) are designed to promote engagement, teamwork, and analytical thinking by aligning game mechanics with science curriculum goals. Research supports the value of collaborative learning in enhancing critical thinking and peer interaction (Padayichie, 2023; Shamuratovich, 2023), while game-based learning fosters creative problem-solving and motivation (Sharma, 2023; University of Waterloo, n.d.). This combined approach creates a dynamic and inclusive learning environment where students develop logical reasoning skills through meaningful, hands-on experiences.

The intervention is grounded in Social Learning Theory, Constructivism, and Connectionism, drawing from the work of Bandura, Vygotsky, and Thorndike. These frameworks emphasize learning through social interaction, the active construction of knowledge, and the strengthening of cognitive associations, respectively (Ravi, n.d.; Surur, 2020). Transitioning from traditional, teacher-centered instruction to CGBAs marks a shift toward student-driven learning, characterized by problem-solving, dialogue, and collaboration. By embedding logical reasoning within purposeful group activities and game-based scenarios, this approach supports deeper cognitive development and prepares students to navigate complex scientific problems with critical insight.

Intervention Activities. To improve students' logical reasoning in science, the researchers implemented Collaborative Game-Based Activities (CGBAs), integrating collaborative learning with gameplay across key third-quarter topics: volcanoes, climate factors, stars, and the relationship between constellations and Earth's orbital position. These activities aimed to foster engagement, critical thinking, and application of concepts through structured teamwork and interactive tasks. Four core activities were conducted: Volcano Word Association, Climate Change Match, Climate Change Mind Mapping, and Move with the Stars, each designed to align with curriculum goals and promote logical thinking in a supportive, participatory environment.

In Volcano Word Association, students generated unique volcano-related terms under time constraints, promoting quick reasoning and group coordination. Climate Change Match involved pairing terminology with definitions, encouraging analytical thinking and peer discussion. The Mind Mapping task helped students visualize climate-related concepts collaboratively, using graphic organizers to reinforce content understanding. In Move with the Stars, a charades-based game, learners conveyed astronomy terms through gestures, enhancing inference and interpretation skills. Collectively, these interventions created an immersive learning experience focused on improving logical reasoning through active collaboration and game-based strategy.

Intervention Procedure. This study used purposive sampling to select 47 Grade 9 students who were specifically identified as having difficulties in logical reasoning when answering science questions, ensuring the sample directly addressed the study's focus. To improve their skills, students participated in collaborative game-based activities. A pre-test was administered to assess their initial performance, using a questionnaire based on first and second grading topics. The test underwent content and construct validity processes. For content validity, two science experts rated each item's relevance, resulting in a Content Validity Index (CVI) of 1.0, indicating strong validity. For construct validity, the pre-test scores were compared to those from an established logical reasoning test, yielding a Pearson correlation coefficient of 0.81, signifying a strong relationship.

Evaluation Specifics. To systematically outline the procedures and evaluation methods used in the intervention, the following table summarizes the implementation process, assessment tools, and performance descriptors applied throughout the study.

Table 1. Summary of Implementation Procedures, Assessment Methods, and Performance Classifications

Evaluation Component	Description
Group Formation	Students were heterogeneously grouped based on pre-test results to encourage peer learning and inclusivity.
Role of High Performers	High-performing students supported their peers during collaborative tasks.
Collaborative Activities	Activities were designed to enhance reasoning and teamwork skills.
Intervention Quality Assessment	Assessed using a rubric adapted from the Science Education Resource Center; criteria included scientific accuracy, alignment, pedagogic effectiveness, and robustness.
Progress Testing	Conducted after each activity; validated by two educators; CVI scores ranged from 0.95 to 1.0.
Post-Test Administration	Same as pre-test; implemented after all interventions; results analyzed using a Paired T-Test.
Evaluation Strategy	Used both descriptive and inferential statistics to assess the effectiveness of CGBAs.
Descriptive Statistics	Summarized outcomes from pre-tests, post-tests, progress tests, and intervention quality assessments.
Performance Descriptors	"Very good," "Good," "Satisfactory," "Sufficient," "Fail" or "Did not meet expectations" (for intervention quality)
Scoring Intervals	Pre/Post-tests (25 items): 5-point intervals (e.g., 21–25 = "Very Good") Progress tests (10 items): 2-point intervals and Intervention (16 max): 3-point intervals
Data Visualization	Charts were used to illustrate trends and changes in performance throughout the intervention.

As outlined in Table 1, the intervention employed a holistic approach to assessment, combining structured grouping, rubric-based evaluations, and both quantitative and visual analyses. These methodologies ensured a reliable and comprehensive evaluation of students' logical reasoning development.

To determine whether observed improvements were statistically significant, the Paired Sample T-Test was conducted using SPSS. This test compared mean scores before and after the CGBA intervention. As defined by Kent State University (2023), the Paired Sample T-Test assesses whether the means of two related groups—such as pre-test and post-test scores—are significantly different. Prior to analysis, normality of the data distribution was verified using the Kolmogorov-Smirnov and Shapiro-Wilk tests. These tests evaluate whether the data approximate a normal (Gaussian) distribution, a key assumption for parametric testing such as the T-Test. According to Mishra et al. (2019), violating this assumption can compromise the validity of statistical conclusions. By ensuring these conditions were met, the study provided a robust basis for evaluating the impact of CGBAs on students' logical reasoning development.

Limitations of the Methodology. This study was limited to a section of Grade 9 students of a university in Cebu City, focusing on improving their logical reasoning in science through Collaborative Game-Based Activities (CGBA). The research focused on short-term improvements and did not evaluate the long-term effects of the intervention. In addition, variables such as students' backgrounds, learning styles, and cognitive differences were not examined, as these required extended data collection procedures and privacy clearances beyond the study's scope. Furthermore, the test instruments—pre-test, post-test, and progress assessments—were validated by two Grade 9 science teachers, as they were the only subject experts available in the school. While their insights ensured curricular alignment, the limited number of validators may affect the broader generalizability of the tools. Despite these constraints, the researchers strived to maintain methodological rigor and transparency throughout the implementation.

Results and Discussion

Characteristics of the Collaborative Game-Based Activities. To evaluate the quality of the implemented Collaborative Game-Based Activities (CGBAs), a rubric-based assessment was conducted by subject matter validators. Table 2 presents the scores assigned to each CGBA, reflecting the consistency and effectiveness of the interventions.

Table 2. Scores for Intervention Quality as Scored by Validators

Title of CGBA	Rating	Descriptor
1. Volcano Word Association	15	Very good
2. Climate Change Matchmaking	15	Very good
3. Climate Change Mind Mapping	15	Very good
4. Move with the Stars, a Game of Charades	15	Very good

All four Collaborative Game-Based Activities (CGBAs) received a validator score of 15, placing them within the "Very Good" category. This consistent rating suggests that each activity met or exceeded expectations across key evaluative criteria, including scientific accuracy, pedagogical alignment, and instructional effectiveness. The use of expert validation strengthens the credibility of the intervention, as validator scoring remains a widely accepted method for ensuring the quality and relevance of instructional materials (Mor & Erşen, 2023). These results affirm the soundness of the CGBA design and its potential to support meaningful learning outcomes.

Students' Baseline Competency. To establish a baseline for students' logical reasoning abilities in science, a pretest was administered prior to the implementation of Collaborative Game-Based Activities (CGBA). Table 3 presents the frequency and percentage distribution of students' scores, categorized into five performance descriptors. The results provide an overview of the participants' initial competency levels in answering science questions that required logical reasoning.

Table 3. Pretest Performance Levels in Logical Reasoning Among Grade 9 Students Prior to CGBA Implementation

Range	Descriptor	Frequency	Percent
21-25	Very Good	0	0.00
16-20	Good	7	14.89
11-15	Satisfactory	30	63.83
6-10	Sufficient	10	21.28
5 and below	Fail	0	0.00
Total		47	100.00

The pretest score distribution underscores a prevailing need to strengthen students' logical reasoning skills in scientific contexts. With 63.83% of students performing within the "Satisfactory" range (scores of 11–15) and an additional 21.28% in the "Sufficient" bracket (scores of 6–10), the results suggest that most learners were operating at a basic or emerging level of competency prior to the intervention. The modest 14.89% attaining a "Good" rating (16–20) reflects isolated instances of higher proficiency, while the absence of "Very Good" or "Fail" scores indicates a clustering around the midrange. This pattern suggests that while severe underperformance was not observed, the overall cohort exhibited untapped potential—positioned to benefit meaningfully from targeted instructional support aimed at advancing their reasoning capacities. These findings underscore the importance of pre-assessment in identifying learning gaps and tailoring instruction accordingly, as pretests provide valuable diagnostic insight into students' prior knowledge and readiness for new content (Pan & Carpenter, 2023).

Progress after each Collaborative Game-Based Activity. Table 4 presents the descriptive statistics of students' performance on progress tests administered after each Collaborative Game-Based Activity. The mean scores reflect students' logical reasoning abilities in addressing science-related questions across four thematic topics: volcanoes, climate change, stars, and constellations. Descriptors corresponding to each mean score provide a qualitative interpretation of students' progress, based on a standardized scale ranging from "Fail" to "Very Good."

Table 4. Descriptive Statistics of Logical Reasoning Progress Test Scores Across Collaborative Game-Based Activities

Progress Test	N	Mean Score	Descriptor
volcano	47	5.83	Satisfactory
climate change	47	7.32	Good
stars	47	7.87	Good
constellation	47	8.47	Good

The data reveal a steady upward trajectory in students' logical reasoning performance throughout the series of Collaborative Game-Based Activities (CGBAs), suggesting a cumulative learning effect. The initial mean score of 5.83 (Satisfactory) on the volcano test points to foundational skills that, while emerging, still required development. However, the successive increases—7.32 on climate change, 7.87 on stars, and 8.47 on constellation, all within the "Good" performance range—indicate not only improving proficiency but also growing confidence and cognitive engagement. This progression implies that sustained exposure to CGBA interventions fostered deeper conceptual understanding and more consistent application of logical reasoning across varied scientific topics.

This upward trend highlights the effectiveness of CGBAs in promoting critical thinking and collaborative engagement. The consistently rising mean scores, paired with improved descriptors, point to a sustained enhancement in students' performance over time. These findings support the pedagogical value of collaborative, game-based learning in fostering logical reasoning in science education—particularly when students are actively engaged and encouraged to exchange ideas with peers (Padayichie, 2023).

While the results in Table 4 indicate a positive trajectory in students' logical reasoning performance, several limitations must be considered when interpreting these outcomes. The absence of a control group restricts causal inferences, as improvements might also stem from external factors beyond the intervention. Additionally, the relatively small and homogeneous sample may limit the generalizability of findings to broader populations. Repeated exposure to similar testing formats could have introduced practice effects, potentially inflating scores. The narrow scoring range may also have constrained the ability to detect nuanced variations in performance. Finally, while the tests were validated, potential bias in scoring and content familiarity across topics may have influenced results, underscoring the need for cautious interpretation.

Overall Post-intervention Competency. Table 5 presents the frequency and percentage distribution of students' post-test scores following their participation in Collaborative Game-Based Activities (CGBA). The table reflects students' competency in answering science questions that required logical reasoning, as measured by a standardized 25-point scale.

Table 5. Distribution of Students' Logical Reasoning Competency in Science Post-Test Following CGBA

Range	Descriptor	Frequency	Percent
21-25	Very Good	5	10.64
16-20	Good	34	72.34
11-15	Satisfactory	8	17.02
6-10	Sufficient	0	0.00
5 and below	Fail	0	0.00
Total		47	100.00

The distribution of post-test scores provides meaningful insight into the impact of the instructional interventions on students' logical reasoning abilities. The high proportion of learners achieving classifications of Good (72.34%) and Very Good (10.64%) reflects not only academic progress but also a notable shift in students' capacity to engage with complex scientific reasoning tasks. This pattern points to the effectiveness of the learning design—particularly its emphasis on cooperative, game-based strategies—in cultivating higher-order thinking. Rather than simply improving test performance, the interventions appear to have empowered students to apply logical reasoning more confidently and consistently, marking a positive transformation in both skill acquisition and cognitive engagement. Sharma (2023) noted that game-based learning environments not only stimulate creative thinking but also enhance students' logical reasoning abilities by encouraging exploration and inventive problem-solving.

The complete absence of scores in the Sufficient and Fail ranges reflects the effectiveness of the interventions in minimizing learning gaps. Although a small portion of students (17.02%) scored in the Satisfactory range, this suggests that individualized support may still be beneficial for some learners. The findings affirm the pedagogical value of interactive learning strategies and align with Constructivist principles, where students are active participants in their learning process—engaging in reflection, critical thinking, and reasoned decision-making. Empirical support for this approach is echoed by Meisser (2022), who emphasized the value of authentic assessments in fostering student confidence and achievement, and by Killian (2023), whose research highlighted the high impact of concept mapping as a teaching strategy that promotes meaningful learning and schema integration. Shamuratovich (2023) likewise emphasized that collaborative learning environments can significantly cultivate logical thinking skills by accommodating diverse learning needs.

A comparison of pretest and post-test results reveals a significant enhancement in students' logical reasoning following the CGBA intervention. Initially, most students were clustered in the Satisfactory (63.83%) and Sufficient (21.28%) categories, with no one achieving Very Good. After the intervention, 72.34% reached the Good level and 10.64% attained Very Good, while no students remained in the lower categories—indicating a clear upward shift in performance.

Overall Effectiveness of Collaborative Game-Based Activities. These findings underscore the effectiveness of collaborative, game-based learning in fostering logical reasoning. As Di Martino et al. (2024) demonstrated, structured cognitive enhancement programs can significantly improve students' reasoning abilities. Similarly, Bronkhorst et al. (2021) emphasized the importance of linking multiple representations in learning environments to support logical development. The results affirm that CGBA not only promotes engagement but also cultivates higher-order thinking skills essential for science education.

Before evaluating whether there was a significant improvement in students' logical reasoning scores from pre-test to post-test using a paired-samples t-test, a Shapiro–Wilk test was conducted to assess the normality of both distributions. As shown in Table 6, the results confirmed that the pre-test and post-test scores were approximately normally distributed, with p-values exceeding the .05 threshold. This indicates that the assumption of normality was met, supporting the appropriateness of applying parametric statistical analyses.

Table 6. Tests of Normality for Pre-Test and Post-Test Scores (Shapiro–Wilk)

Measure	Statistic (W)	df	*p*
Pre-Test	.958	47	.089
Post-Test	.970	47	.255

The Shapiro–Wilk test is widely regarded as a robust method for assessing normality, particularly in studies with smaller sample sizes. Recent literature affirms its suitability for samples under 50, due to its high statistical power and sensitivity to non-normality (Whitfield, 2025). In this study, the assumption of normality was not violated, thereby supporting the use of parametric procedures such as the paired-samples t-test, which are appropriate when data are approximately normally distributed.

Table 7 presents the results of the paired-samples t-test conducted to determine whether there was a statistically significant difference in students' competency in answering science questions that require logical reasoning before and after exposure to Collaborative Game-Based Activities (CGBA). The table includes the mean scores for pre-test and post-test conditions, the computed t-value, associated p-value, and the corresponding statistical decision and interpretation.

Table 7. Paired-Samples t-Test Results on Students' Logical Reasoning Competency Before and After CGBA

Test	Mean	*t*	*p*-value	Decision	Remarks
Pre-Test	12.70				
Post-Test	17.60	−13.35	< .001	Reject H_0	Significant

A paired-samples t-test was conducted to determine whether students' logical reasoning competencies significantly improved after exposure to Collaborative Game-Based Activities (CGBA). Results revealed a statistically significant increase in scores from the pre-test ($M = 12.70$) to the post-test ($M = 17.60$), $t(46) = -13.35$, $p < .001$. This substantial gain indicates that CGBA had a meaningful and positive impact on students' ability to answer science questions requiring logical reasoning.

The findings suggest that integrating collaborative and game-based strategies into science instruction can effectively enhance students' higher-order thinking skills. As Antonio and Prudente (2024) demonstrated in their meta-analysis, inquiry-based and interactive approaches significantly improve students' cognitive engagement and reasoning in science contexts. Moreover, Manalo and Chua (2020) found that collaborative inquiry models foster deeper conceptual understanding and logical reasoning by encouraging peer interaction and reflective thinking. These results reinforce the pedagogical value of CGBA as a constructivist-aligned intervention that not only boosts academic performance but also cultivates essential 21st-century skills.

The results of the study provide strong evidence for the effectiveness of Collaborative Game-Based Activities (CGBAs) in enhancing students' logical reasoning skills in science. Evaluated using a structured rubric, the CGBAs consistently earned high ratings from the science teacher, affirming their alignment with instructional goals. Pre-test results showed that most students demonstrated only satisfactory reasoning abilities. However, post-intervention data reflected a significant shift, with the majority achieving Good or Very Good scores, and a steady upward trend across successive activities indicated sustained cognitive gains.

Statistical analysis further confirmed the intervention's impact. A paired-samples t-test revealed a highly significant difference between pre-test and post-test performance ($p < .001$), supporting the conclusion that CGBA participation led to measurable improvements in students' ability to reason through science questions. The data met normality assumptions, validating the use of parametric tests and reinforcing the reliability of the findings. These results underscore the pedagogical value of game-based, collaborative instruction for developing logical reasoning and promoting meaningful learning in science education.

Conclusion

The findings of this study affirm the effectiveness of Collaborative Game-Based Activities (CGBAs) in enhancing Grade 9 students' logical reasoning skills within science instruction. Through structured peer collaboration and gamified learning experiences, students demonstrated consistent improvement across progress and post-test assessments, suggesting that CGBAs foster both academic gains and higher-order cognitive development. The shift from satisfactory to good performance over successive interventions indicates that repeated, engaging activities can meaningfully scaffold logical reasoning in scientific contexts.

However, the study is not without limitations. The absence of a control group, a relatively small and context-specific sample, and potential practice effects across repeated assessments temper the generalizability of the results. Additionally, the narrow scoring range may have restricted finer distinctions in performance growth.

Future research should consider implementing more robust experimental designs, including control groups and larger, more diverse samples, to strengthen causal inferences. Investigating the long-term retention of reasoning skills and adapting CGBA interventions across other subject areas or educational levels may also provide valuable insights. Nonetheless, this study offers promising evidence that integrating CGBAs into science classrooms can transform passive instruction into dynamic, cognitively enriching learning experiences.

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