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Energy Quest: A Quasi-Experimental Study of Game-Based Learning on Conceptual Understanding of Mechanical Energy in Secondary Physics Education

Aldrin Boocan[1], Zyrene Joy Naggoc[2], Juana Guinid[2], Christzon Pasigon[2]

[1,2,3,4] Ifugao State University Potia Campus, Alfonso Lista, Ifugao, Philippines

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ABSTRACT

Background: Many secondary students struggle with abstract concepts and formula reliance in mechanical energy. **Objective:** This study evaluated *Energy Quest*, a curriculum-aligned card game, to enhance Grade 9 students' conceptual understanding and problem-solving skills in kinetic and potential energy. **Method:** Employing a quasi-experimental pretest–posttest non-equivalent control group design, 77 students across two intact classes participated. The experimental group (n = 40) engaged in structured game-based learning, while the control group (n = 37) received conventional instruction over two weeks. Data were collected using a validated 20-item achievement test α = 0.860) and analyzed via paired and independent samples t-tests and Cohen's d. **Result:** Posttest performance significantly favored the experimental group ($M = 16.40$, $SD = 1.74$) over the control group (M = 13.20, SD = 1.23), t (75) = 9.26, p < .001. The intervention demonstrated an extraordinarily large effect size (d = 2.11), indicating substantial learning gains. **Conclusion:** Structured game-based learning effectively strengthens conceptual understanding and problem-solving abilities beyond conventional teaching methods. **Contribution:** This study provides empirical evidence that low-cost, non-digital, and curriculum-aligned instructional innovations can successfully bridge persistent physics learning gaps, offering a scalable pedagogical solution for resource-constrained science classrooms.

1. INTRODUCTION

Science education is widely recognized as a key driver of national development through its contributions to economic growth, technological innovation, and improvements in health and industrial systems. Fuente (2019) and Padolina (2023) emphasize that science education develops competencies essential for innovation and global competitiveness, positioning it as a continuing priority in basic education systems worldwide. Despite this recognition, many education systems continue to struggle in translating science education goals into measurable learner achievement.

* **Corresponding Author:** Aldrin Boocan, aboocan.research@gmail.com

Ifugao State University Potia Campus, Alfonso Lista, Ifugao. Philippines

Address: College of Education, Ifugao State University Potia Campus, Alfonso Lista, Ifugao, Philippines

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Ideally, science learning should be grounded in sound educational theories that foster conceptual understanding and student engagement. Constructivist Learning Theory (Piaget, 1970; Vygotsky, 1978) emphasizes knowledge construction through active engagement and social interaction, aligning with collaborative learning in structured environments. Furthermore, the Cognitive Theory of Multimedia Learning (Mayer, 2020) explains how dual channel processing of visual and verbal information enhances cognitive integration and retention, while Self Determination Theory (Ryan & Deci, 2000) highlights autonomy, competence, and relatedness as key drivers of intrinsic motivation.

However, persistent underperformance in science remains a major concern in the Philippines, as national and international assessments consistently report low levels of scientific proficiency among learners. De Borja (2020) attributes this to sustained academic underachievement, while Tabamo (2023) identifies instructional practices that emphasize procedural recall rather than conceptual understanding. Calo & De Vera (2025) highlight systemic constraints, including limited teacher preparedness and inadequate instructional resources. In contrast, Bernardo et al. (2023), Acido & Caballes (2024), and Cabural (2024) report low PISA performance linked to structural inequities, despite Department of Education reforms (DepEd, 2019). At the classroom level, physics remains challenging due to fragmented prior knowledge and reliance on rote memorization despite inquiry-based approaches (Eviota & Liangco, 2020; Resbianto et al., 2022). In mechanical energy, learners struggle with energy transformation, conservation, and modeling (Halilović et al., 2021; Anandita et al., 2025; Kubsch et al., 2021; Munfaridah et al., 2021), a situation aggravated by cognitive, affective, and environmental factors (Novianti et al., 2022; Amaliyah et al., 2024; Gui & Akuba, 2023; Wardani et al., 2023; Frey et al., 2020; Liu et al., 2022).

In recent years, game-based learning (GBL) has emerged as a promising instructional approach for improving engagement and conceptual learning outcomes. Evidence shows that GBL enhances student participation, collaboration, and critical thinking (Khoo et al., 2023; Caparoso & Orleans, 2024; Jiménez et al., 2024), partly due to immediate feedback mechanisms that support conceptual correction (Plass et al., 2020). Among its formats, card-based learning systems are particularly relevant in resource-constrained classrooms due to their affordability, flexibility, and ease of implementation (Muthiyan et al., 2023). Empirical studies further demonstrate that GBL improves knowledge acquisition, problem-solving skills, conceptual understanding, motivation, and confidence (Eslami & Chowdhury, 2021; Mikrouli et al., 2024; Suriyabutr & Yasri, 2023; Wilcox et al., 2020; Nadeem et al., 2023; Matthew et al., 2025).

Despite increasing support for game-based learning, three key gaps remain in the literature. First, most studies focus on digital or technology-enhanced platforms, with limited attention to low-cost, classroom-based interventions suitable for resource-constrained settings. Second, there is limited empirical research specifically addressing mechanical energy in secondary physics education. Third, few studies have explicitly aligned game-based learning interventions with the Department of Education's Most Essential Learning Competencies (MELC), indicating a need for curriculum-embedded instructional innovations that are contextually responsive.

Addressing these gaps, this study contributes to science education research by examining the effectiveness of a low-cost, card-based game-based learning intervention within a Philippine secondary school context. At San Mateo Vocational and Industrial High School, Grade 9 science teachers report persistent difficulties among learners in understanding mechanical energy, particularly in identifying relevant variables and selecting appropriate formulas. In response, this action research introduces Energy Quest, a curriculum-aligned card-based game-based learning intervention designed to enhance Grade 9 students' understanding of mechanical energy, strengthen problem-solving skills, and promote learner autonomy through structured gameplay.

This study aims to investigate the effectiveness of Energy Quest in teaching mechanical energy concepts to Grade 9 students and their ability to apply concepts for kinetic and potential energy in real-life situations. Specifically, the study seeks to answer four research questions: (1) what are the mean scores of the pretest and posttest of the control and experimental groups; (2) is there a significant difference between the pretest and posttest scores within each group; (3) is there a significant difference between the pretest and posttest scores between the two groups; and (4) what is the effect size of Energy Quest on students mastery and problem solving performance in mechanical energy.

2. METHOD

2.1 Research Design

This study employed a quasi-experimental pretest–posttest non-equivalent control group design to examine the effects of the Energy Quest game-based learning (GBL) intervention on Grade 9 students' achievement in mechanical energy. This design is appropriate in educational settings where random assignment is not feasible due to intact class structures (Campbell & Stanley, 1963; Creswell & Creswell, 2018; Shadish et al., 2002). Random assignment was not possible; therefore, pretest measures were used to establish baseline equivalence and control for selection bias. The design allowed for systematic comparison of instructional effects while maintaining ecological validity within the natural classroom context.

2.2 Participants

The study was conducted from January to March 2026 at San Mateo Vocational and Industrial High School (SMVIHS), Philippines, involving 77 Grade 9 students from two intact class sections during School Year 2025–2026. Purposive sampling was used to select the sections based on (a) comparable first-quarter science performance, (b) accessibility to the researcher, and (c) no prior exposure to game-based learning in science instruction (Patton, 2002; Creswell & Plano Clark, 2018). The use of intact classes reflects the natural constraints of school-based research where random assignment is not feasible, thereby maintaining ecological validity while supporting quasi-experimental comparison.

Table 1. Distribution of Participants Across Experimental and Control Groups

Section	N	Group
Euphorbia	40	Experimental
Gerbera	37	Control

Section Euphorbia (n = 40) was assigned as the experimental group, while Section Gerbera (n = 37) served as the control group, yielding a total sample of N = 77. The unequal group sizes reflect natural classroom enrollment and were retained to preserve ecological validity typical of school-based research.

2.3 Instruments

Data were collected using a researcher-adapted 20-item multiple-choice achievement test designed to measure Grade 9 students' conceptual understanding and problem-solving skills in mechanical energy, specifically kinetic and potential energy. The instrument was aligned with the Department of Education (DepEd) Most Essential Learning Competencies (MELCs) for Grade 9 Science.

The intervention, *Energy Quest*, is a curriculum-aligned, non-digital card-based game designed to enhance students' conceptual understanding of mechanical energy through structured and collaborative problem-solving. The game consists of three core components: problem cards, value cards, and action cards. Each component serves a specific cognitive and instructional function that supports conceptual reasoning and active engagement.

Problem cards present contextualized mechanical energy scenarios that require students to identify relevant variables such as mass, velocity, and height, and to select appropriate solution strategies based on kinetic and potential energy principles. Value cards contain the corresponding numerical solutions with correct units, allowing immediate feedback and supporting self-correction. Action cards introduce rule-based constraints such as pass, reverse, and block, which regulate turn-taking and require players to make strategic decisions during gameplay. As shown in Figure 1, these components collectively structure the interaction between conceptual understanding and game mechanics.

a) problem card b) action card c) value card d) back of the card e) back of the card

Figure 1. Sample Energy Quest Problem, Value, Action Cards and Back of the cards

The intervention was implemented through iterative gameplay cycles conducted in small groups of five to seven students. Each cycle followed a standardized sequence consisting of problem selection, analysis of the scenario, formulation of a solution, submission of an answer using value or action cards, and validation through peer discussion with teacher facilitation. Answer validation was guided by a predefined answer key to ensure accuracy and consistency across groups. Immediate feedback was integrated into the process through verification of responses, enabling students to identify misconceptions and refine their understanding during gameplay. The overall sequence of interaction is presented in Figure 2.

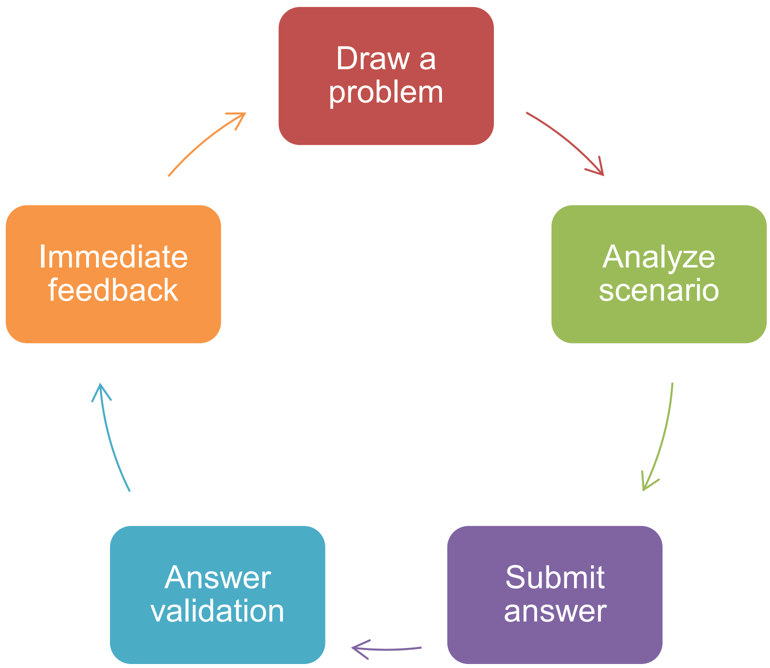

Figure 2. Gameplay Sequence of the Energy Quest Intervention

The design of *Energy Quest* is grounded in established learning theories and is operationalized through specific game mechanics. Constructivist Learning Theory is reflected in the requirement for learners to construct knowledge through peer interaction and collaborative reasoning actively. Principles from the Cognitive Theory of Multimedia Learning are applied through the integration of visual and textual representations in problem cards, which supports dual-channel processing and reduces cognitive load. Self-Determination Theory is incorporated through structured opportunities for autonomy in decision-making, competence through feedback and successful task completion, and relatedness through group-based interaction.

The intervention was conducted over two weeks during regular instructional sessions lasting 30 to 40 minutes. All sessions followed a consistent structure, and instructional time and content coverage were equivalent to those of the control group to ensure comparability. The teacher maintained a facilitative role by providing guidance, monitoring group interactions, and ensuring alignment with learning objectives. Through repeated engagement in gameplay cycles, students were exposed to retrieval practice, collaborative problem-solving, and immediate feedback, which supported the development of deeper conceptual understanding of mechanical energy.

2.4 Content Validity and Reliability

Content validity was established through expert validation by three experienced Grade 9 Science teachers. The experts independently evaluated each test item using a structured checklist covering alignment with MELC competencies, scientific accuracy, cognitive level appropriateness, clarity of language, and effectiveness of distractors. Items were revised based on the synthesis of expert feedback to improve clarity and strengthen alignment with the intended learning competencies in mechanical energy.

For reliability, the instrument was pilot-tested on a comparable group of Grade 9 students who were not part of the main study. Internal consistency was computed using Cronbach's alpha, yielding $\alpha = 0.860$, indicating high reliability for educational assessment instruments (George & Mallery, 2003; Taber, 2017)

Table 2. Scale Reliability Statistics

	No. of Items	Cronbach's α
Scale	20	0.860

2.5 Energy Quest Intervention

Energy Quest is a structured, curriculum-aligned card-based game-based learning intervention designed to develop Grade 9 students' conceptual understanding and problem-solving skills in mechanical energy through structured collaborative problem-solving tasks.

The intervention was implemented during regular science classes over two weeks through 30–40-minute sessions. Each session followed a consistent gameplay cycle: (1) formation of small groups (3–5 students), (2) distribution of MELC-aligned problem cards, (3) collaborative analysis and solution construction, (4) use of action cards to address misconceptions and conceptual challenges, and (5) immediate formative feedback embedded within game rules and teacher facilitation. This structured cycle was designed to promote iterative reasoning, peer explanation, and concept refinement.

The design of Energy Quest is grounded in three complementary theoretical frameworks. Constructivist Learning Theory (Piaget, 1952; Vygotsky, 1978) supports knowledge construction through social interaction and guided peer collaboration during problem-solving tasks. Cognitive Theory of Multimedia Learning (Mayer, 2014) informs the integration of verbal and visual representations within problem cards to facilitate dual-channel processing and reduce cognitive load. Self-Determination Theory (Deci & Ryan, 2000) underpins motivational features that promote autonomy, competence, and relatedness through structured gameplay, feedback, and cooperative tasks.

Collectively, these frameworks position Energy Quest as a low-cost, classroom-based instructional innovation that transforms abstract mechanical energy concepts into interactive, socially mediated learning experiences aligned with DepEd Most Essential Learning Competencies (MELCs).

2.6 Procedure

The study employed a three-phase quasi-experimental procedure consisting of pretest administration, instructional implementation, and posttest administration. Pretest Administration: Both the experimental and control groups were administered a 20-item achievement test on mechanical energy under standardized classroom conditions to establish baseline equivalence prior to the intervention.

Instructional Implementation: Over two weeks, both groups received instruction covering identical MELC-aligned competencies in mechanical energy. The experimental group was exposed to the Energy Quest card-based learning intervention during regular class sessions. In contrast, the control group received conventional instruction consisting of lecture-discussion, teacher-guided problem-solving, and worksheet-based activities. Both groups were allocated equal instructional time to ensure comparability of exposure. To strengthen internal validity, instructional sessions for the two groups were conducted separately to minimize interaction and treatment contamination. Classroom conditions, including instructional duration and learning objectives, were kept consistent across groups.

Posttest Administration: After the intervention period, both groups completed the same achievement test under identical administration conditions to measure learning gains in mechanical energy.

2.7 Data Collection Procedure

Ethical approval was obtained from the school administration prior to data collection. Informed consent, parental consent, and student assent were secured due to the involvement of minors. Participation was voluntary, and students were informed of their right to withdraw at any time without academic penalty. Data confidentiality was maintained in accordance with the Data Privacy Act of 2012 (Republic Act No. 10173), with all responses anonymized using coded identifiers and accessed only for research purposes.

Pretest and posttest papers were collected, checked for completeness, scored using a standardized answer key, and encoded in a spreadsheet before being analyzed using Jamovi (Version 2.3).

2.8 Data Analysis

Data were analyzed using Jamovi (Version 2.3) with a significance level set at $\alpha = .05$. Descriptive statistics (mean and standard deviation) were computed to summarize student performance in the pretest and posttest. A paired samples t-test was conducted to determine within-group differences between pretest and posttest scores for both the experimental and control groups. An independent samples t-test was used to examine baseline equivalence between groups and to compare posttest performance following the intervention. To determine the magnitude of the intervention effect, Cohen's d was computed to assess practical significance (Cohen, 1988).

2.9 Ethical Considerations

Ethical approval was obtained from the school administration prior to the conduct of the study. Informed consent, parental consent, and student assent were secured from all participants before data collection. Participation was voluntary, and students were informed of their right to withdraw at any time without academic penalty. All data were anonymized using coded identifiers, treated as confidential, and used solely for research purposes. Data were securely stored and accessible only to the researchers. The study complied with the Data Privacy Act of 2012 (Republic Act No. 10173) and adhered to established ethical standards for educational research involving human participants.

3. RESULT AND DISCUSSION

3.1 Result

This chapter presents the analyzed data in relation to the research objectives of the study. Results are organized sequentially in accordance with the stated research questions and are presented through descriptive and inferential statistical tables. Each set of findings is interpreted and situated within the broader empirical literature to contextualize the results, validate the patterns observed, and provide a scholarly basis for the conclusions drawn.

3.1.1 Descriptive Statistics: Pretest and Posttest Mean Scores of Both Groups

This section presents the descriptive statistics of the pretest and posttest scores of both the control and experimental groups. Means and standard deviations were computed to assess students' baseline knowledge and post-intervention performance in mechanical energy. These statistics provide a preliminary overview of learning gains within each group and allow for an initial comparative assessment of improvement across instructional conditions.

Table 3: Descriptive Statistics of Pretest and Posttest Scores for the Control and Experimental Groups

Group	PRETEST		POSTTEST		Mean Gain
	Mean	SD	Mean	SD	
Control	11.6	1.48	13.2	1.23	+1.60
Experimental	11.6	1.45	16.4	1.74	+4.80

Note. Scores are based on a 20-item multiple-choice achievement test on mechanical energy. SD = standard deviation. Mean Gain = posttest mean minus pretest mean.

Table 3 presents the pretest and posttest performance of the control and experimental groups in mechanical energy. Both groups demonstrated identical baseline performance ($M = 11.60$, $SD \approx = 1.45$), indicating statistical equivalence prior to the intervention. This confirms that any subsequent differences can be attributed to the instructional treatment rather than pre-existing ability differences.

Following the intervention, both groups improved; however, the experimental group showed substantially greater gains. The control group increased modestly from $M = 11.60$ to $M = 13.20$ (gain = +1.60), while the experimental group increased from $M = 11.60$ to $M = 16.40$ (gain = +4.80). The larger gain observed in the experimental condition suggests that the Energy Quest intervention contributed additional learning benefits beyond conventional instruction.

Although both groups improved, the magnitude of difference at posttest indicates a clear instructional advantage for the game-based learning approach, warranting further inferential analysis to determine statistical significance.

a) Within-Group Differences: Paired Samples T-Test Results

This section presents the results of the paired samples t-test conducted to determine whether there was a statistically significant difference between the pretest and posttest scores of students in both the experimental and control groups. The analysis examined changes in students' mechanical energy achievement before and after the instructional period. Specifically, the experimental group was exposed to the Energy Quest game-based learning intervention, while the control group received conventional instruction. The null hypothesis tested states that there is no significant difference between pretest and posttest mean scores within each group.

Table 4 Paired Samples T-Test: Significant Difference Between Pretest and Posttest Scores Across Both Groups

Group	Measure	Mean	SD	t	df	p
Experimental	Pretest	11.60	1.45	-41.70	39	< .001
	Posttest	16.40	1.74			
Control	Pretest	11.60	1.48	-19.20	36	< .001
	Posttest	13.20	1.23			

Note. Two-tailed paired samples t-test. df = degrees of freedom. SD = standard deviation. The significance level was set at α = .05. p < .001 indicates a statistically significant within-group difference

The results of the paired samples t-test show that there is a statistically significant difference between the pretest and posttest scores in both the experimental and control groups. For the experimental group, the mean score increased from M = 11.60 (SD = 1.45) at pretest to M = 16.40 (SD = 1.74) at posttest, t (39) = −41.70, p < .001. This indicates a significant improvement in students' mechanical energy achievement after the intervention.

Similarly, the control group showed a significant increase in scores from M = 11.60 (SD = 1.48) at pretest to M = 13.20 (SD = 1.23) at posttest, t (36) = −19.20, p < .001, indicating a statistically significant gain in performance following conventional instruction.

Both groups demonstrated significant improvements from pretest to posttest, with the experimental group showing a larger increase in mean scores compared to the control group.

b) Between-Group Differences: Independent Samples T-Test Results

This section presents the comparative analysis of pretest and posttest scores between the control and experimental groups using an independent samples t-test. The pretest comparison was conducted to confirm pre-intervention equivalence between the two groups, thereby establishing the internal validity of the quasi-experimental design. The posttest comparison was subsequently employed to determine whether the *Energy Quest* GBL intervention produced a statistically significant differential effect on students' academic performance in mechanical energy relative to conventional instruction alone.

Table 5. Independent Samples T-Test: Between-Group Comparison of Pretest and Posttest Scores

	Group	Mean	SD	SE	t-Value	p-Value	Decision
Pretest	experimental	11.6	1.45	0.229	0.0971	0.923	Retain H_0
	control	11.6	1.48	0.244			
Posttest	experimental	16.4	1.45	1.74	9.26[a]	<.001	Reject H_0
	control	13.2	1.48	1.23			

Note. Two-tailed independent samples t-test. df = degrees of freedom. SD = standard deviation. SE = standard error. The significance level was set at α = .05. Superscript a on the posttest t-value denotes Welch correction applied where variance homogeneity could not be assumed.

Table 5 presents the results of the independent samples t-test comparing the control and experimental groups at pretest and posttest. At baseline, no significant difference was found between the experimental group (M = 11.60, SD = 1.45) and the control group (M = 11.60, SD = 1.48), t(75) = 0.097, p = .923, confirming that both groups were statistically equivalent prior to the intervention. This supports the internal validity of the quasi-experimental design by indicating that the groups began with comparable levels of mechanical energy understanding.

At posttest, a statistically significant difference emerged in favor of the experimental group, t(75) = 9.26, p < .001. The experimental group (M = 16.40, SD = 1.74) outperformed the control group (M = 13.20, SD = 1.23), indicating that students exposed to the Energy Quest intervention achieved substantially higher learning outcomes than those who received conventional instruction.

Given the established baseline equivalence, this posttest difference provides strong evidence that the observed performance gain is attributable to the instructional intervention rather than pre-existing group differences.

c) Effect Size: Practical Significance of the Energy Quest Intervention

This section presents the effect size analysis of the *Energy Quest* GBL intervention on students' mastery and problem-solving performance in mechanical energy. Cohen's d was computed to determine the magnitude of the difference between the experimental and control groups beyond what statistical significance alone can convey. Effect size estimation is a methodologically essential complement to inferential testing, as it quantifies the practical and substantive importance of an intervention's impact independent of sample size (Cohen, 1988).

Table 6. Effect Size of the Energy Quest Intervention on Students' Mechanical Energy Achievement

Group	Cohen's d	Remarks	Reference Benchmark
experimental control	2.11	Large Effect	d ≥ 0.80 (Cohen, 1988)

Note. Cohen's d was computed using the posttest mean scores and pooled standard deviations of the experimental and control groups. Cohen's (1988) conventional benchmarks were applied: small (d = 0.20), medium (d = 0.50), large (d ≥ 0.80).

Table 6 presents the effect size of the Energy Quest intervention using Cohen's d to determine the practical significance of the observed difference between the experimental and control groups. The computed effect size (d = 2.11) indicates a very large magnitude of difference in posttest performance, far exceeding Cohen's (1988) benchmark for a large effect (d ≥ 0.80).

This result suggests that students exposed to the Energy Quest intervention performed over two standard deviations higher than those in the control group, indicating a substantial and educationally meaningful improvement in mechanical energy achievement. Beyond statistical significance, this magnitude of effect demonstrates strong practical significance, implying that the intervention had a pronounced impact on students' learning outcomes.

The large effect size provides robust evidence that the Energy Quest game-based learning approach produced a significantly stronger learning effect compared to conventional instruction. In educational terms, this indicates that the intervention is not only effective in controlled analysis but also potentially valuable for classroom implementation.

3.2. Discussion

The findings of this study demonstrate that the use of a structured educational card game significantly enhances secondary students' conceptual understanding and problem-solving skills in mechanical energy. Substantively, these findings address the main objective by showing that non-digital game-based instruction transforms student learning approaches from formula reliance to deep physical comprehension. This pattern reinforces the importance of incorporating interactive and contextually responsive learning experiences to overcome persistent learning difficulties in physics education.

The emergence of these dynamics is driven by the structural mechanisms of the Energy Quest intervention, where Problem Cards facilitate the identification of core variables such as mass, velocity, and height before equation selection. Additionally, the availability of Value Cards provides immediate feedback that enables self-correction regarding numerical and unit errors. Internally, this success occurs because Action Cards introduce rule-based constraints that sustain intrinsic motivation and foster self-regulation during small group problem solving.

The findings of this study support and extend the conceptual frameworks of Constructivist Learning Theory, Cognitive Theory of Multimedia Learning, and Self Determination Theory (Piaget, 1952, 1970; Vygotsky, 1978; Mayer, 2009, 2020; Deci & Ryan, 2000; Ryan & Deci, 2017). Integrating visual and verbal representations on problem cards optimizes dual-channel cognitive processing and reduces cognitive load when grappling with abstract concepts (Sweller, 2020, 2024). In line with expert perspectives, this paradigm demonstrates that collaborative gameplay environments trigger intrinsic motivation, competence, and learner autonomy in constructing physics knowledge (Darling-Hammond et al., 2019).

The findings of this study confirm prior research reporting that game-based learning effectively improves cognitive engagement, problem-solving skills, and learning outcomes compared to passive instructional exposure. However, a fundamental difference lies in efficiency and accessibility, as this study proves that low-cost non-digital card games can yield powerful cognitive gains without technological dependency. This variation is attributed to intensive face-to-face interaction and peer conceptual negotiation during gameplay.

The findings of this study extend existing literature by revealing novelty in the form of a physical card game directly aligned with Most Essential Learning Competencies (MELCs). These findings successfully fill empirical and practical gaps regarding the scarcity of low-cost, flexible, and easily implementable physics interventions in resource-constrained classrooms where access to digital tools is limited. The academic novelty of these findings lies in offering a transformative pedagogical framework for teaching abstract physics topics in developing contexts.

The findings of this study indicate a conceptual shift from procedural, formula-based memorization toward flexible conceptual understanding. Deeper analysis reveals that the tension between students' tendency to randomly apply mathematical expressions and their understanding of underlying physical principles is resolved through peer discussion during answer validation. This dynamic demonstrates that structured gameplay facilitates natural cognitive restructuring through active knowledge manipulation.

Although the findings of this study are predominantly driven by the game intervention, interpretation of the data must account for external factors such as initial student enthusiasm toward novel instructional media and social dynamics within small groups. Beyond the primary variables, classroom climate and teacher facilitation may have exerted a secondary influence on observed outcomes. This alternative perspective underscores the necessity of considering environmental context when evaluating game-based instructional strategies.

The synthesis of this discussion confirms that the findings of this study result from a complex interaction among structured game design, cognitive motivational supports, and active collaborative learning. This sequence highlights a central conceptual thread: instructional innovation does not necessitate high technology infrastructure to achieve maximum pedagogical effectiveness. Based on the integration of empirical findings, theoretical frameworks, and prior literature, this discussion concludes that Energy Quest serves as a scalable and measurable model for addressing conceptual barriers in secondary physics education.

4. IMPLICATIONS AND CONTRIBUTIONS

4.1 Reseach Implication

The findings of this study provide theoretical, practical, and policy implications for the research on game-based learning in physics education, specifically regarding mechanical energy, by demonstrating that a curriculum-aligned card game intervention (*Energy Quest*) significantly enhances students' conceptual understanding and problem-solving skills compared to conventional instruction. The findings of this study fill empirical and practical gaps regarding the effectiveness of low-cost, non-digital game-based learning strategies aligned with the Most Essential Learning Competencies (MELCs) and successfully implemented in resource-constrained educational settings.

4.2 Reseach Contribution

The findings of this study contribute as a new source of scientific knowledge in the field of science education and physics pedagogy by providing a new framework regarding curriculum-embedded card-based learning design. This framework can be used to transform abstract formula-based physics concepts into interactive visual representations, reduce cognitive load, and foster collaborative problem-solving based on actual field evidence and empirical data.

5. LIMITATIONS AND FUTURE RESEARCH DIRECTIONS

5.1 Reseach Limitations

This study has several limitations that should be acknowledged when interpreting the findings. First, the use of a quasi-experimental design with intact classes and no random assignment, conducted within a single public school over a brief two-week period, limits the generalizability of the results and conclusions regarding long-term conceptual retention. Second, the instructional scope was strictly confined to Grade 9 mechanical energy, meaning the findings may not directly extend to other science topics. Finally, despite controlled classroom conditions, unmeasured individual variables such as student motivation, prior achievement, and group dynamics during gameplay may have influenced student performance.

5.2 Recommendations for Future Research

To build upon these findings, several avenues for future research are recommended. Researchers should conduct multi-school randomized controlled trials across diverse grade levels and socioeconomic settings, alongside longitudinal tracking to evaluate whether learning gains are sustained over time. Furthermore, adapting the *Energy Quest* framework to other abstract science domains, such as electricity or chemistry, can establish its broader pedagogical adaptability. Subsequent studies should also compare non-digital card games directly against digital platforms while using qualitative methods such as interviews and classroom observations to gain deeper insights into how specific game mechanics affect cognitive load, motivation, and collaboration.

6. CONCLUSION

This study demonstrates that the *Energy Quest* curriculum-aligned card game intervention significantly improves Grade 9 students' conceptual understanding and problem-solving skills in mechanical energy compared to conventional instruction. Although both instructional methods resulted in posttest performance gains, the experimental group achieved substantially higher scores with a remarkably large effect size. These findings provide empirical evidence that structured, non-digital game-based learning functions as a high-impact pedagogical approach that actively drives learning rather than serving merely as a supplementary classroom exercise.

Theoretically and practically, the results confirm that learning abstract physics concepts is strongly enhanced when instruction incorporates interactive visual-verbal representations, peer collaboration, and immediate feedback mechanisms. By grounding game design in constructivist, cognitive multimedia, and self-determination theories, *Energy Quest* effectively reduced cognitive load and minimized reliance on formula-based rote recall. Furthermore, its direct alignment with the Most Essential Learning Competencies (MELCs) highlights the feasibility of embedding game mechanics into existing secondary science curricula without requiring high technological infrastructure.

In conclusion, low-cost, non-digital game-based learning offers a viable, context-responsive, and scalable solution for addressing persistent performance gaps in science education. While the study is limited by its single-site quasi-experimental design and short intervention period, it establishes a solid foundation for future research on gamified science pedagogy. Educational stakeholders are encouraged to institutionalize theory-driven, curriculum-aligned card games to enhance conceptual transfer, foster student autonomy, and elevate instructional quality in resource-constrained classrooms.

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Author Contribution Statement

All authors discussed the results, contributed to the final manuscript, and approved the final version for publication. Aldrin Boocan: Conceptualization; Methodology; Investigation; Data curation; Formal analysis; Visualization; Writing – original draft; Writing – review & editing; Project administration. Zyrene Joy Naggoc: Investigation; Data curation; Validation; Writing – review & editing. Juana Guinid: Investigation; Data curation; Validation; Writing – review & editing. Christzon Pasigon: Supervision; Conceptualization; Methodology; Validation; Writing – review & editing.

Declaration of Generative AI (GenAI) Usage in Scientific Writing

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Conflict of Interest Statement

The authors declare that they have no significant competing financial, professional or personal interests that might have influenced the performance or presentation of the work described in this manuscript

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