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Gamified Inquiry-Based Science Learning to Improve Environmental Awareness and Problem-Solving Skills: A Quasi-Experimental Study

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ABSTRACT

This quasi-experimental study aimed to investigate the effectiveness of gamified inquiry-based science learning in improving students' environmental awareness and problem-solving skills. The study employed a non-equivalent control group design involving an experimental group and a control group consisting of senior high school students. The experimental group received gamified inquiry-based science learning, while the control group received conventional instruction. Data were collected through environmental awareness and problem-solving tests, questionnaires, observations, and learning documentation. The instructional intervention integrated inquiry-based learning activities with gamification elements such as mission cards, challenges, collaborative tasks, rewards, and point systems. Students were encouraged to identify environmental problems, analyse causes, formulate solutions, and evaluate environmental impacts through contextual inquiry missions. The findings showed that both groups experienced significant improvement after the instructional intervention. The experimental group achieved slightly higher post-test scores and demonstrated stronger participation, collaboration, motivation, and engagement during classroom activities. However, the independent sample t-test indicated no statistically significant difference between the experimental and control groups. These findings suggest that gamified inquiry-based science learning has the potential to support more interactive, contextual, and student-centred environmental learning experiences. Therefore, gamified inquiry-based science learning can be considered a promising instructional approach for supporting environmental education and sustainability-oriented science learning in secondary schools.

Keywords: environmental awareness, gamification, inquiry-based learning, problem-solving skills, science learning

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INTRODUCTION

The escalating global environmental crisis has emerged as one of the most critical challenges confronting humanities in the 21st century. Environmental degradation continues to threaten ecological sustainability, public

health, economic stability, and social welfare across the globe. Major environmental issues – including climate change, deforestation, biodiversity loss, water pollution, plastic waste accumulation, and ecosystem destruction – have intensified significantly over the past decades and are projected to worsen if preventive actions are not immediately implemented. The increasing frequency of natural disasters, rising global temperatures, declining biodiversity, and environmental pollution demonstrate that environmental problems are no longer isolated ecological concerns but multidimensional global crises affecting nearly all aspects of human life (Merz et al., 2023; UNEP, 2024). Furthermore, sustainability challenges increasingly require educational systems to prepare younger generations who are capable of responding critically and responsibly to environmental problems. Recent studies emphasize that environmental education has become an essential component of sustainable development because ecological literacy and environmental responsibility are fundamental competencies needed in future societies (Mabalay, 2025).

Developing countries are among the most vulnerable regions facing environmental degradation due to rapid urbanization, industrial expansion, population growth, and unsustainable resource exploitation. Indonesia, as one of the world's mega biodiversity countries, possesses enormous ecological wealth but simultaneously faces severe environmental pressures. Deforestation, illegal mining, excessive plastic waste, forest fires, water contamination, and land conversion continue to threaten environmental sustainability throughout the country (Novienty et al., 2026; Rachmawati et al., 2026). Furthermore, environmental problems in Indonesia are increasingly linked to social behaviour patterns, including unsustainable consumption habits, weak environmental responsibility, and limited public participation in environmental conservation initiatives. These conditions indicate the urgent need for educational interventions capable of fostering environmental awareness, ecological responsibility, and sustainable behaviour among younger generations. Recent educational studies conducted in Indonesian contexts also reveal that students' environmental awareness remains relatively low, particularly regarding active participation in environmental preservation and sustainable behaviour implementation (Syamsudin et al., 2025).

Education plays a fundamental role in shaping environmentally responsible citizens capable of addressing complex environmental challenges. Environmental education is not merely intended to transfer ecological knowledge but also to develop environmental attitudes, ethical awareness, critical thinking skills, and pro-environmental behaviour (Ardoin et al., 2020). Within science education, environmental awareness is closely associated with students' ability to understand ecological systems, interpret environmental phenomena scientifically, evaluate environmental problems critically, and make informed decisions regarding sustainability issues (Kazazoglu, 2025). Therefore, environmental education should encourage students to become active problem-solvers who are capable of analysing environmental issues and proposing sustainable solutions. Recent studies further emphasize that environmental education should integrate cognitive, affective, and behavioural dimensions simultaneously because environmental responsibility cannot be developed solely through theoretical instruction (Talavera-Mendoza et al., 2025).

However, despite the increasing integration of environmental topics into school curricula, numerous studies indicate that students' environmental awareness remains relatively low. Many students possess only superficial conceptual understanding and experience difficulties in translating environmental knowledge into meaningful environmental actions (Susanti et al., 2026). This phenomenon can be observed in students' behaviours, such as improper waste disposal, low participation in environmental programs, weak environmental responsibility, and limited concern toward sustainability issues within their surrounding communities. In many educational contexts, environmental learning remains dominated by theoretical instruction rather than experiential engagement, resulting in limited development of environmental sensitivity and ecological responsibility. Similar findings were reported in recent sustainability education studies showing that students frequently understand environmental concepts conceptually but demonstrate weak pro-environmental behaviour and limited ecological engagement in practice (Talavera-Mendoza et al., 2025).

One of the major contributing factors to this problem is the persistence of teacher-centred instructional practices that prioritize memorization and content delivery over active engagement and critical inquiry (Zhu et al., 2026). Traditional science instruction frequently emphasizes factual recall, textbook-based learning, and routine exercises, while providing limited opportunities for students to investigate authentic environmental problems. Consequently, students may acquire declarative knowledge about environmental concepts but fail to develop deeper

analytical abilities, problem-solving competencies, and environmentally responsible behaviour (Fortunato et al., 2026). Such instructional approaches often limit students' opportunities to engage in meaningful learning experiences capable of connecting scientific knowledge with real-world environmental challenges. Contemporary educational research increasingly criticizes passive learning approaches because they are considered insufficient for developing higher-order thinking skills and sustainability competencies required in modern society (Zhang et al., 2025).

In addition to limited environmental awareness, students' problem-solving skills also remain a major concern in contemporary education. Problem-solving skills are widely recognized as one of the essential competencies required in 21st-century learning because modern societal challenges are increasingly complex, interdisciplinary, and dynamic (OECD, 2023). Environmental issues, in particular, require individuals who can identify problems, analyse causal relationships, evaluate evidence, generate alternative solutions, and make responsible decisions. According to Jonassen (2011), effective problem-solving involves multiple cognitive processes, including problem identification, conceptual analysis, planning, decision-making, implementation, and evaluation. These competencies are essential for preparing students to face future environmental and societal challenges. Recent studies similarly emphasize that science education should prioritize the development of critical thinking, inquiry abilities, and contextual problem-solving skills to prepare students for sustainability-related challenges (Zhang et al., 2025).

Nevertheless, recent educational studies indicate that many students still experience difficulties in solving contextual scientific and environmental problems. Students frequently struggle to analyse environmental phenomena critically, connect concepts across disciplines, and formulate feasible solutions to environmental issues (Affandy et al., 2026; Salsabila et al., 2026). Such limitations suggest that conventional learning approaches may not sufficiently support the development of higher-order thinking skills necessary for addressing complex real-world problems. Similar findings were also identified in recent environmental learning studies reporting that students often show low engagement and weak analytical reasoning when environmental learning is delivered through conventional lecture-based methods (Syamsudin et al., 2025).

To overcome these challenges, educational researchers and practitioners increasingly emphasize the importance of student-centred instructional approaches capable of promoting active learning, critical thinking, collaboration, and authentic problem-solving experiences. One instructional model that has gained significant attention in science education is Inquiry-Based Learning (IBL). Inquiry-based learning encourages students to actively construct knowledge through questioning, investigation, experimentation, evidence analysis, and reflective reasoning (Lazonder & Harmsen, 2016; Pedaste et al., 2015). Rather than passively receiving information, students become investigators who explore problems and develop understanding through experiential learning processes. Research consistently demonstrates that inquiry-based learning significantly improves conceptual understanding, scientific literacy, analytical reasoning, and problem-solving abilities. Inquiry learning also promotes deeper cognitive engagement because students participate directly in scientific investigation and evidence-based reasoning activities. In environmental education contexts, inquiry-based approaches enable students to explore authentic environmental issues, analyse ecological relationships, and evaluate the impacts of human activities on sustainability. Recent studies further confirm that inquiry-based science learning positively contributes to students' environmental awareness, collaborative learning behaviour, and scientific reasoning performance (Zhang et al., 2025).

Despite its advantages, inquiry-based learning implementation often encounters challenges related to student motivation and engagement. Some students may perceive inquiry activities as cognitively demanding and time-consuming, particularly when learning environments lack sufficient stimulation or interactive elements. Therefore, innovative instructional strategies are needed to maintain students' participation and enthusiasm throughout inquiry learning processes.

In this context, gamification has emerged as a promising educational strategy for enhancing learning motivation, engagement, and participation. Gamification refers to the integration of game design elements – such as points, rewards, missions, challenges, badges, competition, feedback, and progression systems – into non-game educational settings (Deterding et al., 2011). The primary purpose of gamification is to create enjoyable and motivating learning experiences capable of increasing students' intrinsic motivation and active involvement in

learning activities. Recent empirical studies indicate that gamification positively influences students' motivation, engagement, persistence, and learning satisfaction across various educational contexts (Mabalay, 2025).

In science education, gamified learning environments have been shown to improve both cognitive achievement and affective engagement by creating interactive, collaborative, and emotionally stimulating learning experiences (Sari et al., 2026; Su & Cheng, 2015). Recent studies demonstrate that gamification can effectively increase ecological awareness, environmental responsibility, and critical thinking skills in environmental education contexts. Talavera-Mendoza et al. (2025) reported that gamified environmental learning environments significantly strengthened students' ecological awareness and pro-environmental intentions because game elements increased emotional engagement and learning motivation. Similarly, Aragón and Brenes-Cuevas (2025) found that gamified environmental learning activities involving marine plastic pollution successfully enhanced students' motivation, environmental literacy, and understanding of sustainability issues.

The integration of inquiry-based learning and gamification – referred to in this study as Gamified Inquiry-Based Science Learning – represents an innovative instructional approach that simultaneously addresses cognitive, affective, motivational, and behavioural dimensions of learning. Through this integrated model, students engage in structured inquiry processes while being supported by game-based motivational elements. This combination potentially creates learning environments that are both intellectually challenging and emotionally engaging.

Furthermore, gamified inquiry learning provides authentic opportunities for students to investigate environmental problems collaboratively while maintaining motivation through mission-based activities and interactive challenges. To reconcile the potential tension between the intrinsic nature of inquiry-based learning and the extrinsic mechanics of gamification, this study utilizes Self-Determination Theory (SDT) as a conceptual bridge. While gamification introduces extrinsic elements like points and rewards, which could theoretically trigger the over justification effect and undermine intrinsic drive, these elements were intentionally designed to support students' basic psychological needs: autonomy (by allowing choices in mission pathways), competence (through immediate feedback and progressive mastery levels), and relatedness (via collaborative team challenges). Consequently, these extrinsic motivators serve to internalize students' engagement, transitioning them into autonomous drivers of the scientific inquiry process.

Furthermore, from the perspective of Cognitive Load Theory (CLT), the integration of gamified layers was strictly managed to prevent cognitive overload. Instead of introducing flashing, non-educational mechanics that constitute extraneous cognitive load, the game elements (such as mission cards and challenge metrics) were embedded as germane cognitive load. They functioned as structural scaffolds that guided students through the complex steps of the inquiry cycle, thereby optimizing working memory for deeper science learning and problem-solving. Previous studies suggest that gamified inquiry environments can foster stronger environmental awareness, increase collaborative engagement, and improve students' problem-solving performance in science learning contexts. Recent research on gamified climate change education and environmental STEM learning also demonstrates that gamified inquiry activities significantly improve students' critical thinking, environmental engagement, and sustainability literacy.

However, despite the growing interest in gamification and inquiry learning, empirical studies examining their combined implementation specifically in environmental science education remain relatively limited, particularly in Indonesian secondary school contexts. Several previous studies have investigated inquiry-based learning and gamification separately; however, only limited research has explored how the integration of these two approaches influences both environmental awareness and problem-solving skills simultaneously. Moreover, many prior studies focus predominantly on cognitive achievement while giving less attention to environmental awareness as an affective and behavioural educational outcome. This indicates the existence of a significant research gap concerning the effectiveness of integrated gamified inquiry learning models in promoting holistic environmental learning outcomes.

Preliminary observations conducted in a senior high school context further revealed that students' environmental awareness and problem-solving skills were still relatively low. Students experienced difficulties in identifying environmental problems, analysing causal relationships, proposing feasible solutions, and evaluating environmental impacts critically. Classroom learning activities were often dominated by teacher explanations and textbook-based instruction, resulting in limited student participation and low engagement during environmental

learning sessions. Students also showed relatively low motivation and enthusiasm when discussing environmental topics. Similar classroom conditions have been identified in recent environmental education studies emphasizing the urgent need for innovative, student-centred, and interactive instructional strategies capable of improving both engagement and higher-order thinking skills.

To address these challenges, the present study implements a Gamified Inquiry-Based Science Learning model supported by contextual environmental scenarios and mission-based learning activities. The instructional design incorporates authentic environmental issues such as waste management, deforestation, environmental ethics, and ecological sustainability into inquiry missions designed to stimulate students' analytical thinking and environmental responsibility. Mission cards are used as gamification elements to guide students through inquiry stages while simultaneously maintaining motivation, participation, and collaborative interaction during learning activities.

This study employs a quasi-experimental design involving an experimental group and a control group, each consisting of 36 senior high school students. The experimental group receives instruction through the Gamified Inquiry-Based Science Learning model, whereas the control group receives conventional teacher-centred instruction. The effectiveness of the intervention is evaluated through pre-test and post-test assessments focusing on environmental awareness and problem-solving skills, as well as students' responses toward the learning process.

Based on the theoretical background, empirical evidence, and identified research gaps, this study aims to investigate the effectiveness of Gamified Inquiry-Based Science Learning in improving students' environmental awareness and problem-solving skills in science education. Additionally, the study seeks to examine students' responses toward the implementation of the learning model and contribute to the development of innovative, student-centred, and sustainability-oriented instructional practices in contemporary science education.

METHOD

Research Design

This study employed a quasi-experimental research design using a non-equivalent control group design to examine the effectiveness of Gamified Inquiry-Based Science Learning in improving students' environmental awareness and problem-solving skills. This design was selected due to practical constraints in educational settings where random assignment was not feasible.

Two intact classes were involved in the study, consisting of an experimental group and a control group. Each group consisted of 36 senior high school students with relatively similar academic characteristics. The experimental group received instruction using Gamified Inquiry-Based Science Learning, while the control group received conventional teacher-centred instruction. Both groups were administered pre-tests and post-tests to measure students' environmental awareness and problem-solving skills before and after the intervention.

Participants and Sampling Technique

The participants were selected using purposive sampling based on similarities in academic ability, curriculum exposure, and classroom characteristics. The study was conducted in a senior high school where environmental topics were integrated into science learning activities. The equivalence of both groups prior to treatment was verified using pre-test results. The pre-test analysis indicated that the experimental and control groups possessed relatively similar initial abilities.

Instructional Treatment

The instructional treatment implemented in the experimental group integrated inquiry-based learning with gamification elements. The learning process followed several inquiry stages, including problem identification, hypothesis formulation, investigation, analysis, discussion, and conclusion. Gamification elements were implemented through mission-based learning activities using "mission cards" containing contextual environmental problems such as waste management, deforestation, pollution, and environmental ethics. Students worked collaboratively to complete missions, solve environmental problems, earn points, and progress through learning

challenges. The control group received conventional instruction emphasizing teacher explanation, textbook-based learning, and routine exercises without gamification or structured inquiry activities.

The instructional intervention was conducted over a period of four weeks, comprising five 45-minute sessions per week. To mitigate the Hawthorne effect (novelty effect)—where student engagement temporarily spikes simply due to the novelty of the gamified format—a one-week orientation phase was implemented prior to data collection. During this phase, students in the experimental group were familiarized with the point systems, badges, and mission card rules using non-target science topics. This ensured that behavioral and cognitive measurements captured during the actual intervention reflected genuine pedagogical impacts rather than initial excitement toward the game mechanics.

Research Instruments

Data were collected using several research instruments aligned with the research variables. Environmental awareness and problem-solving skills were measured using essay-based tests consisting of contextual environmental scenarios. The instruments assessed students' abilities in: 1) identifying environmental problems, 2) analysing causal relationships, 3) proposing alternative solutions, 4) making decisions, and 5) evaluating environmental impacts. An analytical scoring rubric was used to assess students' responses. Each indicator was rated on a four-point scale ranging from low to high performance. Additionally, a student response questionnaire was administered to identify students' perceptions regarding learning experiences, motivation, engagement, collaboration, and environmental awareness during the instructional process. The questionnaire employed a four-point Likert scale.

Instrument Validity and Reliability

Instrument validity was established through expert judgment involving three experts in science education and educational evaluation. The experts evaluated the relevance, clarity, and alignment of each instrument item with the indicators of environmental awareness and problem-solving skills. Revisions were conducted based on the experts' suggestions and recommendations.

Instrument validity was established through expert judgment involving three experts in science education and educational evaluation. The quantification of content validity using the Content Validity Index (CVI) yielded a score of 0.89 for the environmental awareness instrument and 0.91 for the problem-solving skills instrument, exceeding the minimum threshold of 0.80 and indicating excellent content relevance and clarity. Revisions were conducted based on the experts' qualitative recommendations before final deployment

Reliability testing was conducted using Cronbach's alpha coefficient to measure internal consistency. The environmental awareness instrument obtained a reliability coefficient of 0.82, while the problem-solving skills instrument obtained a coefficient of 0.85. These coefficients indicate that the instruments possessed good reliability and were appropriate for data collection.

Data Analysis Techniques

Data analysis was conducted using descriptive and inferential statistical techniques. Descriptive statistics included mean scores, standard deviations, minimum scores, and maximum scores for both pre-test and post-test results. The improvement in students' learning outcomes was measured using the normalized gain (N-gain) formula:

$$g = \frac{S_{posttest} - S_{pretest}}{S_{max} - S_{pretest}}$$

The N-gain score was interpreted based on the following criteria: high improvement ($g > 0.7$), moderate improvement ($0.3 \leq g \leq 0.7$), and low improvement ($g < 0.3$). Prior to hypothesis testing, prerequisite analyses were conducted using the Shapiro–Wilk normality test and Levene's homogeneity test. An independent sample t-test was conducted to identify differences between the experimental and control groups, while paired sample t-tests were conducted to examine improvements within each group. Questionnaire data were analysed descriptively using percentages and mean scores.

Research Procedures

The research procedure was conducted in three main stages: preparation, implementation, and evaluation. During the preparation stage, instruments were developed and validated, and research permissions were obtained. In the implementation stage, both groups underwent pre-testing, followed by the instructional treatment over a specified period, and concluded with post-testing. In the evaluation stage, data were analysed to determine the effectiveness of the intervention.

RESULTS AND DISCUSSION

Descriptive Analysis of Students' Learning Outcomes

The descriptive statistical analysis was conducted to examine students' environmental awareness and problem-solving skills before and after the instructional intervention. The pre-test results showed that both groups had relatively similar initial abilities. The experimental group obtained a mean score of 37.50 (SD = 2.813), while the control group obtained a mean score of 37.90 (SD = 2.781). These findings indicate that both groups possessed comparable baseline competencies prior to the intervention.

Following the instructional treatment, both groups demonstrated improvement in post-test performance. The experimental group achieved a mean score of 84.45 (SD = 1.600), while the control group obtained a mean score of 83.60 (SD = 1.542). The increase in post-test scores suggests that the instructional process contributed positively to students' environmental awareness and problem-solving skills. The reduction in standard deviation values also indicates that students' learning outcomes became more homogeneous after instruction. The descriptive statistics are presented in Table 1.

Table 1. Descriptive statistics of pre-test and post-test scores

Group	Test	N	Mean	Std. Deviation	Minimum	Maximum
Experimental	Pre-test	36	37.50	2.813	10.00	70.00
	Post-test	36	84.45	1.600	65.00	100.00
Control	Pre-test	36	37.90	2.781	00.00	60.00
	Post-test	36	83.60	1.542	65.00	100.00

The substantial increase in post-test scores in the experimental group indicates that the implementation of Gamified Inquiry-Based Science Learning positively facilitated students' conceptual understanding and problem-solving performance. During the intervention, students were actively involved in mission-based inquiry activities requiring them to identify environmental issues, investigate causes, propose solutions, and evaluate consequences. Such learning experiences encouraged deeper cognitive engagement compared to conventional instruction.

Moreover, the gamification elements embedded in the instructional process appeared to increase students' motivation and participation. The use of mission cards, challenges, collaborative tasks, and point systems created a more interactive learning atmosphere that encouraged students to remain actively engaged throughout the learning process. These findings align with previous studies indicating that gamification enhances learning engagement, persistence, and cognitive performance in science education contexts.

Normality Test

Before conducting inferential statistical analysis, prerequisite tests were performed to determine whether the data met the assumptions of normal distribution. The normality test was conducted using the Shapiro–Wilk test because the sample size in each group was fewer than 50 participants. The results of the Shapiro–Wilk test for the pre-test scores showed significance values of 0.447 for the experimental group and 0.161 for the control group. Since both significance values were greater than 0.05, the pre-test data were considered normally distributed.

Similarly, the post-test scores yielded significance values of 0.133 for the experimental group and 0.108 for the control group. These values also exceeded the significance threshold of 0.05, indicating that the post-test data were normally distributed. The results are presented in Table 2.

Table 2. Results of the Shapiro-Wilk normality test

Group	Variable	Sig. Value	Interpretation
Experimental	Pre-test	0.447	Normal
	Post-test	0.133	Normal
Control	Pre-test	0.161	Normal
	Post-test	0.108	Normal

The normality test results indicate that the data fulfilled the assumptions required for parametric statistical analysis. Therefore, further analyses using independent sample t-tests and paired sample t-tests were considered appropriate.

Homogeneity Test

A homogeneity test was conducted using Levene's test to determine whether the variances of both groups were statistically equal. For the pre-test scores, the significance value obtained was 0.671. Meanwhile, the post-test scores produced a significance value of 0.889. Since both significance values were greater than 0.05, the variances between the experimental and control groups were considered homogeneous. The results are summarized in Table 3.

Table 3. Results of the homogeneity test

Variable	Levene Statistic	Sig. Value	Interpretation
Pre-test	0.182	0.671	Homogeneous
Post-test	0.020	0.889	Homogeneous

These findings indicate that the assumption of homogeneity of variance was satisfied, allowing the use of parametric inferential statistics for further hypothesis testing.

Independent Sample t-Test Analysis

The independent sample t-test was conducted to determine whether there were significant differences between the experimental and control groups. The pre-test analysis produced a significance value of 0.900 ($p > 0.05$), indicating no statistically significant difference between the groups before the intervention. This finding confirms that both groups possessed relatively equivalent initial abilities.

The post-test analysis produced a significance value of 0.654 ($p > 0.05$). Although the experimental group achieved slightly higher mean scores, the difference between the two groups was not statistically significant. These findings indicate that both instructional approaches contributed positively to students' learning improvement. However, the implementation of Gamified Inquiry-Based Science Learning appeared to provide additional benefits related to classroom engagement, participation, and collaborative inquiry experiences.

To establish baseline equivalence between the experimental and control groups, an independent sample t-test was computed on the pre-test scores. The analysis revealed no statistically significant difference between the two groups prior to the intervention ($t = -0.126$, $p = 0.900$). This statistical equivalence confirms that both groups possessed identical baseline competencies in environmental awareness and problem-solving skills, thereby satisfying the fundamental requirement of a non-equivalent control group design without requiring initial covariate adjustments. The results are presented in Table 4.

Table 4. Independent sample t-test results

Variable	Mean Experimental	Mean Control	t-Value	Sig. (2-tailed)	Interpretation
Pre-test	37.50	37.90	-0.126	0.900	No significant difference
Post-test	84.45	83.60	0.450	0.654	No significant difference

Although the post-test difference was not statistically significant, the experimental group consistently achieved slightly higher outcomes. Several factors may explain why the statistical difference was relatively small. First, both groups experienced substantial learning improvement throughout the instructional process. Even though the control group received conventional instruction, exposure to environmental learning materials may still have contributed positively to students' understanding and awareness. Second, the duration of the intervention may not have been sufficiently long to produce a stronger statistical effect between groups. Gamified inquiry learning often requires extended implementation to fully optimize students' inquiry habits, critical thinking patterns, and environmental attitudes. Third, environmental awareness is not solely influenced by classroom instruction but also by external factors such as family habits, school culture, social environment, and prior experiences. Consequently, the measurable impact of instructional intervention may require longer-term reinforcement.

Nevertheless, the qualitative learning process observed during implementation suggested that students in the experimental group demonstrated higher enthusiasm, more active participation, stronger collaboration, and greater engagement in environmental discussions. Students appeared more motivated to solve contextual environmental problems when learning activities were integrated with game-based missions and collaborative inquiry tasks.

Paired Sample t-Test Analysis

The paired sample t-test analysis demonstrated statistically significant improvement in both groups. The experimental group showed a significance value of 0.000 ($p < 0.05$) with a mean difference of 46.95, indicating substantial improvement after the implementation of Gamified Inquiry-Based Science Learning.

Similarly, the control group also demonstrated statistically significant improvement with a significance value of 0.000 ($p < 0.05$) and a mean difference of 45.70. These findings suggest that the instructional process positively influenced students' environmental awareness and problem-solving abilities in both groups. The results are summarized in Table 5.

Table 5. Paired sample t-test results

Group	Mean Pre-test	Mean Post-test	Mean Difference	t-Value	Sig. (2-tailed)	Interpretation
Experimental	37.50	84.45	46.95	-16.408	0.000	Significant improvement
Control	37.90	83.60	45.70	-16.548	0.000	Significant improvement

The significant increase in both groups indicates that the instructional process generally improved students' learning outcomes. However, the experimental group demonstrated slightly higher gains, suggesting that Gamified Inquiry-Based Science Learning provided additional benefits in fostering active engagement and contextual problem-solving experiences.

The inquiry process encouraged students to construct understanding through investigation and evidence-based reasoning rather than memorization. Simultaneously, gamification elements increased emotional engagement, participation, and motivation during learning activities. These findings support constructivist learning theory, which emphasizes that meaningful learning occurs when students actively construct knowledge through authentic experiences and social interaction. The integration of inquiry and gamification creates a learning environment that combines cognitive challenge with motivational support, thereby facilitating deeper learning experiences.

Furthermore, the use of contextual environmental scenarios allowed students to connect classroom learning with real-world issues. This contextualization likely contributed to stronger environmental awareness because students were required to evaluate realistic environmental problems affecting society.

Discussion

The findings of this study provide evidence regarding the potential contribution of Gamified Inquiry-Based Science Learning in supporting students' environmental awareness and problem-solving skills. Statistical analysis demonstrated that both the experimental and control groups experienced significant improvement after the instructional intervention. Nevertheless, the experimental group consistently obtained slightly higher post-test scores and demonstrated stronger participation and engagement during classroom activities. These findings indicate that integrating inquiry-based learning with gamification creates a more interactive and student-centred learning environment.

From the perspective of inquiry-based pedagogy, the improvement in students' learning outcomes can be attributed to the active learning processes embedded in the instructional design. Inquiry learning encourages students to investigate problems, formulate hypotheses, collect information, analyse evidence, and construct conclusions independently. Through these stages, students become active participants in knowledge construction rather than passive recipients of information. This finding is consistent with studies emphasizing that inquiry-based science learning improves students' analytical thinking, scientific reasoning, and problem-solving abilities through authentic investigative processes (Zhang et al., 2025).

In this study, students in the experimental class were actively engaged in solving contextual environmental missions related to deforestation, waste management, pollution, and environmental ethics. The contextual nature of these problems likely contributed to deeper conceptual understanding because students connected scientific concepts with real environmental challenges. Environmental education research has consistently highlighted that contextual and problem-oriented learning environments are more effective in fostering environmental awareness compared to conventional instruction focused on memorization (Syamsudin et al., 2025).

The findings also support constructivist learning theory, which argues that knowledge is actively constructed through interaction, experience, and social engagement. During inquiry activities, students collaborated in identifying environmental problems, discussing solutions, evaluating evidence, and reflecting on environmental consequences. Such collaborative inquiry activities promote deeper cognitive engagement and higher-order thinking skills. Recent studies similarly demonstrate that inquiry-based and problem-based learning approaches strengthen critical thinking, collaboration, and scientific literacy among secondary school students (Zhang et al., 2025).

Another important finding concerns the positive role of gamification in increasing students' motivation and classroom participation. The use of mission cards, challenges, reward systems, and collaborative tasks created a more engaging classroom atmosphere. Students appeared more enthusiastic because the instructional process incorporated game-like experiences that reduced monotony and increased emotional involvement in learning.

This finding aligns with research indicating that gamification enhances intrinsic motivation, participation, persistence, and learning enjoyment in educational settings. Gamification provides students with clear goals, immediate feedback, and progressive challenges that contribute positively to student engagement. A systematic review on gamification for sustainability education found that engagement, motivation, and social interaction are among the most significant benefits of gamified educational environments (Mabalay, 2025).

Furthermore, studies on gamified science learning environments demonstrate that gamification improves students' perceived learning outcomes and enjoyment in inquiry-based science education. Zhang et al. (2025), through the "Experiverse" inquiry-gamification framework, reported that students' motivation strongly correlated with learning enjoyment and perceived learning achievement during inquiry-based science activities. This supports the findings of the present study, where students in the experimental group displayed stronger engagement throughout the inquiry process.

Although the independent sample t-test indicated that the difference between the experimental and control groups was not statistically significant ($p = 0.654$), several important interpretations can still be drawn. First, both groups experienced substantial learning improvement, indicating that environmental learning itself positively contributed to students' understanding and problem-solving abilities. Second, the relatively short intervention period may have limited the magnitude of the treatment effect because environmental awareness involves long-term attitude formation and behavioural transformation. Third, classroom observations suggested that students in the experimental group demonstrated higher participation, stronger collaboration, and greater enthusiasm during environmental discussions.

This interpretation is supported by studies emphasizing that gamified learning environments frequently generate stronger improvements in motivation, engagement, and participation than in short-term cognitive achievement alone. Gamification contributes substantially to affective learning outcomes, including enjoyment, self-confidence, collaboration, and persistence (Mabalay, 2025).

The paired sample t-test results demonstrated statistically significant improvement in both groups, although the experimental group achieved a slightly larger mean gain. One possible explanation is that inquiry learning trains students to think systematically through stages of problem identification, evidence analysis, solution planning, and evaluation. At the same time, gamification elements help maintain students' motivation during cognitively demanding inquiry tasks.

The findings also revealed a decrease in standard deviation values from pre-test to post-test in both groups, indicating more homogeneous learning achievement after instruction. In the experimental class, collaborative inquiry activities likely contributed to reducing learning disparities because students worked together in solving environmental missions. Collaborative inquiry learning has been widely recognized as an effective strategy for promoting knowledge sharing, communication skills, and cooperative problem-solving.

From the perspective of environmental education, this study highlights the importance of designing instructional models that emphasize authentic, participatory, and contextual learning experiences. Environmental problems are closely connected to human behaviour and societal practices; therefore, environmental education requires instructional strategies capable of fostering critical reflection and active problem-solving competencies.

The implementation of Gamified Inquiry-Based Science Learning demonstrates that environmental learning can become more engaging and meaningful when students are directly involved in authentic environmental investigations supported by motivational game-based elements. Recent sustainability education studies similarly conclude that gamified environmental learning environments effectively support environmental literacy, sustainability awareness, and pro-environmental attitudes among students.

The findings of this study also have practical implications for science teachers and educational institutions. Teachers should consider integrating inquiry processes with interactive learning strategies such as mission-based learning, contextual environmental scenarios, collaborative tasks, and gamification elements to increase student participation and motivation. Environmental learning should also prioritize authentic environmental problems encountered within students' communities to strengthen environmental responsibility and sustainability awareness.

Despite its contributions, this study has several limitations. The sample size was relatively limited and involved only two classes within one educational context, which may reduce the generalizability of the findings. Additionally, the intervention period was relatively short, limiting the observation of long-term changes in environmental behaviour and attitudes. Future studies are therefore recommended to involve larger samples, longer intervention durations, and mixed-method approaches incorporating interviews, observations, and reflective journals.

Overall, the findings indicate that Gamified Inquiry-Based Science Learning represents a promising instructional innovation capable of supporting students' environmental awareness, problem-solving abilities, motivation, and engagement. The integration of inquiry activities and gamification elements creates learning experiences that are cognitively challenging, emotionally engaging, socially interactive, and contextually meaningful for environmental and sustainability education.

CONCLUSION

The implementation of gamified inquiry-based science learning contributed positively to students' environmental awareness and problem-solving skills. Both the experimental and control groups demonstrated significant improvement after the instructional process. Although the experimental group achieved slightly higher post-test scores and demonstrated stronger participation, collaboration, and engagement during classroom activities, the statistical analysis indicated no significant difference between the two groups.

These findings suggest that gamified inquiry-based science learning has the potential to create more interactive, contextual, and student-centred environmental learning experiences. The integration of inquiry activities and gamification elements may support students' motivation, participation, and problem-solving engagement in

science learning contexts. Therefore, this instructional approach can be considered a promising alternative strategy for supporting environmental education and sustainability-oriented learning in secondary schools.

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