Game-Based Learning to Promote Environmental Citizenship in Elementary Education

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Manuscript received September 30, 2025; revised October 27, 2025; accepted December 11, 2025; published May 13, 2026

***Abstract*—This study investigates the effectiveness of *EcoChallenge*, an online game-based learning intervention, in promoting environmental global citizenship among Grade 6 students. A quasi-experimental pre-test/post-test design with a control group was employed. Participants completed a learning achievement test, an environmental citizenship skills assessment (knowledge, attitudes, and behaviors), and a satisfaction questionnaire. Instruments underwent expert review and standard quality checks, with the support of the CRAFT framework in design and validation. The intervention was implemented over six weeks with structured missions (e.g., waste management scenarios) and real-time feedback. Results show statistically significant gains in learning achievement from pre-test to post-test for students using *EcoChallenge*, with concurrent improvements across all three domains of environmental citizenship skills. Students also reported very high satisfaction with usability, enjoyment, and motivation. A positive association was observed between academic achievement and environmental citizenship skills (r = 0.608, p < 0.001), indicating that cognitive gains and pro-environmental competencies advanced together. These findings suggest that well-designed game-based learning can operationalize Global Citizenship Education (GCE) and Education for Sustainable Development (ESD) for primary learners. Practical implications include integrating similar digital games into elementary curricula to support knowledge, attitudes, and behaviors aligned with sustainability goals. Future work should examine long-term retention and transfer, teacher facilitation strategies, and scalability across diverse school contexts.**

***Keywords*—game-based learning, online game, global citizenship, environment, waste management**

I. Introduction

In the 21st century, global citizenship education has become increasingly significant in preparing learners to engage responsibly with global challenges, particularly those related to environmental sustainability [1]. Education for Sustainable Development (ESD) encourages learners to cultivate knowledge, attitudes, and skills necessary to address environmental problems through critical thinking and collective responsibility [2]. Within this framework, global citizenship emphasizes the integration of local and global perspectives, empowering learners to recognize their role in protecting natural resources and mitigating environmental issues [3].

Recent studies have indicated that elementary school students often lack adequate awareness and skills to practice sustainable environmental behaviors in daily life [4]. Traditional teaching methods, which mainly rely on textbooks and rote learning, have shown limited effectiveness in cultivating active engagement and critical environmental responsibility among young learners [5]. To bridge this gap, innovative pedagogical strategies are needed to enhance students' motivation and develop their global citizenship competencies [6].

Game-based learning has emerged as a powerful educational approach, offering interactive experiences that stimulate motivation, problem-solving, and collaboration [7]. Online learning games provide opportunities for personalized learning and can be designed to simulate real-life environmental challenges in an engaging format [8].

Grounded in constructivist and experiential learning theories, *EcoChallenge* encourages learners to actively construct knowledge through meaningful interaction and reflection. Drawing on Piaget's [9] view of learning as active construction, Vygotsky's [10] emphasis on social scaffolding, and Kolb's [11] experiential cycle, the game design integrates hands-on exploration and feedback to reinforce environmental concepts.

Research has shown that integrating environmental education into digital game-based learning can significantly enhance knowledge acquisition and promote positive attitudes toward sustainability [12].

This study, therefore, aims to develop and evaluate an online learning game, named *EcoChallenge*, designed to promote environmental global citizenship skills among Grade 6 students. By integrating interactive digital environments with global citizenship competencies, the research seeks to address the limitations of traditional instruction and contribute to innovative practices in elementary environmental education [13].

In reviewing prior research across GCE, ESD, GBL, and online learning, several critical gaps become evident. First, GCE remains policy-driven rather than practice-driven, with few studies translating these frameworks into structured pedagogical practices suitable for primary learners [14]. Second, although project-based and experiential learning in sustainability education has been shown to raise awareness, these efforts are often fragmented, short-term, and disconnected from digital platforms [15]. Third, while GBL has been widely applied in mathematics, science, and language learning [16], its potential in fostering environmental responsibility and global citizenship remains underexplored in elementary education. Lastly, most digital learning tools used in Thailand and Southeast Asia continue to focus on academic subjects such as mathematics and science [17], with limited integration into sustainability or citizenship education.

These gaps collectively suggest the need for an integrated educational innovation that draws upon established theoretical frameworks while addressing the interests and learning behaviors of digital-native students. *EcoChallenge* responds to this need by combining GCE, ESD, and GBL principles within an online learning environment designed specifically for young learners.

II. Literature Review

A. Global Citizenship and Environmental Education

Global Citizenship Education (GCE) has been broadly defined as a transformative educational paradigm that equips learners with the knowledge, values, and competencies to act responsibly in interconnected local and global contexts [18]. UNESCO identifies GCE as one of the key drivers of quality education in the 21st century, emphasizing critical inquiry, respect for diversity, human rights, and sustainability [19]. Similarly, Oxfam frames GCE as a holistic process that nurtures empathy, social justice, and active participation in addressing global challenges [20].

The environmental dimension of GCE emphasizes ecological awareness, stewardship of natural resources, and responsibility toward mitigating environmental crises [21]. Scholars argue that environmental citizenship, as an extension of GCE, requires learners not only to acquire factual knowledge about the environment but also to develop an ecocentric worldview that informs daily practices [22]. These conceptual frameworks provide the foundation for integrating sustainability education into global citizenship discourses, particularly in school curricula.

Research has increasingly emphasized the importance of introducing GCE principles in early education, particularly at the elementary level. A study by Loy *et al.* [3] demonstrated that children exposed to GCE frameworks were more likely to demonstrate pro-environmental behaviors and empathetic attitudes toward global issues. In Southeast Asia, Torres and Bosio [5] documented that embedding global responsibility themes into classroom activities encouraged elementary students to engage in waste reduction and recycling initiatives.

In Thailand, initiatives aligned with the "Sufficiency Economy Philosophy" have incorporated elements of GCE and environmental education in schools, though primarily through extracurricular activities such as community clean-ups and environmental clubs [23, 24]. While these activities raise awareness, they often remain disconnected from formal curricula and lack integration into digital or interactive learning environments [25].

Despite the growing recognition of GCE's importance, research highlights significant challenges in applying its principles effectively in primary education. First, GCE curricula are often abstract and policy-driven, making them difficult to translate into practical classroom strategies for young learners [26]. Second, most implementations emphasize theoretical understanding of global issues, without sufficient focus on experiential or participatory learning methods [27]. Third, teachers frequently report a lack of resources, training, and support to implement GCE effectively, particularly in developing countries [28].

Another challenge is cultural contextualization. While GCE is promoted as a global framework, studies suggest that localized adaptations are necessary to ensure relevance to students' lived experiences [29]. For example, in Thailand, students may understand the importance of sustainability when linked to familiar community issues such as waste management or plastic reduction campaigns. Yet, these examples are seldom integrated into interactive digital platforms that could amplify engagement.

B. Education for Sustainable Development (ESD)

Education for Sustainable Development (ESD) is an educational paradigm that seeks to integrate sustainability principles into all aspects of learning, emphasizing not only cognitive knowledge but also socio-emotional and behavioral competencies [30]. UNESCO identifies ESD as one of the key pillars in achieving the Sustainable Development Goals (SDGs), highlighting its role in fostering critical thinking, problem-solving, and responsible decision-making among learners [31].

Scholars argue that ESD represents a shift from traditional, content-based instruction toward transformative learning approaches that empower students to take action in their communities [32]. The theoretical framework of ESD builds upon systems thinking, experiential learning, and participatory education, encouraging learners to understand the interconnectedness of environmental, social, and economic dimensions [33]. This holistic perspective makes ESD particularly relevant for elementary education, where early exposure to sustainability can shape long-term attitudes and behaviors.

Research across different countries has demonstrated the positive impact of ESD initiatives on young learners. For example, a study in Japan showed that integrating ESD into science curricula enhanced students' understanding of ecological interdependence and encouraged sustainable practices such as energy conservation and recycling [34]. In Thailand, ESD has been promoted through initiatives aligned with the Sufficiency Economy Philosophy, with programs encouraging students to engage in activities such as organic gardening, waste management, and water conservation [35].

Empirical studies also reveal that project-based ESD activities significantly improve students' critical thinking and problem-solving abilities. For instance, outdoor learning projects that involve biodiversity observation or recycling campaigns have been shown to increase students' sense of responsibility and community engagement [36]. Furthermore, collaborative ESD programs that connect schools with local communities have been found to strengthen both environmental knowledge and civic responsibility [37].

Despite its potential, the implementation of ESD in primary schools faces several limitations. First, many ESD initiatives are short-term projects rather than integrated parts of the curriculum, leading to temporary gains in awareness but limited long-term behavioral change [38]. Second, ESD activities often rely on traditional methods such as lectures, posters, and school campaigns, which may not sustain the interest of digital-native learners [39]. Third, teachers frequently report a lack of professional development and resources to effectively implement ESD in classroom settings [40].

A notable gap in literature is the limited use of digital and interactive tools in ESD. While research has highlighted the

benefits of experiential and project-based learning, relatively few studies have explored how online platforms and game-based environments can reinforce sustainability principles [41]. This absence is significant given that children today are highly engaged with digital media, suggesting that the integration of ESD with technology could increase both relevance and impact.

C. Game-Based Learning (GBL) in Education

Game-Based Learning (GBL) has its theoretical roots in constructivist and experiential learning theories, which emphasize the importance of active engagement, interaction, and feedback in the learning process [42]. According to Piaget's constructivism, learners build new knowledge through direct experiences, while Vygotsky's sociocultural theory underscores the value of collaboration and scaffolding—both of which align closely with the interactive nature of games [43]. Kolb's experiential learning cycle further reinforces GBL by framing learning as a continuous process of concrete experience, reflection, abstract conceptualization, and active experimentation [44].

Games provide a unique pedagogical environment that naturally integrates these theoretical principles. They allow learners to explore problems, receive immediate feedback, and apply strategies repeatedly until mastery is achieved [45]. Digital games are designed around the principles of motivation, challenge, and reward, which sustain learners' attention and encourage persistence [46]. Research has consistently shown that the motivational aspects of games are linked to deeper learning outcomes, as learners are more willing to invest time and effort in challenging tasks when they are framed as playful activities [47].

Empirical studies demonstrate that GBL is widely effective in elementary education, particularly in core academic subjects such as mathematics, science, and language arts. For instance, Qian and Clark [48] found that GBL improved student achievement and engagement in mathematics through adaptive challenges that adjusted to learners' skill levels. In science, interactive simulations and role-playing games have been shown to enhance understanding of complex concepts such as ecosystems, energy flow, and weather systems [49]. Language learning studies further highlight the ability of GBL to improve vocabulary retention and communication skills through immersive storytelling and role-play [50].

Meta-analyses confirm that GBL not only increases academic performance but also fosters higher-order skills such as problem-solving, critical thinking, and collaboration. For elementary students, these benefits are especially important, as engagement and motivation are critical predictors of long-term learning success [51]. Beyond academics, GBL has also been applied to promote Social and Emotional Learning (SEL), encouraging cooperation, empathy, and resilience [52]. These findings suggest that GBL has broad applications beyond traditional academic outcomes, making it a powerful tool for interdisciplinary education.

Despite its effectiveness demonstrated in many domains, GBL remains underutilized in environmental and global citizenship education. A systematic review of GBL applications found that most studies focused on mathematics and science, with relatively few addressing sustainability or citizenship themes [53]. While some projects have simulated environmental systems to illustrate ecological principles, these were often designed for secondary or higher education contexts, leaving primary education largely overlooked [54].

Another gap is the limited integration of GBL with broader educational frameworks such as UNESCO's Education for Sustainable Development (ESD) and Global Citizenship Education (GCE). Studies highlight the potential of using games to simulate real-world sustainability challenges—such as waste management, climate change, and resource allocation—but few concrete examples exist at the elementary school level [55]. Furthermore, while students are enthusiastic about games, teachers often lack training, resources, or confidence to implement GBL effectively in the classroom [56].

D. Online and Digital Learning Tools

Over the past two decades, online learning has evolved from supplementary distance education into a mainstream instructional approach across all educational levels [57]. The COVID-19 pandemic further accelerated this trend, forcing schools worldwide to adopt digital platforms as primary modes of instruction [58]. Scholars note that online learning offers unique advantages, including flexibility in time and place, personalization of learning experiences, and opportunities for collaborative engagement beyond the classroom [59].

For primary education, digital platforms provide interactive environments that can capture children's attention more effectively than traditional methods [60]. Studies reveal that younger learners, who are often considered "digital natives", are particularly receptive to multimedia-rich learning tools such as interactive videos, animations, and games [61]. The ubiquity of mobile devices and internet access has also contributed to the rapid expansion of digital learning opportunities, enabling students to engage with content anytime and anywhere [62].

A growing body of research supports the use of online games as powerful tools for education. Games provide immediate feedback, adaptive difficulty levels, and immersive storylines, all of which contribute to sustained engagement [63]. Unlike static resources such as textbooks or videos, interactive games allow learners to actively experiment, make decisions, and observe the consequences of their actions in real time [64]. These affordances make online games particularly suited for teaching complex and abstract concepts, including environmental systems and sustainability challenges [65].

Empirical studies confirm that online game-based platforms enhance learning outcomes by promoting problem-solving, critical thinking, and creativity. For example, Connolly *et al.* [66] conducted a systematic review showing that serious games improved both cognitive and affective learning outcomes across diverse subject areas. Hamari *et al.* [67] further showed that challenging and well-designed online games increased students' intrinsic motivation and persistence in learning tasks. At the elementary level, interactive storytelling games have been found to strengthen literacy skills, while science-based games improve conceptual understanding and inquiry

skills [68].

Another benefit of online learning tools is their potential for personalization. Adaptive learning technologies allow games to adjust difficulty levels based on learner performance, providing tailored support that meets the needs of individual students [69]. This is particularly important for heterogeneous classrooms where learners may vary widely in prior knowledge, motivation, and abilities.

Despite these advantages, the integration of online learning tools in Thai primary education remains limited. Research highlights several barriers: unequal access to technology, inadequate teacher training, and insufficient infrastructure in rural schools. A study by Sriprachyakul [69] revealed that while many Thai schools have adopted digital platforms, these initiatives primarily focus on mathematics and science, with little attention given to subjects like environmental or citizenship education.

Moreover, there is often a disconnect between national digital education policies and classroom-level implementation. Teachers report challenges in aligning online tools with curricula, managing technical issues, and ensuring equitable participation among students [70]. Cultural factors also play a role, as some educators and parents express skepticism about the educational value of digital games, viewing them primarily as sources of entertainment rather than serious learning tools [71].

In Southeast Asia more broadly, UNESCO Bangkok [72] notes that while digital integration is improving, it remains uneven across countries, with resource disparities exacerbating educational inequalities.

III. Materials and Methods

A. Research Design

This study adopted a quasi-experimental design with a pre-test and post-test control group to examine the effectiveness of *EcoChallenge*, an online game-based learning intervention, in fostering environmental citizenship among elementary students. The design allowed comparisons of knowledge, attitudes, and behavior changes between the experimental and control groups.

B. Participants

The study adopted a non-random quasi-experimental design. Class sections were assigned based on school scheduling constraints, while ensuring comparable baseline characteristics between groups. Informed consent was obtained from students' guardians prior to participation.

C. Instruments

Four instruments were employed:

1) The online learning game (*EcoChallenge*) comprises three learning levels: Waste Sorting, Smart Waste Management, and Green Hero.
2) Learning Achievement Test: 20 multiple-choice items assessing conceptual understanding.
3) Environmental Citizenship Skills Assessment: 15 Likert-scale items measuring knowledge, attitudes, and sustainable practices.
4) Satisfaction Questionnaire: 10 items evaluating enjoyment, usability, and perceived learning benefits.

Instrument Quality: All instruments were reviewed by three experts in science education and instructional technology. The Index of Item-Objective Congruence (IOC) was used to assess content validity, with acceptable values ranging from 0.67 to 1.00.

Reliability was examined through Cronbach's alpha, with coefficients of 0.82 for the attitude scale and 0.79 for the behavioral checklist, exceeding the 0.70 threshold recommended for internal consistency.

CRAFT-supported instrument design. The design and validation of all instruments were additionally guided by the CRAFT framework—Collecting, Reviewing, Analyzing, Framing, and Tailoring—which operationalizes AI-augmented research workflows. In this study, CRAFT streamlined (i) Collecting prior instruments and item pools, (ii) Reviewing content against GCE/ESD constructs, (iii) Analyzing overlaps and gaps to reduce redundancy, (iv) Framing measurable indicators for knowledge, attitudes, and behaviors, and (v) Tailoring wording for Grade-6 readability before expert IOC and pilot reliability checks. Prior work shows CRAFT improves literature-instrument alignment and researcher efficiency, supporting rigor in educational studies [17].

AI tools within CRAFT. Across the five CRAFT phases, we leveraged scholar search and screening tools (e.g., Google Scholar, Semantic Scholar), organization tools (Mendeley), and academic writing utilities (e.g., grammar/paraphrase assistants) strictly for *instrument refinement* and *evidence mapping*—not for generating test items without human review—thereby maintaining validity and ethical standards [17]

D. Research Procedure

The study followed three phases (Fig. 1), explicitly aligned with the CRAFT framework to scaffold the research workflow:

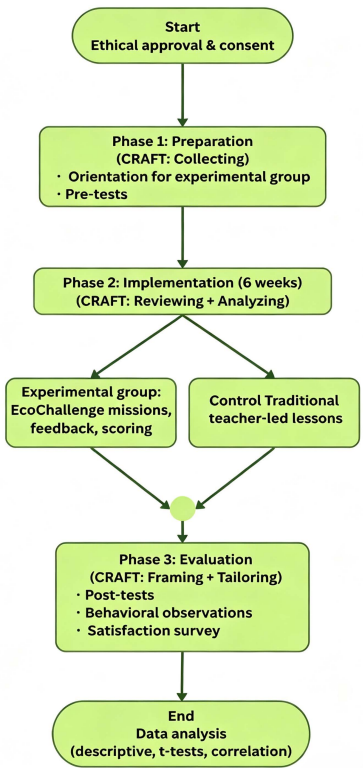

Fig. 1. Research procedure and CRAFT alignment.

Phase 1: Preparation. Ethical approval and guardian consent were secured; the experimental group received an orientation to *EcoChallenge*; both groups completed pre-tests. Prior instruments, rubrics, and learning objectives were *collected* to ensure construct coverage [17].

Phase 2: Implementation. The experimental group engaged in scenario-based *EcoChallenge* missions with real-time feedback and scoring; the control group continued traditional teacher-led lessons. Ongoing *reviewing* of mission logs and *analysis* of formative feedback informed minor usability refinements without altering target constructs [17].

Phase 3: Evaluation. Post-tests, behavioral observations, and satisfaction surveys were administered. Indicators were *framed* to align with learning outcomes and *tailored* for Grade-appropriate interpretation prior to statistical analysis [17].

Assumption tests indicated no significant violations of normality (Shapiro–Wilk, $p > 0.05$) or homogeneity (Levene's test, $p > 0.05$). Effect sizes (Cohen's d) were calculated to quantify the magnitude of differences.

E. Data Analysis

Descriptive statistics (mean, SD) summarized student performance. Paired samples t-tests assessed pre- to post-test improvements within groups. Effect sizes (Cohen's d) quantified the magnitude of differences.

F. Ethical Considerations

This research was approved by the Human Research Ethics Committee of Naresuan University (Approval No. 012/2025). Written informed consent was obtained from all participants' guardians. Data confidentiality and voluntary participation were strictly maintained.

IV. Findings

A. Quality of the Developed Game

The *EcoChallenge* game, consisting of three levels (Waste Sorting, Smart Waste Management, and Green Hero), was evaluated by experts.

Table 1. Evaluation results of the *EcoChallenge* game quality

Criteria (mapped)	$\bar{x}$	SD	Level
Content accuracy	4.90	0.23	Very High
Instructional design	4.90	0.15	Very High
Usability & interface	4.89	0.33	Very High
Overall	4.90	0.05	Very High

The EcoChallenge game was evaluated by experts, and the evaluation results are presented in Table 1. All dimensions were rated Very High ($\bar{x}$ = 4.89–4.90) with low variability (SD = 0.05–0.33), indicating strong, consistent perceived quality and clear classroom readiness.

B. System Implementation and User Interface

The system was implemented on a multimedia platform that supported interactive challenges, scoring, and real-time feedback.

As shown in Fig. 2, the user flow starts from sign-in and profile setup, proceeds to learning objectives and guidance, then lessons and units, followed by assessment and the scoring system.

The screenshot in Fig. 3 displays the main game interface, showing navigation menus, mission instructions, and feedback mechanisms, reflecting user-friendly design and ease of use.

Fig. 2. User flow of *EcoChallenge*.

Fig. 3. Screenshot of the *EcoChallenge* user interface.

C. Students' Learning Achievement

Students' pre-test and post-test scores were compared to evaluating the effect of *EcoChallenge* on academic performance. Table 2 demonstrates that students' post-test scores were significantly higher than their pre-test scores at the 0.01 level, indicating the effectiveness of the game in enhancing knowledge.

Table 2. Comparison of students' pre-test and post-test achievement scores

Test	Mean	SD	t	Sig. (p)	Cohen's d
Pre-test	12.35	3.12	$t(34) = -8.523^{**}$	< 0.001	1.35
Post-test	17.85	1.97			

Note: ** $p < 0.01$ indicates statistical significance at the 0.01 level.

D. Environmental Citizenship Skills

The intervention's impact on environmental citizenship was assessed across three domains: knowledge, attitudes, and behaviors.

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behaviors, as detailed in Table 3, indicating that the game successfully enhanced students' environmental citizenship competencies.

Table 3. Pre- and post-test results of environmental citizenship skills

Skills	Pre-test Mean	Post-test Mean	SD	$t(34)$	Sig. (p)	Cohen's d
Knowledge	65.40	82.15	4.21	−7.112	< 0.001	1.20
Attitudes	66.85	84.75	3.98	−8.025	< 0.001	1.38
Behaviors	64.75	83.40	4.35	−7.844	< 0.001	1.33

The results confirm statistically significant improvements in all three domains, indicating that the game successfully enhanced students' environmental citizenship competencies. To visualize these gains, Fig. 4 presents a comparison of pre-test and post-test mean scores across all measured domains. The bar chart clearly demonstrates consistent improvements in learning achievement and environmental citizenship skills following the *EcoChallenge* intervention.

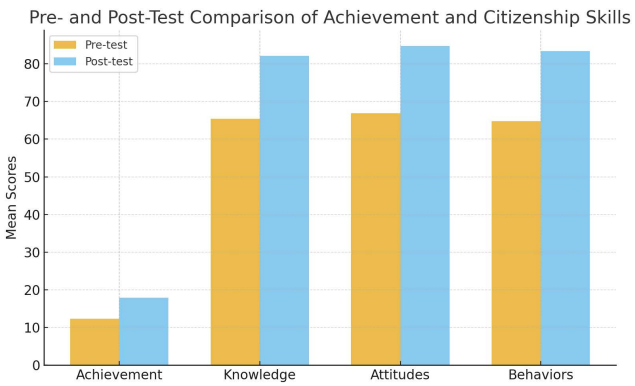

Fig. 4. Comparison of pre- and post-test mean scores for learning achievement and environmental citizenship skills.

E. Correlation Analysis and Students' Satisfaction

A Pearson correlation analysis was conducted to examine the relationship between students' learning achievement and their environmental citizenship skills. A significant positive correlation was found between learning achievement and environmental citizenship skills ($r = 0.608$, $p < 0.001$).

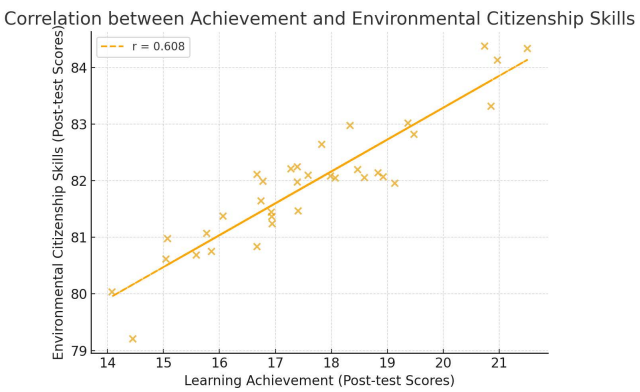

Fig. 5. Scatterplot illustrating the correlation between learning achievement and environmental citizenship skills.

To further illustrate this relationship, Fig. 5 shows the scatterplot of learning achievement and environmental citizenship skills. The upward trend line ($r = 0.608$) confirms a moderate positive association between the two constructions.

Table 4 presents the results of the satisfaction survey, showing that students reported very high satisfaction across enjoyment, motivation, and usability. These results complement the correlation analysis, as higher satisfaction is likely to contribute to both improved achievement and stronger environmental citizenship skills.

Methodologically, integrating the AI-augmented CRAFT framework strengthened instrument-outcome alignment and improved efficiency during preparation and evaluation, echoing prior evidence on CRAFT-supported research processes [17].

Table 4. Students' satisfaction levels with the *EcoChallenge* game

Aspect	Mean	SD	Level
Content	4.90	0.23	Very High
Media	4.90	0.15	Very High
Application of Knowledge	4.91	0.15	Very High
Use of Technology in Learning	4.89	0.33	Very High
Overall	4.90	0.05	Very High

V. Discussion

Theoretically, this study demonstrates how digital games can operate constructivist learning within GCE and ESD frameworks. Practically, educators should integrate similar games into curricula to develop environmental citizenship. These findings are consistent with prior research indicating that well-designed educational games can promote both cognitive and affective learning outcomes related to environmental education [73–75]. A significant positive association was observed between students' learning achievement and environmental citizenship skills ($r = 0.608$, $p < 0.001$). Students who attained higher academic scores also tended to demonstrate stronger environmental citizenship competencies. This reflects an associative rather than a causal relationship between cognitive achievement and pro-environmental behaviors. Beyond confirming prior findings on game-based learning, this study offers several novel contributions to GBL and ESD literature [76]. First, *EcoChallenge* integrates Global Citizenship Education (GCE), Education for Sustainable Development (ESD), and game-based learning into a single, theory-driven model specifically designed for elementary learners, whereas most previous studies examined these domains separately or focused on secondary and higher education contexts. Second, by targeting not only knowledge but also environmental attitudes and self-reported behaviors, the study extends existing GBL research that has predominantly emphasized cognitive outcomes. Third, the use of the AI-augmented CRAFT framework to align instruments with GCE/ESD constructs demonstrates a systematic approach to designing and validating measures for environmental citizenship. Together, these contributions advance theoretical understanding of how digital games can operationalize citizenship-oriented sustainability education for young learners.

The application of the CRAFT framework strengthened the research process by enhancing the quality of instrument development and overall efficiency. CRAFT helped ensure alignment between the GCE/ESD constructs and the assessment indicators, reduced redundancy among items, and streamlined workflow during instrument validation. These outcomes reinforce the framework's value in supporting rigorous and AI-augmented educational research design [17].

Successful implementation of *EcoChallenge* also depends on teacher facilitation and the availability of digital

infrastructure. Teachers play a crucial role in guiding student reflection and ensuring appropriate use of the platform. Moreover, access to stable internet, adequate devices, and digital literacy support are necessary conditions for sustainable adoption of game-based learning in schools. Although the findings provide promising evidence of the effectiveness of the *EcoChallenge* game, several limitations should be acknowledged. The small sample size (n = 35) restricts generalizability, and the six-week intervention period may not capture long-term behavioral changes. Furthermore, the non-random quasi-experimental design limits causal inference, as class sections were pre-assigned rather than randomly allocated. Potential researcher bias arising from the authors' involvement in the game design was minimized through expert review and ethical oversight. Future studies should address these limitations by expanding the sample size, extending intervention duration, and employing randomized designs to strengthen internal validity.

VI. Conclusion

This study examined the effects of *EcoChallenge*, an online game-based learning intervention, on Grade 6 students' environmental citizenship. The findings show substantial and statistically significant gains in learning achievement as well as in knowledge, attitudes, and self-reported behaviors related to environmental citizenship among students who participated in the game. In addition, students reported very high levels of satisfaction with the content, usability, and motivational aspects of the platform. A positive association between achievement and environmental citizenship skills further suggests that cognitive growth and pro-environmental competencies developed in tandem during the intervention.

These results indicate that a carefully designed, theory-informed digital game can serve as an effective vehicle for promoting environmental citizenship among young learners. For practice, schools and teachers may consider integrating similar game-based tools into science and social studies curricula, using them as structured supplements to existing lessons on waste management, sustainability, and global responsibility. Teacher facilitation remains essential, particularly in guiding reflection and helping students connect in-game experiences to real-world environmental actions.

Despite these promising results, the study has several limitations. The relatively small sample size (n = 35) and the use of a quasi-experimental design restrict the generalizability of the findings and limit causal inference. The six-week intervention period may also be insufficient to capture long-term changes in environmental behaviors. Furthermore, the authors' direct involvement in game design may introduce potential bias, even though expert review and ethical oversight were used to mitigate this risk.

Future research should therefore replicate and extend this work with larger and more diverse samples across multiple schools, as well as employ randomized designs and longer-term follow-up studies. Additional studies could also explore how teacher professional development, family involvement, and community-based activities might amplify the impact of game-based environmental citizenship interventions such as *EcoChallenge*.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

K.T. was responsible for conducting the research, including data collection, data analysis, and implementation of the research procedures. S.D. contributed substantially to the conceptual development, research design, methodology, interpretation of results, and was responsible for the complete preparation, revision, and submission of the manuscript through to publication. T.J. contributed to methodological consultation, academic guidance, and critical review of the study. T.J. assisted in data management and provided review and feedback on the manuscript. All authors worked collaboratively as a research team, read, and approved the final version of the manuscript.

Acknowledgment

We would like to express our sincere thanks to the special experts and other people for their suggestions and all their help with our research. Including King Mongkut's University of Technology North Bangkok, Thailand.

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