Enhancing Undergraduate Students' Understanding of Environmental Concepts through Digital Learning Materials

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***Abstract*—Misconceptions hinder effective environmental education. This action research examined the conceptual understanding of five key environmental topics—climate change, the greenhouse effect, global warming, the carbon cycle, and ozone depletion—among 290 Science, Technology, and Society (STS) students across four campuses of Aklan State University in the Philippines. Employing a one-group quasi-experimental pretest–intervention–posttest design, data were collected through a validated 30-item Concept Test on Climate Change (CTCC) administered online via Google Forms. A digital Learning Material (dLM) served as the intervention. Statistical analyses, including descriptive and inferential statistics, were conducted using Jamovi software. Results revealed that students performed best on items related to ozone depletion, while their understanding of the carbon cycle was the weakest. No significant differences in scores were found by sex; however, significant differences emerged across academic strands. Importantly, post-test results showed a substantial improvement in students' conceptual understanding after the intervention. The study recommends diversifying technology-supported teaching strategies and strengthening environmental advocacy programs in higher education to foster deeper environmental literacy among 21st-century learners.**

***Keywords*—climate change, conceptual understanding, digital learning material, environmental education, inquiry-based learning**

I. Introduction

Escalating environmental challenges such as climate change, global warming, and ozone depletion underscore the urgency of strengthening environmental education. Such education equips students with the capacity to make informed and responsible decisions in addressing ecological problems. At the tertiary level, general education courses such as Science, Technology, and Society (STS) serve as essential venues for cultivating environmental literacy among undergraduates. However, research indicates that while students often express concern about environmental issues, they frequently hold misconceptions about key concepts such as the greenhouse effect, the carbon cycle, and climate change [1, 2]. This gap between awareness and conceptual accuracy underscores the need for teaching approaches that extend beyond rote memorization to foster a more profound, more comprehensive understanding.

Although environmental themes are increasingly integrated into the Philippine general education curriculum, studies on students' initial conceptions of these topics remain limited. Furthermore, interventions employing locally developed, digitally mediated learning materials tailored to these conceptual gaps are rare. International evidence suggests that well-designed digital tools—such as interactive modules, multimedia assessments, and self-paced quizzes—can improve student engagement and comprehension [3, 4]. However, their impact within Philippine state universities, particularly in STS classrooms, has yet to be systematically evaluated. Moreover, demographic variables such as sex and academic strand, which have been shown to influence environmental attitudes and learning outcomes [5, 6], are often neglected in local research

This study addresses these gaps by examining STS students' conceptual understanding of five critical environmental topics: climate change, the greenhouse effect, global warming, the carbon cycle, and ozone depletion. Specifically, the research seeks to: (1) identify students' initial conceptions; (2) determine the effectiveness of digital learning materials in enhancing understanding; and (3) assess whether conceptual change differs by sex and academic strand.

This study is significant in several respects. It generates empirical evidence on the prevalence of misconceptions in a Philippine tertiary context, evaluates a targeted digital intervention, and explores demographic factors that may shape learning outcomes. In doing so, it contributes to the development of inclusive and evidence-based instructional strategies in environmental education. Furthermore, the study aligns with national educational reforms and global sustainability priorities, specifically Sustainable Development Goals (SDGs) 4 (Quality Education) and 13 (Climate Action).

The motivation behind this research stems from the need to bridge the gap between environmental awareness and understanding among Filipino college students. While policy initiatives have mandated ecological education, there is a lack of empirical data on what students actually understand, how their misconceptions form, and which teaching methods most effectively address them. This study responds to that need by testing a contextually relevant digital intervention in an actual classroom setting.

To guide readers, the article proceeds as follows. The next section reviews literature on students' environmental conceptions and digital instructional strategies. The methodology section outlines the research design, participants, and instruments employed. Results are then presented, followed by a discussion interpreting the findings in relation to prior research. The article concludes with implications for teaching practice, policy recommendations, and directions for future inquiry.

II. Literature Review

A. Environmental Education and Global Relevance

In today's world, environmental concerns such as climate change, global warming, and ozone depletion pose escalating threats that demand collective awareness and informed action. Environmental Education (EE) plays a vital role in developing environmentally responsible citizens who are capable of addressing pressing ecological challenges. Its primary goal is to cultivate awareness, knowledge, and practical skills that empower individuals to make informed decisions and take proactive steps toward sustainability (UNESCO, 2014). EE also contributes significantly to achieving global targets, such as Sustainable Development Goals (SDGs) 4 on Quality Education and 13 on Climate Action. A good education equips students with the skills to help combat the challenges posed by environmental change. If education is to contribute to addressing current challenges, improvements must be made to ensure graduates are well-equipped to do so. Curricular content, teaching materials, and delivery methods should be structured to provide students with the essential skills and knowledge needed to address global challenges.

In the Philippine context, the Commission on Higher Education (CHED) mandates the integration of climate change education into tertiary curricula through CMO No. 20, series of 2013 [7]. This directive requires the inclusion of environmental topics within the Science, Technology, and Society (STS) course for all first-year college students. Integrating environmental concepts into the STS curriculum enables students to grasp complex scientific phenomena and understand their real-world implications. This approach is particularly relevant in the Philippines, where the country's geographic and climatic conditions make it highly vulnerable to natural disasters. Strengthening environmental literacy through education is thus a national imperative to promote resilience and adaptive strategies [8].

B. Conceptual Understanding

Conceptual understanding is central to environmental education, as it enables students to comprehend complex interactions among natural systems, human activities, and societal structures. Accurate conceptual understanding is not only essential for academic performance but also for making informed choices in climate adaptation and mitigation. Several studies in the Philippines have investigated students' conceptual understanding in Science and Mathematics education [9, 10].

Recent studies have examined how digital instructional materials can enhance students' conceptual understanding, particularly in environmental education. Research using digital modules based on the Science, Environment, Technology, and Society (SETS) framework found significant improvements in both conceptual understanding and critical thinking among students after using these modules on environmental change topics, as demonstrated by pre- and post-test results [11]. Similarly, integrating digital escape room games with e-books in environmental science courses is a highly valid and practical approach, offering engaging experiences that support conceptual learning and critical thinking [12]. Digital games created with Web 2.0 tools have also been effective in increasing students' environmental knowledge, responsible behaviors, and digital literacy, suggesting that interactive digital interventions can foster deeper learning [13]. Overall, the evidence indicates that well-designed digital instructional materials, particularly those that promote higher-order thinking and interactive engagement, can significantly enhance students' conceptual understanding in environmental education.

C. Factors Influencing Conceptual Understanding

Student characteristics such as sex and academic background also influence learning outcomes in environmental education. Although some studies find no significant gender differences, others report that female students exhibit greater concern for environmental issues and are more inclined toward pro-environmental behavior [6]. Nonetheless, after instructional interventions, both male and female students generally benefit equally from effective teaching strategies [14].

Another key factor is academic track. Under the Philippine K–12 system, senior high school students choose from strands such as STEM (Science, Technology, Engineering, and Mathematics), HUMSS (Humanities and Social Sciences), ABM (Accountancy, Business, and Management), GAS (General Academic Strand), and TECHVOC (Technical-Vocational), which vary in content and scientific rigor. Research indicates that students from academic strands, particularly STEM, tend to perform better on environmental literacy and conceptual assessments due to greater exposure to scientific reasoning and critical thinking [15]. Understanding how such demographic variables shape conceptual understanding can inform the development of more inclusive and responsive instructional designs.

D. Inquiry-Based Learning

Instructional pedagogy plays a crucial role in shaping how students acquire and internalize environmental knowledge. Traditional lecture-based approaches, however, are often insufficient for addressing deeply rooted scientific misconceptions. To overcome these limitations, research supports the use of constructivist, interactive, and student-centered teaching methods that promote engagement and facilitate conceptual change [16]. Among these, Inquiry-Based Learning (IBL) has gained wide recognition for encouraging critical thinking and deep understanding through active exploration and problem-solving. IBL is a student-centered approach that promotes questioning, exploration, investigation, and reflection. Rather than passively receiving information, students in this study actively engaged with environmental problems through tasks such as analyzing local climate data, simulating the effects of greenhouse gases, and tracing carbon flows. These inquiry tasks required critical thinking, collaboration, and evidence-based reasoning—skills essential for understanding dynamic scientific processes. According to Bruner's discovery learning theory, such experiences foster deeper cognitive engagement, enabling learners to construct meaning independently rather than merely memorize facts [17].

Recent research frameworks have enhanced IBL by integrating digital assessment tools into instructional practice. Specifically, platforms such as Google Forms are increasingly used to support the phases of IBL—including orientation, hypothesizing, planning, data analysis, and conclusion—while enabling educators to collect and evaluate student performance data in real-time [18, 19]. Systematic reviews further confirm that digital tools, including collaborative platforms and online forms, enrich IBL by fostering scientific literacy, critical thinking, and learner engagement, while also improving accessibility and immediacy of assessment [20, 21]. The Inquiry-Based Learning 2.0 framework advocates blending online and offline inquiry activities with digital assessments to promote flexibility and student-centered learning [22]. Although Google Forms is not always explicitly named, its usage aligns with recommended practices for real-time, embedded assessment to support ongoing inquiry learning [23]. Collectively, these studies highlight the potential of integrating IBL with digital assessment platforms to improve both learning outcomes and instructional efficiency in digital learning environments.

Complementing these frameworks, several studies have adopted a one-group pretest–digital intervention–posttest design to assess the impact of inquiry-based instruction in environmental education. For example, Solomo and Solomo [24] implemented Inquiry-Based Online Learning (IBOL) modules in a graduate-level environmental chemistry course. They reported significant gains in students' academic performance, cognitive skill development, and environmental responsibility. While students also encountered challenges related to technology use and coordination of community-based research, the intervention improved autonomy and conceptual application. Similar findings have emerged in related research on IBL and digital tools, demonstrating their capacity to cultivate pro-environmental behaviors, critical thinking, and action competence, even when different experimental designs are employed [25, 26]. Overall, the literature supports the effectiveness of digital, inquiry-based interventions in promoting meaningful learning and engagement in environmental education contexts.

The literature emphasizes the crucial importance of cultivating in-depth conceptual understanding in environmental science education. It emphasizes the need to address common misconceptions related to climate change, greenhouse effect, global warming, carbon cycle, and ozone depletion through learner-centered and technology-enhanced instruction.

Previous studies have confirmed that demographic variables, such as sex and academic track, can influence students' learning outcomes. However, findings remain inconclusive, especially after targeted instruction. Moreover, while digital tools like Google Forms are increasingly being used in classrooms, limited research has been done on their specific impact on environmental concept mastery, particularly in higher education institutions in the Philippines.

Although Inquiry-Based Learning (IBL) has been widely recognized and applied to improve science instruction, limited research has focused on its implementation within Science, Technology, and Society (STS) courses in state universities—particularly in multi-campus institutions such as Aklan State University. Given the diverse backgrounds of students enrolled in these programs, there is a pressing need to explore how they respond to digital instructional interventions and whether such tools effectively address conceptual gaps in environmental education. Despite growing interest in ecological literacy, no study to date in the Philippine context has specifically examined the conceptual understanding of STS college students concerning key environmental topics.

III. Methodology

A. Type of Research

This study employed the Plan-Do-Study-Act (PDSA) Action Research model employing the pretest-intervention-posttest design. The PDSA cycle, as illustrated in Fig. 1, is a framework for testing instructional strategies that encompasses planning, implementation, observation of outcomes, and adjustments based on the findings. This action research consists of two phases: Phase I—Development and validation of the digital Learning Material (dLM), and Phase II—Implementation of the dLM as an intervention and evaluation of its effects.

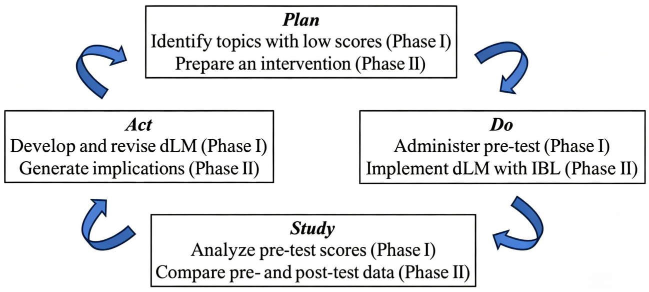

Fig. 1. PDSA action research framework.

1) Phase I: Development and validation of the digital learning material

Plan: The study began by identifying environmental topics that STS students struggled with, as indicated by their low quiz scores. Ethical approvals and coordination with the academic affairs office ensured compliance with institutional standards and regulations.

Do: The validated 30-item Concept Test on Climate Change (CTCC) was converted to Google Forms and distributed to professors teaching STS courses across four ASU campuses. Data gathered from this pre-test established baseline scores.

Study: Descriptive statistics of the pre-test scores were analyzed to determine the students' initial understanding of five key concepts: climate change, global warming, ozone depletion, greenhouse effect, and carbon cycle.

Act: Based on the analysis, a digital learning material (dLM) was developed to emphasize the most challenging concepts. The dLM was evaluated by the campus instructional materials committee and revised according to feedback.

2) Phase II: Implementation of the digital learning material

Plan: Coordination with professors, student assent, and ethics approval preceded the intervention. Revisions to the dLM based on committee feedback were finalized at this stage.

Do: The dLM was deployed online through Google Forms and accessed asynchronously by students within one week. It was structured around a five-phase Inquiry-Based Learning (IBL) cycle: students were first engaged with real-world scenarios, then explored data-driven tasks, explained their reasoning with automated feedback, elaborated through case-based applications, and finally evaluated through pre- and post-tests with reflection prompts. This design ensured that the intervention was student-centered, inquiry-driven, and supported by the interactive features of Google Forms.

Study: Data analysis was conducted using the Jamovi statistical tool, employing descriptive statistics, paired-samples t-tests, independent-samples t-tests, homogeneity tests, normality tests, one-way ANOVAs, and post hoc comparisons.

Act: Findings were synthesized to generate instructional and policy implications.

B. Research Subject

The study involved 290 students enrolled in the STS course from four Aklan State University (ASU) campuses (Banga, Ibajay, Kalibo, and New Washington). Inclusion criteria were: (1) official enrollment in the STS course; and (2) completion of the pre-test, digital LM, and post-test.

C. Research Instruments

Two research instruments were used in the study. (1) Concept Test on Climate Change (CTCC): A 30-item adopted instrument measuring conceptual understanding of five environmental topics (six items per concept) [27]. Administered as both a pre-test and a post-test. (2) digital Learning Material (dLM): The dLM served as the core intervention tool. It comprised 12 interactive pages, each with concise explanations, visuals, and guided inquiry questions. The material was developed in Google Forms for easy access and automatic data collection. Each environmental topic (climate change, greenhouse effect, global warming, carbon cycle, ozone depletion) included: short content overviews with embedded visuals, scaffolded questions to stimulate reflection and self-assessment, and links to credible resources for extended learning. The dLM underwent pilot testing with Environmental Science students and was evaluated by the campus instructional materials committee for accuracy, clarity, and instructional quality. Revisions were made before its deployment to STS students.

IV. Result and Discussion

This study examined college students' conceptual understanding of five environmental concepts—climate change, global warming, ozone depletion, the greenhouse effect, and the carbon cycle—and found a statistically significant improvement following an Inquiry-Based digital Learning (IBL) intervention. This indicates that integrating inquiry-driven tasks into digital formats can strengthen students' understanding of complex environmental issues.

A. Respondent Profile

Table 1 presents the demographic profile of the 290 respondents. Most participants were female (69%), with males representing 31%. The largest age group was 19-year-olds (56.2%), followed by 20-year-olds (29.7%) and 18-year-olds (8.9%), indicating a relatively young, homogeneous undergraduate population.

In terms of degree programs, respondents were most frequently enrolled in a Bachelor of Science (BS) in Hospitality Management (29.7%), a BS in Information Technology (21.7%), and a BS in Nursing (18.6%), with smaller numbers from other programs. Regarding campus affiliation, the most significant proportion came from Kalibo Campus (40%), followed by Banga (33.4%), Ibajay (22.1%), and New Washington (4.5%).

This demographic distribution suggests the intervention reached a diverse range of degree programs but was concentrated among younger, female students. The mix of programs and campuses also indicates the material's broad applicability across different disciplines within Aklan State University.

Table 1. Demographic profile of respondents (n = 290)

Profile	Demographics	Frequency	Percentage
Sex	Male	90	31.0
	Female	200	69.0
Age	18	26	8.9
	19	163	56.2
	20	86	29.7
	>20	15	5.2
Degree Program	BS Business Administration	36	12.4
	BS Criminology	10	3.4
	BS Computer Science	19	6.6
	BS Hospitality Management	86	29.7
	BS Information Technology	63	21.7
	BS Nursing	54	18.6
	BS Public Administration	7	2.4
	BS Tourism Management	15	5.2
Campus	Banga	97	33.4
	Ibajay	64	22.1
	Kalibo	116	40.0
	New Washington	13	4.5

B. Initial Understanding of Environmental Concepts among STS Students

Descriptive statistics were used to examine the respondents' initial understanding of environmental concepts. Table 2 presents the mean scores of students across the five topics, with each mean representing the average points earned (out of six) on a given concept. Scores were interpreted using the following scale: 0–1.20 = Poor; 1.21–2.40 = Below Average; 2.41–3.60 = Average; 3.61–4.80 = Above Average; 4.81–6.00 = Outstanding.

Table 2. Initial conceptual understanding of STS students

Concepts	Mean, (n = 290)	Interpretation
Climate Change	3.02	Average
Greenhouse Effect	2.80	Average
Global Warming	3.30	Average
Carbon Cycle	2.00	Below Average
Ozone Depletion	3.61	Above Average

Interpretation: 0–1.20 Poor; 1.21–2.40 Below Average; 2.41–3.60 Average; 3.61–4.80 Above Average; 4.81–6.00 Outstanding.

As shown in Table 2, the CSTS students demonstrated the strongest prior knowledge on ozone depletion (M = 3.61), which falls into the "Above Average" range. This finding aligns with previous research showing that college students have a better understanding of ozone depletion compared to other environmental topics [28]. Previous studies have highlighted the dangers of ozone-depleting substances, particularly Chlorofluorocarbons (CFCs), and their connection to health risks, including skin cancer, which are widely emphasized in curricula and public campaigns [29, 30]. These exposures may explain students' higher baseline understanding.

In contrast, students exhibited the lowest conceptual understanding of the carbon cycle (M = 2.00), interpreted as "Below Average". This finding aligns with prior research showing that misconceptions about the carbon cycle persist even among advanced learners. For example, studies have reported that only about half of students in chemistry education can demonstrate accurate comprehension, while the rest display partial or incorrect ideas [31]. The carbon cycle is an abstract and systems-based concept that requires integrating multiple scientific processes, making it harder to grasp through memorization alone. This knowledge gap highlights the need for stronger instructional emphasis and targeted interventions to clarify students' conceptual frameworks.

Meanwhile, students' understanding of global warming (M = 3.30), climate change (M = 3.02), and the greenhouse effect (M = 2.80) was rated as "Average." These results suggest that, although students had some prior exposure to these concepts, their knowledge remained moderate, leaving room for misconceptions and incomplete reasoning. This is important because these topics are highly interrelated; gaps in one area can hinder a holistic understanding of environmental systems.

Overall, the descriptive analysis highlights a differentiated baseline knowledge profile, characterized by relatively higher familiarity with ozone depletion, a moderate grasp of climate-related issues, and weaker comprehension of the carbon cycle. These findings provide a foundation for assessing the effectiveness of the instructional intervention and signal which concepts require more focused pedagogical support.

C. Difference in the Conceptual Understanding of Students after the Intervention

To analyze differences in students' understanding after the intervention, a paired-samples t-test was employed. Results revealed a statistically significant difference between students' pre-test and post-test scores, $t(289) = -17.6$, $p < 0.001$. The negative t-value shows that post-test scores exceed pre-test scores by a significant margin, demonstrating a substantial improvement in performance after the intervention, despite measurement limitations. A p-value below 0.001 indicates that the difference is unlikely to have occurred by chance, strongly supporting the reliability of the finding. In practical terms, this result demonstrates that the instructional intervention effectively enhanced students' conceptual understanding. The magnitude of the improvement suggests that the intervention not only produced statistically significant results but also had a meaningful educational impact on student learning outcomes.

The effectiveness of this method is consistent with findings from science education research, which has shown that inquiry learning can deepen conceptual understanding [16, 32, 33]. In the Philippine context, this approach aligns well with the Department of Education's K-12 curriculum and CHED's general education reforms, both of which emphasize outcomes-based education and science. Local studies further validate this: for instance, Verangel & Prudente [9] found that IBL improved conceptual mastery in balancing chemical equations among senior high school students in the Philippines.

D. Difference in Conceptual Understanding among STS Students in Terms of Sex

To examine whether students' conceptual understanding differed by sex, an independent-samples t-test was conducted in Jamovi. Male and female students showed no statistically significant difference in gains in conceptual understanding, $t(288) = 0.913$, $p = 0.362$. Since the p-value exceeds the conventional threshold of 0.05, the observed differences in average scores are likely due to random variation rather than systematic gender effects. In other words, both male and female students showed statistically comparable improvements after the intervention.

This result suggests that the variable sex did not influence students' learning gains**.** The intervention was equally effective for both groups, reinforcing the principle of inclusive instructional design. Educational interventions such as digital assessments and inquiry-based strategies can therefore be applied broadly without the need for gender-specific modifications.

The finding is consistent with prior studies, which report that sex is generally not a significant predictor of environmental understanding following structured instruction [6, 14]. While minor variations between males and females may occur, earlier research indicates these differences are inconsistent and usually negligible [34]. Together, these results emphasize that instructional quality, rather than demographic factors such as sex, is the key determinant of improved conceptual understanding.

E. Difference in Conceptual Understanding by Academic Strand

Before the primary analyses, assumption checks were performed. Levene's test confirmed that the variances were homogeneous, $F(5, 284) = 1.06$, $p = 0.381$. Since the p-value is greater than 0.05, the variability across groups is comparable, allowing for a fair comparison of group means.

However, the Shapiro–Wilk test of normality was significant ($W = 0.986$, $p = 0.006$), indicating that the distribution of scores deviated slightly from normality. While this suggests unevenness in the data, the large sample size ($n = 290$) mitigates concerns, and a nonparametric test was conducted alongside parametric procedures to ensure robustness.

To further examine group differences across strands, a Kruskal–Wallis test was conducted. The analysis yielded a significant result, $\chi^2(5) = 17.6$, $p = 0.003$, suggesting that conceptual understanding varied significantly across academic strands. This means not all strands benefited equally from the intervention, highlighting the role of students' educational backgrounds in shaping learning outcomes.

This finding aligns with research by Chao [15], who discovered that academic-track students in Taiwan demonstrated stronger environmental knowledge and pro-environmental behavior, likely due to differences in curriculum design and socioeconomic status. Vocational tracks, while increasingly integrating sustainability topics, often emphasize practical skills over conceptual depth, which may affect students' ability to engage in transformative environmental learning [35]. Therefore, the academic strand type does matter for post-test outcomes in the study. Similarly, the academic strand of the students significantly influences how well they performed after using the developed instructional material on environmental topics. Thus, prior specialization may be a significant factor affecting performance in this context. These findings underscore the value of the developed inquiry-based educational materials, which bridge academic differences and promote environmental awareness among students.

Post-hoc comparisons using the Dwass-Steel-Critchlow-Fligner test were performed to determine which strands differed. Results are displayed in Table 3, where a significant difference emerged between GAS and Technical Vocational (TECHVOC) students ($W = -5.18$, $p = 0.003$). Specifically, GAS students showed greater gains in conceptual understanding than TECHVOC students. No other pairwise differences were statistically significant. This suggests that while the intervention was generally effective, its impact was not uniform across strands, with TECHVOC students potentially requiring more targeted support to maximize learning.

Table 3. Dwass-Steel-Critchlow-Fligner post-hoc comparisons

Strand	Strand	*W*	*p*
ABM	GAS	2.5171	0.479
ABM	HUMSS	2.3731	0.547
ABM	STEM	0.6046	0.998
ABM	TECHVOC	−1.1881	0.960
ABM	Others	0.5186	0.999
GAS	HUMSS	0.8290	0.992
GAS	STEM	−2.0966	0.676
GAS	TECHVOC	−5.1837	0.003
GAS	Others	−1.1101	0.970
HUMSS	STEM	−2.1415	0.655
HUMSS	TECHVOC	−3.7249	0.089
HUMSS	Others	−1.4544	0.909
STEM	TECHVOC	−2.5351	0.471
STEM	Others	0.0966	1.000
TECHVOC	Others	1.4821	0.902

The findings confirm that the intervention successfully enhanced students' conceptual understanding of environmental concepts; however, its effectiveness varied across different strands. These results underscore the importance of tailoring instructional strategies to meet students' diverse needs. The use of Google Forms not only provided an effective platform for engagement and assessment but also contributed to differentiated instruction, aligning with the goals of equity and inclusivity in education.

This study underscores several key implications for educational leaders and policymakers in strengthening environmental education. First, the significant post-test gains highlight the value of adopting Inquiry-Based Digital Learning (IBL), with tools such as Google Forms providing scalable, effective means to enhance conceptual understanding. Second, because sex did not influence learning gains, instructional interventions can be applied broadly, reinforcing the importance of inclusive approaches that provide equitable opportunities for all learners. Third, the variation in outcomes across academic strands points to the need for differentiated support, particularly for technical-vocational students who may benefit from additional scaffolding and tailored strategies. Fourth, persistent misconceptions—especially regarding the carbon cycle—call for stronger teacher training and curricular emphasis on complex, systems-based environmental concepts. Finally, by advancing environmental knowledge, higher education institutions contribute directly to Sustainable Development Goals (SDG 4: Quality Education and SDG 13: Climate Action), ensuring that instructional design promotes both equity and global sustainability. Overall, the findings affirm that well-designed, inquiry-based, and digitally supported instruction is the driving force behind learning success, rather than demographic factors.

Although the study provides valuable insights, it is important to recognize several limitations. First, the participants were 290 students from a single state university, which may limit the applicability of the findings to other settings or institutions. Second, the measurement of conceptual understanding relied on pre- and post-test instruments administered through Google Forms. Although this digital platform facilitated efficient data collection, it may not have fully captured deeper reasoning or long-term retention. Finally, demographic variables such as socio-economic background, prior academic performance, or access to technology were not considered, which may also influence learning outcomes.

V. Conclusion

In summary, this study showed that inquiry-based digital learning led to significant improvements in college students' conceptual understanding of key environmental topics, with the most critical gains observed in climate-related concepts and the weakest baseline knowledge in the carbon cycle. The results further revealed that sex did not influence learning gains, underscoring the intervention's inclusivity. In contrast, the academic strand emerged as a meaningful factor, suggesting the need for differentiated instructional support. These findings highlight that effective teaching strategies—particularly inquiry-driven, digitally supported approaches—can bridge learning gaps and foster a deeper understanding of environmental literacy. Beyond classroom practice, the study highlights the role of higher education in advancing sustainability goals by providing students with the knowledge and skills needed to address urgent environmental issues.

Future studies should explore how different inquiry-based digital learning strategies can be further refined and adapted to address specific conceptual gaps, such as students' persistent difficulties with the carbon cycle and other systems-based topics. Comparative research across instructional approaches—such as gamified learning, blended learning, or collaborative digital tasks—may reveal which strategies are most effective in promoting long-term conceptual change. Additionally, longitudinal studies are needed to assess the sustained impact of digital inquiry-based interventions on environmental literacy and to determine how these methods can be systematically integrated into curricula across academic strands. Expanding research in this direction will not only strengthen the evidence base for effective teaching strategies but also guide the development of more inclusive and responsive instructional designs.

Conflict of Interest

The author declares no conflict of interest.

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