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Sustainability-Integrated Ecology Lessons: Effects on Students' Conceptual Understanding, Attitudes and Perceptions Toward Sustainable Development

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ABSTRACT

Purpose of the study: This study investigated the impact of sustainability-integrated lessons in ecology on Grade 11 students' conceptual understanding, attitudes, and perceptions toward sustainable development.

Methodology: An explanatory sequential mixed-methods design was employed, involving quantitative data collection followed by qualitative exploration. A purposive sampling technique was used to select one intact class of 38 Grade 11 students, ensuring that both male and female students were represented. Pre- and post-tests assessed students' conceptual understanding, while attitude scales measured shifts in sustainability attitudes. Qualitative data, gathered from student-written journals, provided insights into personal reflections and behavioral intentions.

Main Findings: Results demonstrated significant ($p<0.001$) gains in students' conceptual understanding and attitudes toward sustainability, regardless of gender. Qualitative analysis revealed students' increased sense of personal responsibility, community involvement, and environmental awareness.

Novelty/Originality of this study: The present study addresses a gap in the local curriculum by investigating the impact of lessons that integrate sustainability principles into ecology education. The study findings underscore the value of embedding sustainability concepts in ecology education through active and experiential learning, fostering knowledge, positive attitudes, and a commitment to sustainable practices among students, empowering them to be proactive environmental stewards in their communities.

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1. INTRODUCTION

In 2015, the United Nations adopted the 2030 Sustainable Development Framework, emphasizing the critical role of education in fostering a sustainable future [1]. Education for Sustainable Development (ESD) has emerged as a transformative approach to instill the knowledge, skills, and values necessary for addressing complex global challenges such as environmental degradation, resource scarcity, and climate change [2], [3]. Recent research highlights that effective ESD not only deepens students' understanding but also promotes action competence, a key element in enabling learners to apply and embody sustainability principles in real-world contexts [4]-[6].

A recent study by Olsson et al. [7] highlights the impact of ESD on developing students' action competence for sustainability, defined as the skills, confidence, and motivation to make sustainable choices, empowering themselves as catalysts for a sustainable future. Their findings indicate that sustained ESD interventions can foster significant growth in students' self-perceived action competence, though improvements in certain components, such as confidence, may require extended exposure and reinforcement. This underscores the importance of embedding ESD consistently within formal education to support gradual, long-term development of students' capability to take meaningful, sustainable actions [8]-[11]. Furthermore, studies have documented that action competence is closely tied to students' ability to connect theoretical knowledge with practical, real-world applications, demonstrating that the integration of ESD into curricula fosters an interdisciplinary approach to learning [12]-[14].

Despite strong global support for ESD, sustainability concepts in many educational curricula remain insufficiently integrated, particularly in local, context-specific ways that can enhance students' engagement and relevance [15], [16]. In the Philippines, for instance, the Department of Education (DepEd) has implemented sustainable development programs like the Youth for Environment in Schools (YES) organization and ecological solid waste management initiatives [17], [18]. However, limited emphasis has been placed on developing concrete knowledge, attitudes, and competencies through these initiatives. This lack of focus presents a significant barrier to achieving the goals of ESD, as students require both theoretical knowledge and practical tools to develop as agents of sustainable change. Given the pivotal role of Grade 11 learners [19]-[21] in shaping future environmental and societal outcomes, this study provides a localized perspective, ensuring cultural and contextual relevance contrasting prior studies that often emphasize broad or global approaches [22]. The present study focuses on contextualized lesson design that resonates with the unique challenges and opportunities faced by Filipino learners. This is to ensure that students not only learn about sustainability but also see its relevance to their immediate environments and communities [23].

The escalating threats posed by environmental degradation, resource scarcity, and climate change [24] paved way for the conceptualization of this study. With the Philippines being one of the countries most vulnerable to these challenges [25], [26], equipping students with the skills and knowledge to address sustainability issues is critical [27]. This study's focus on Grade 11 students aligns with their developmental stage, a time when learners are forming the values and competencies that will influence their future actions. By addressing this critical juncture, the study seeks to lay a foundation for long-term, systemic change in sustainability education involving Filipino learners.

In general, this study aims to evaluate the effects of developed lessons in ecology by Cajurao [28] that integrate sustainable development concepts on Grade 11 students' conceptual understanding, attitudes, and perceptions of sustainable development. It seeks to determine the effectiveness of these lessons in improving students' understanding of bio-sustainability concepts and fostering positive attitudes toward sustainable development. Additionally, it examines how students perceive the importance of sustainability principles after engaging with the lessons, providing insights into their readiness to adopt pro-sustainability behaviors.

By focusing on contextualized lesson design, this study contributes to the growing body of ESD literature and provides a model for integrating sustainability concepts into formal education in resource-constrained settings. The findings have implications for curriculum developers, educators, and policymakers aiming to advance sustainability education in the Philippines and beyond. Furthermore, the lessons developed and evaluated through this study offer a scalable approach, with potential for adaptation and implementation in other contexts [42]. This adaptability emphasizes the broader significance of the research, as it provides a template for integrating sustainability concepts in diverse educational settings, fostering a global network of informed, proactive learners equipped to tackle sustainability challenges [29], [30].

2. METHODOLOGY

2.1. Research Design

This study employed an explanatory sequential mixed-methods approach, adopting a pre-experimental one-group pretest/posttest research design and phenomenological investigation to determine the effectiveness of the developed lessons in ecology integrated with sustainability concepts in enhancing students' conceptual understanding and attitudes toward sustainable development [31]. Thematical analysis was carried out to carefully examine and code the students' responses in the journal following the lesson's intervention.

2.2. Study Participants and Sampling Method

The study recruited one intact class of 38 Grade 11 students (16 males and 22 females) from Cabitan National High School, a public secondary school in Masbate, Philippines. This school was chosen as the study site because it represents a typical rural educational setting in the Philippines, where access to sustainability education resources and integration of environmental concepts into the curriculum may be limited. Selecting Grade 11 students aligns with prior research indicating that learners at this level are in a crucial developmental

stage for forming environmental attitudes and understanding complex ecological concepts [20], [21]. These students were purposively selected to participate in a three-week intervention involving sustainability-integrated ecology lessons, aiming to evaluate the potential impact of these lessons within a local and contextually relevant educational environment.

2.3. Research Instruments

Three instruments were developed and employed to gather data: the Ecology and Sustainability Achievement Test (ESAT), the Attitudes toward Sustainable Development Scale (ASDS), and the Student's Written Journal (SWJ).

The Ecology and Sustainability Achievement Test (ESAT), a 60-item multiple-choice test, was designed to assess students' conceptual understanding of core bio-sustainability concepts covered in the lessons. This instrument was developed following a review of relevant literature on ecology and sustainability topics, with items crafted to align with both local and global sustainability competencies. To establish the test's content validity, three subject matter experts in environmental science and education reviewed the items for accuracy, relevance, and alignment with the lesson objectives. The ESAT demonstrated good reliability, with a Kuder-Richardson 21 (KR-21) index of 0.77, which indicates a high level of internal consistency.

The Attitudes toward Sustainable Development Scale (ASDS) is a 20-item Likert-type questionnaire that measures students' attitudes toward sustainable development. This researcher-made scale was used to capture essential attitudinal dimensions that align with the objectives of Education for Sustainable Development (ESD). The ASDS items were evaluated by experts in environmental education to ensure they were contextually and culturally appropriate for high school students in the Philippines. The ASDS obtained a Cronbach's alpha reliability index of 0.78, exceeding the acceptable threshold of 0.70, which confirms the scale's reliability [32].

Lastly, the Student's Written Journal (SWJ) comprised open-ended questions that encouraged students to reflect on their experiences and perceptions following exposure to the lessons. This qualitative instrument allowed for deeper insight into students' personal reflections on sustainability topics and the formation of their attitudes and perceptions. Questions were reviewed by content experts to ensure they were clear, relevant, and open-ended enough to elicit rich qualitative responses.

2.4. Developed Lessons

The five lessons developed by Cajurao [28] were: 1) Ecosystem: The principles within; 2) Biodiversity: Stability in the diversity of life; 3) Biotic potential and environmental resistance: Limiting population growth; 4) Terrestrial and aquatic ecosystems: Interconnectivity in the biosphere; and 5) The ecological footprint: Assessing human environmental impact. A detailed summary of the five developed lessons and the integrated sustainability concepts and prinicples is presented in Table 1.

The five lessons developed concentrate on ecology and sustainable development integration, and each lesson followed the structure recommended by SEAMEO INNOTECH [33]. The lesson structure comprised five salient parts: 1) Lesson objectives; 2) Starter activity; 3) Main lesson content; 4) Suggested class activities, and 5) Plenary. The lesson objectives were anchored on the learning competencies, performance and content standards prescribed in the course curriculum guide of Earth and Life Science subject with the addition of sustainability principles.

2.5. Data Collection

In line with ethical research practices, participants were given an informed consent form at the beginning of the study to ensure their participation was voluntary and that they understood the study's purpose and procedures [34]. A pretest of the ESAT and ASDS was administered to assess students' baseline knowledge of bio-sustainability concepts and their initial attitudes toward sustainable development. Pretesting is essential in educational research as it establishes a baseline against which to measure the effects of an intervention [35].

The instructional intervention comprised five lessons, each delivered during the regular Earth and Life Science classes. The classroom setting provides a naturalistic context that enhances the ecological validity of the findings, as suggested by prior research emphasizing the effectiveness of real-world instructional settings for educational interventions [36]. After each lesson, students completed the SWJ, which captured their reflections and personal insights, a method consistent with Patton [37] approach to gathering qualitative data for understanding participants' personal perspectives.

Upon completing all five lessons, the ESAT and ASDS were re-administered as posttests. Conducting pre- and posttests is a widely recognized method for measuring the impact of an educational intervention, as it allows for a comparison of changes in knowledge and attitudes over time [31], [38]. Collected data were recorded and tabulated in MS Excel for organization and preliminary review, then analyzed in Jamovi, a free statistical software package.

Table 1. Summary of ecology lessons, lesson objectives, integrated sustainability concepts, activities, values and attitudes and evaluation techniques.

Lesson	Objectives	Integrated Sustainability Concepts	Activities	Values and Attitudes	Assessment
Lesson 1 Ecosystem: The Principles Within	1. Define what is meant by ecology and ecosystem. 2. Describe the fundamental principles that govern an ecosystem such as the levels of organization, the flow of energy and recycling of materials in the ecosystem. 3. Imbibe and explain the importance of water conservation and other environmental conservation measures.	Water Conservation	Video Presentation: Water Conservation: Why is it important? Activity 1 What Makes Up Our Ecosystem Assignment: Water Usage Audit	• Appreciate the role of each living organism in maintaining ecological balance • Develop a positive attitude towards the preservation of our finite natural resources such as water.	Activity Worksheets Student's Journal Scoring Rubrics
Lesson 2 Biodiversity: Stability in the Diversity of Life	1. Define what is meant by biodiversity. 2. Explain the role and importance of biodiversity in the ecosystem. 3. Identify major threats to biodiversity brought about by human activities. 4. Think of sustainable ways to address human impacts on biodiversity.	Biodiversity Conservation	Video Presentation: What is biodiversity and why is it important? Activity 2 Human Actions and Biodiversity Reading Assignment: *5 Major Threats To Biodiversity, and How We Can Help Curb Them*	• Appreciate the importance of biodiversity • Develop the willingness to participate in biodiversity conservation activities	Worksheets Write-ups/Reaction paper Scoring Rubrics Student's Journal

Lesson 3 Biotic Potential and Environmental	1. Describe and categorize different biotic potential and environmental resistance that affect population explosion. 2. Plot and predict future population growth. 3. Identify the carrying capacity of the human population on Earth and propose strategies to prevent a population explosion that is greater than the carrying capacity of the planet. 4. Appreciate the importance of responsible parenting and family planning as a way of curbing rapid population growth.	Earth's Carrying capacity Responsible parenthood and Family planning	Activity 3 Future population growth: How much can Earth handle? Research Paper: *Pros and Cons of Reproductive Health Law*	• Learn about the factors that affect Earth's carrying capacity and its role in keeping a balanced and stable ecosystem • Know the importance of responsible parenthood and family planning in averting population explosion • Respect for limits	Activity worksheets Scoring Rubrics Student's Journal
Lesson 4 Terrestrial and Aquatic Ecosystems: Interconnectivity in the Biosphere	1. Identify the different types of terrestrial and aquatic ecosystems and their characteristics. 2. Describe how the different terrestrial and aquatic ecosystems are interlinked with one another. 3. Explain how different man-made activities have affected both terrestrial and aquatic ecosystems.	Interdependency Environmental Justice	Activity 4 Interconnectivity in the Ecosystem Activity 5 Sustainability Issues in Interconnected Ecosystems Research paper	• Cultivate awareness of various man-made activities that have adversely affected our environment and think of sustainable solutions to address them. • Embrace the fact that people are interdependent with nature and other life forms. • Respect for nature	Activity worksheets Scoring Rubrics Short quiz Student's Journal

Lesson 5 The Ecological Footprint	1. Define what is meant by Ecological Footprint and Biocapacity. 2. Compare the Ecological Footprint of different countries. 3. Calculate their own personal Ecological Footprint using an Ecological Footprint calculator. 4. Identify ways in which individuals can reduce their impact on the environment.	Human Ecological Footprint Environmental stewardship	Activity 6 How much Earth do we have? Video presentation: Ecological footprint: Do we fit on our planet? Activity 7 How BIG is your Footprint? Activity 8 Ecological Footprint of the ASEAN Nations	• Develop a strong sense of consciousness of humans' ecological impact on the ecosystem that affects the planet • Appreciate the importance and meaning of knowing our own Ecological Footprint. • Be able to think of small yet sustainable and working strategies for reducing one's impact on the environment	Activity worksheets Student's Journal Scoring rubrics

2.6. Data Analysis

Mean scores and the Mean Percentage Score (MPS) interpreted as the Performance Level (%) were used to assess the level of students' conceptual understanding based on the results of the pretest and posttest. A weighted mean was calculated to determine the students' attitude level and was interpreted using the scale below:

Table 2. Student attitude level scale

Scale	Attitude Level
4.50-5.00	Highly positive
3.50-4.49	Positive
2.50-3.49	Neutral
1.50-2.49	Negative
1.00-1.49	Highly negative

The normality of the data was tested using the Shapiro-Wilk test, and Levene's test was used for the homogeneity of variances. Since the data was found to be normally distributed, parametric tests such as the paired and independent samples t-tests were employed to determine if there was a significant difference between the pretest and posttest results of female and male students from the ESAT and ASDS. The level of significance was set at 0.05.

For the qualitative data from the Student's Written Journal (SWJ), thematic analysis was employed. This approach is commonly used in educational research to identify and interpret patterns within qualitative data [39]. First, students' written responses were transcribed and reviewed multiple times to ensure familiarity with the data. Next, open coding was applied, allowing initial codes to emerge directly from the data. These codes were then grouped into themes related to students' perceptions, reflections on sustainability concepts, and personal insights gained from the lessons.

3. RESULTS AND DISCUSSION

3.1. Students' Conceptual Understanding of Bio-sustainability Concepts

Based on the results presented in Table 3, it can be observed that the five lessons had a significant effects in improving students' conceptual understanding of bio-sustainability concepts. The overall performance of the students in ESAT increased by 15.16%, which is a noteworthy improvement. Specifically, the lessons had the greatest impact on the students' understanding of Lessons 1, 3, 4, and 5, with increases of 11.72%, 13.60%, 19.01%, and 25.33%, respectively. These findings are in line with previous research that has shown the effectiveness of instructional interventions in improving students' understanding of ecological concepts [27], [40]-[42].

Table 3. Comparison of the students' pretest and posttest mean scores and performance levels in the Ecology and Sustainability Achievement Test (ESAT) (n=38).

Lessons	No. of Items	Pre-test		Post-test		Gain	
		MS	PL (%)	MS	PL (%)	MS	PL (%)
Ecosystem: The Principles Within	22	10.42	47.37	13.00	59.09	2.58	11.72
Biodiversity: Stability in the Diversity of Life	9	5.03	55.85	5.58	61.99	0.55	6.14
Biotic Potential and Environmental Resistance: Limiting Population Growth	12	4.13	34.43	5.76	48.03	1.63	13.60
Terrestrial and Aquatic Ecosystems: Interconnectivity in the Biosphere	9	4.13	45.91	5.84	64.91	1.71	19.01
The Ecological Footprint: Assessing Human Environmental Impact	8	3.08	38.49	5.11	63.82	2.03	25.33
Overall Mean		26.79	44.41	35.29	59.57	8.50	15.16

MS: Mean Score; PL: Performance Level

However, the results also indicate a slight improvement in Lesson 2, with an increase of only 6.14%. This may suggest that the students may already had a strong knowledge of Biodiversity which is widely taught in previous grade levels. Numerous studies support this notion that students who were found to have a strong prior knowledge of the subject, particularly science concepts, may exhibit better learning outcomes [43]-[45].

Table 4. Paired t-test results comparing the mean pretest and posttest scores of male and female students in ESAT.

Sex	Item	n	Mean	St. dev	Mean difference	t-stat	p-value	Effect size (d)
Female	Pretest	22	28.2	6.43	-8.18	-6.01	.000	1.28
	Posttest	22	36.4	8.80				
Male	Pretest	16	24.9	7.46	-8.94	-6.91	.000	1.73
	Posttest	16	33.8	7.21				

The paired t-test results in Table 4 indicate a significant difference between the mean pretest and posttest scores of both female and male students in the ESAT. The mean posttest score for female students (M = 36.4, SD = 8.80) was significantly higher (t_{21} = -6.01, $p<0.001$) than their mean pretest score (M = 28.2, SD = 6.43), with a large effect size (d = 1.28). Similarly, the mean posttest score for male students (M = 33.8, SD = 7.21) was statistically significantly higher (t_{15} = -6.91, $p<0.001$) than their mean pretest score (M = 24.9, SD = 7.46), with an even larger effect size (d = 1.73). These results suggest that both male and female students exhibited significant improvements in their scores following the intervention, with large effect sizes indicating substantial gains in performance. The larger effect size for male students compared to female students suggests that the intervention may have had a slightly stronger impact on male students.

These findings are consistent with other studies that have reported significant improvements in student learning outcomes following an inquiry-based, contextual and learner-centered approach to the delivery of lessons [41], [46].

Table 5. Independent samples t-test results comparing the male and female mean posttest scores in ESAT.

Group	n	Mean	St. dev	Mean difference	t-stat	p-value	Effect size (d)
Posttest-Female	22	36.4	8.80	2.55	-0.98*	0.33	0.31
Posttest-Male	16	33.8	7.21				

Conversely, the independent-sample t-test revealed no significant difference between male and female mean posttest scores, as shown in Table 5. This indicates that the developed lessons were effective in improving students' conceptual understanding regardless of gender.

3.2. Students' Attitudes toward Sustainable Development

Table 6 shows that both male and female students' attitudes towards sustainability improved substantially after exposure to the developed lessons, with female attitudes increasing from positive (4.16) to highly positive (4.49), and male attitudes increasing from positive (4.34) to highly positive (4.51). Additionally, Table 7 indicates that females showed a slightly higher increase in attitude levels (MD = 0.32) compared to males (MD = 0.18). These results suggest that while both sexes improved, female students developed a higher appreciation of sustainability principles. This conforms with Fromhage and Jennions [47], who found that females generally exhibit stronger attitudes towards environmental stewardship, being more conscientious and goal-directed in their environmental actions than men.

Table 6. Comparison of male and female students' attitude levels before and after exposure to the developed lessons (n=38).

Sex	Pretest (AWM)	Attitude level	Posttest (AWM)	Attitude level
Female	4.16	Positive	4.49	Highly Positive
Male	4.34	Positive	4.51	Highly Positive
Overall Weighted Mean	4.25	Positive	4.50	Highly Positive

AWM: Average Weighted Mean

Nevertheless, this improvement in attitude can be attributed to the reflective, inquiry-based, learner-centered, and contextual nature of the developed lessons. Students were exposed to hands-on, real-world problem-solving collaborative activities that confront locally relevant sustainability issues in the community.

Table 7. Paired t-test results comparing the pre- and post-attitude scores of male and female participants in ASDS.

Sex	Item	n	Mean	St. dev	Mean difference	t-stat	p-value	Effect size (d)
Female	Pretest	22	4.16	0.44	-0.32	-3.35*	<0.01	0.71
	Posttest	22	4.49	0.31				
Male	Pretest	16	4.34	0.26	-0.18	-2.27*	0.03	0.57
	Posttest	16	4.51	0.21				

Table 8. Independent samples t-test results comparing the male and female posttest scores on ASDS.

Group	n	Mean	St. dev	Mean difference	t-stat	p-value	Effect size (d)
Posttest-Female	22	4.49	0.31	-0.02	0.26	0.79	0.09
Posttest-Male	16	4.51	0.21				

Moreover, the paired-sample t-test, as shown in Table 7, revealed that the male respondents' mean posttest score (M = 4.51, SD = 0.21) was significantly higher than their mean pretest score (M = 4.34; SD = 0.26) at a significance level of 0.05. Similarly, the female respondents' mean posttest score (M = 4.49, SD = 0.31) differed significantly from their mean pretest score (M = 4.16, SD = 0.44) at a 0.05 level of significance. There was no significant difference (p-value = 0.79) between the male and female posttest scores, as presented in Table 8. These results show that the attitude of students towards sustainability concepts and principles improved significantly following exposure to the developed lessons. These findings align with previous studies that have shown that integrating environmental and sustainability concepts in the curriculum through learner-centered, active, and experiential learning can significantly improve students' attitudes toward responsible and sustainable living [42], [48], [49].

3.3. Students' Perceptions toward Sustainable Development

Through a thematic analysis of the students' responses in the Student Written Journal (SWJ), three primary themes emerged: 1) Individual responsibility and action toward conservation, 2) Community involvement and participation in sustainability, and 3) Awareness and concern for environmental issues. Each theme was analyzed with specific codes representing key concepts in students' responses, supported by

numerical data to show frequency and significance as presented in Table 9. Names presented are just pseudonyms to maintain the anonymity of the actual respondents.

3.3.1. Individual Responsibility and Action Toward Conservation

This theme highlights students' acknowledgment of personal accountability in contributing to environmental conservation. Responses frequently mentioned actions like conserving water, reducing energy usage, and minimizing their ecological footprint. These actions were coded as "personal responsibility" (24 mentions), "individual action" (18 mentions), and "biodiversity protection" (10 mentions).

For example, Jake (male, 17) noted, "*It made me realize that I can help on water conservation even in just doing little things*." Another student, Alicia (female, 17), emphasized, "*We should start now monitoring our ecological footprint and help our mother earth to recover… Conserve energy, segregate wastes, and recycle*."

The frequent appearance of these codes suggests that the lessons fostered a strong sense of personal responsibility, with students recognizing that their individual efforts contribute to a larger goal of sustainability [50], [51]. This also aligns with Olsson et al. [7] on the effectiveness of education for sustainable development (ESD) in instilling action competence among students, indicating that small personal actions are an accessible starting point for promoting conservation. This sense of empowerment aligns with ESD's objective to develop proactive stewards of the environment [3].

3.3.2. Community Involvement and Participation in Sustainability

Students also expressed the importance of engaging in community-based activities that promote sustainability, coded as "community engagement" (14 mentions) and "collective action" (11 mentions). They recognized that their individual actions could be amplified when part of a collective action.

For instance, Bernadette (female, 17) shared, "*I can do things to promote sustainable development in my community by joining and participating in programs that help conserve water resources*." Similarly, Michael (male, 16) emphasized the need for "*attending programs that tackle sustainability in our community*."

This theme aligns with previous research emphasizing that community participation enhances the effectiveness of ESD by creating shared environmental responsibilities [52]-[54]. Students' awareness of community action suggests a broader understanding of sustainability beyond individual efforts, which, according to Olsson et al. [7], is critical for cultivating collective sustainability competence. Thus, embedding community-focused activities in the curriculum could further bolster students' active engagement in environmental sustainability [55], [56].

Table 9. Summary Results of Thematic Analysis on Student Responses in SWJ.

Theme	Sample Responses	Codes	Freq (%)
1. Individual Responsibility and Action Towards Conservation	"*It made me realize that I can help on water conservation even in just doing little things*." – Jake, 17, male	Personal responsibility	24 (32%)
	"*We should start now monitoring our ecological footprint and help our mother earth to recover… Conserve energy, segregate wastes, and recycle*." – Alicia, 17, female	Individual action	18 (24%)
	"*It is my duty to do things that can make better every species in biodiversity*." – Martin, 17, male	Biodiversity protection	10 (13%)
2. Community Involvement and Participation in Sustainability	"*I can do things to promote sustainable development in my community by joining and participating in programs that help conserve water resources*." – Bernadette, 17, female	Community engagement	14 (18%)
	"*Attending programs that tackle sustainability in our community can help solve the issue of population explosion*." – Michael, 16, male	Collective action	11 (15%)
3. Awareness and	"*Our ecosystem needs immediate action*	Environmental	17 (23%)

Concern for Environmental Issues	*to prevent destruction*." – Sandro, 16, male	awareness	
	"*Discussing the ecological deficit made me realize that we need to conserve essential resources*." – Antonette, 17, female	Conservation urgency	12 (16%)
	"*We should protect living organisms that can help us during calamities*." – Janice, 16, female	Ecosystem preservation	9 (12%)

3.3.3. Awareness and Concern for Environmental Issues

The final theme, "Awareness and Concern for Environmental Issues," was prevalent in responses, with codes such as "environmental awareness" (17 mentions), "conservation urgency" (12 mentions), and "ecosystem preservation" (9 mentions). Students exhibited a heightened concern for environmental degradation and the need for urgent action.

Sandro (male, 16) reflected, "*Our ecosystem needs immediate action to prevent destruction*," while Antonette (female, 17) stated, "*When we discussed the ecological deficit, it made me realize that we need to conserve things we need*."

The students' increased awareness aligns with findings in ESD literature, which emphasizes that awareness is foundational for fostering sustainable behaviors [6], [57], [58]. By instilling awareness of environmental issues, the lessons align with the goals of sustainability education to inspire students toward lifelong ecological consciousness [59], [60]. Furthermore, Olsson et al. [7] noted that ESD positively impacts students' perceived action competence, although it may require sustained reinforcement over time. This suggests that to deepen environmental awareness, sustainability education should be a continuous and embedded aspect of the curriculum [59], [61], [62].

Overall, the findings reveal that individual responsibility, community involvement, and heightened environmental awareness are among the critical aspects of students' perceptions toward sustainable development that were formed after exposure to the developed lessons. The frequent recurrence of these themes, qualitative codes and representative answers, highlights the effectiveness of sustainability-integrated education in shaping students' outlooks on sustainability. Encouraging individual and collective responsibility while fostering environmental awareness can significantly contribute to building environmentally responsible citizens and addressing broader sustainability goals [58], [63], [64].

While this study reveals some interesting findings, it has some limitations. Firstly, it utilized a pre-experimental design which has some inherent weaknesses. Secondly, there were not randomization employed in selecting the participants which may affect the generalizability of the results. Lastly, the study focuses only on one type of population and one location which may limits the applicability of the findings to other populations and environments. Future research may adopt a quasi or true experimental design to minimize the current study limitations and to avoid any potential bias. Replicating this study by utilizing large sample sizes and comparing different educational settings is likewise suggested.

4. CONCLUSION

The findings of the study indicate that the developed lessons in Grade 11 ecology, integrating locally-relevant sustainability concepts and principles, significantly improved students' conceptual understanding of bio-sustainability concepts, regardless of gender. Both male and female students' exhibited highly positive improvement in pro-sustainability attitudes after exposure to the lessons. These substantial improvements in attitude change highlights the transformative power of an inquiry-based, reflective, learner-centered, and locally-relevant approach to learning.

Furthermore, students' exposure to the developed lessons positively influenced their perceptions of the importance of individual responsibility and community involvement in conservation efforts. Ultimately, this study highlights the effects of integrating bio-sustainability concepts through inquiry-based, learner-centered, contextual, and reflective learning methodology, which can significantly improve students' conceptual knowledge, attitudes, and perceptions towards sustainable living, empowering them to become proactive stewards of the environment and catalysts for positive change in their local communities.

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