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Article

Evaluating ESG-Centered PBL in a General Education Course: A Mixed-Methods Study of Student Competency Development

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Abstract

This study investigates the integration of Environmental, Social, and Governance (ESG) themes into a general education course through problem-based learning (PBL), aiming to cultivate sustainability-related competencies among university students. The course design combined lectures, practical tasks, and industry engagement, including carbon inventory simulations, emission assessments, and ESG case analyses. A mixed-methods approach was employed, using pre- and post-course assessments and statistical analysis via paired sample t test and Wilcoxon signed rank test, complemented by qualitative feedback. Results revealed statistically significant improvements in the Innovation and Communication Aspects, while other areas such as Continued Learning and Problem Solving showed positive trends without reaching significance. Student feedback supported these findings, indicating increased ESG awareness, greater motivation, and a deeper connection between sustainability and professional growth. The findings suggest that PBL, when centered on ESG topics, can effectively foster key competencies and enhance student engagement. Future course iterations may further benefit from extending project duration, incorporating advanced data tools, and enhancing interdisciplinary collaboration.

Keywords: sustainability education; ESG; Problem-Based Learning (PBL); competency development; higher education

1. Introduction

As climate change and sustainability challenges intensify globally, the demand for professionals equipped with ESG (Environmental, Social, and Governance) competencies and practical capabilities has grown rapidly across industry, government, and academia [1,2]. Aligned with the United Nations Sustainable Development Goals (SDGs) and Taiwan’s “2050 Net-Zero Emissions” roadmap, higher education now plays a critical role in cultivating students’ sustainability literacy and interdisciplinary problem-solving skills [3,4].

In response to this need, the present study designed and implemented a general education course entitled “ESG: Organizational Greenhouse Gas Inventory, Decarbonization, and Net-Zero Transition.” The course aims to enhance students’ awareness of climate risks and organizational sustainability responsibilities while fostering their ability to apply sustainability strategies in real-world contexts [5,6]. The curriculum was developed based on SDG principles and ESG, with a focus on enabling students to construct a comprehensive view of sustainable development—from individual behaviors to corporate practices and broader societal frameworks [7].

To achieve these goals, the course employed Problem-Based Learning (PBL) and discussion-based pedagogy, engaging students in midterm and final projects rooted in real or simulated ESG scenarios [8]. Key instructional themes included ESG frameworks, GHG accounting methodologies, net-zero strategies, and international regulatory standards (e.g., ISO guidelines, Taiwan EPA

definitions, CDP, SBTi, CBAM), thereby equipping students with both conceptual understanding and practical tools for sustainability transition.

Previous teaching experiences have revealed that while students generally possess sound digital literacy, they often require further development in core competencies such as communication, collaboration, and problem-solving. Our previous teaching project, which integrated digital learning and hands-on tasks in a materials science course, found that contextualized, experiential learning significantly improved student outcomes in innovation and analytical thinking. Building on this foundation, the present course incorporated ESG-centered topics with a more challenging and interdisciplinary task design [9].

To evaluate the course's educational impact, this study employed the UCAN Common Competency Survey a national instrument promoted by the Ministry of Education Republic of China, administered both before and after the course. The six assessed dimensions included: communication, continued learning, interpersonal interaction, problem-solving, innovation, and information technology application. Quantitative analysis was conducted to determine whether the course significantly enhanced student competencies, and to inform future curriculum refinement [10–12].

Accordingly, the study addresses two main research questions:

- (1) Does the course effectively enhance students' competencies across the six UCAN domains?
- (2) Can a curriculum integrating ESG topics, PBL pedagogy, and practice-based assignments foster students' interdisciplinary sustainability capabilities?

This research seeks to develop a transferable instructional model for general education, offering empirical evidence to support the design of ESG-related courses in higher education. By embedding complex sustainability issues within practice-driven, student-centered learning environments, the study contributes to the advancement of competence-based sustainability education.

2. Materials and Methods

2.1. Background

In recent years, with the promotion of the United Nations Sustainable Development Goals (SDGs) in higher education, Education for Sustainable Development (ESD) has evolved beyond mere knowledge transmission, emphasizing instead students' participation in action, reflection, and social practice. Corresponding to this pedagogical shift, traditional lecture-based teaching has gradually been replaced by student-centered approaches such as Problem-Based Learning (PBL), Challenge-Based Learning (CBL), and the Flipped Classroom.

For instance, integrating local issues into STEAM curricula using PBL strategies has been shown to significantly enhance students' sense of place and environmental literacy, particularly in relation to SDG 11: Sustainable Cities and Communities [13]. In the field of engineering education, PBL has further evolved into Practice-Based Education (PBE) to meet the industry's demand for students with practical and decision-making competencies. While PBL focuses on problem-solving processes, a lack of hands-on experience may limit its effectiveness in engineering practice. Therefore, PBE emphasizes scenario-based and task-integrated learning to equip students with the ability to analyze problems from multiple perspectives and develop appropriate solutions. Studies further indicate that ethical responsibility and cross-cultural communication are also essential competencies to be cultivated through ESD [14].

CBL takes this further by challenging students with open-ended problems that lack predefined solutions, requiring them to work collaboratively and synthesize diverse information to propose creative and feasible strategies. When CBL is integrated with the flipped classroom model in engineering courses, students acquire foundational knowledge through digital resources before class and engage in thematic problem discussions during class. Such integration has been found to strengthen students' systems thinking and action competence on topics like the circular economy [15], while also enhancing student engagement and motivation [16].

The flipped classroom, widely applied in recent years, emphasizes pre-class knowledge acquisition and in-class interactive learning. In ESD, it is often combined with PBL or CBL, allowing for “preparation before class and hands-on activities during class.” Students involved in flipped and challenge-based courses tend to show greater initiative and deeper understanding of sustainability topics such as circular economy, suggesting that the flipped classroom facilitates knowledge internalization and learning transfer [17].

ESD emphasizes not only knowledge acquisition but also the cultivation of diverse competencies including action competence, systems thinking, ethical reasoning, and communication and collaboration skills. Literature has shown that ESD can significantly enhance students’ motivation and confidence to engage in social and environmental issues, shifting their learning from cognition to action and cultivating responsible, civic-minded learners [18]. Some studies have noted gender and disciplinary differences in the development of action competence after ESD instruction, underscoring the importance of inclusivity and diversity in curriculum design [19].

Regarding ethics and social responsibility, studies suggest that current curricula still lack sufficient emphasis on macro-ethical practices. Through cross-cultural comparisons and teacher perspectives, researchers advocate for the integration of sustainability themes with ethical deliberation, supported by simulation and discussion-based pedagogies to enhance students’ critical thinking and moral sensitivity [20].

Effective ESD also relies on collaboration and interdisciplinary communication. Teaching strategies such as cooperative learning, group projects, and reflective journaling have been shown to improve students’ teamwork and coordination skills while fostering a stronger willingness to engage in sustainability challenges. Such courses typically incorporate real-world issues and community resources to help students develop interdisciplinary integration capabilities [21].

Given the complexity and interdisciplinary nature of sustainability—spanning environmental, ecological, economic, social, technological, and ethical dimensions—higher education curricula must integrate diverse knowledge areas and practical contexts. Studies have repeatedly emphasized that interdisciplinary collaboration and practice-based teaching have become mainstream trends in ESD, serving as key mechanisms for developing the comprehensive competencies needed to meet future societal challenges.

The European Project Semester (EPS), an innovative ESD teaching model, exemplifies this approach. Implemented through cross-national university partnerships, students work in multinational teams to complete project designs aligned with the SDGs. By engaging in long-term, real-world projects, students cultivate collaboration, project management, and social responsibility skills. This model effectively expands their global perspectives and problem-solving pathways [22].

At the institutional and curricular level, surveys on faculty engagement with ESD reveal that while interdisciplinary teaching is highly valued, its implementation faces challenges such as varying faculty backgrounds, coordination difficulties, and insufficient institutional support. It is therefore recommended that institutions establish support systems and resource platforms to facilitate cross-departmental and cross-disciplinary collaboration and integrate sustainability into academic program planning [23].

Technological advancement has also transformed interdisciplinary learning environments. Tools such as virtual reality, open educational resources, and hybrid learning models have brought unprecedented flexibility and interactivity to ESD. These tools reshape classroom dynamics and expand students’ exposure to real-world issues and international case studies. In particular, they enable meaningful connections between local contexts and global challenges, providing students with more comprehensive problem understanding and reflective capacity [24].

Furthermore, systematic literature reviews suggest that higher education institutions should embed sustainability literacy into curriculum design, integrating theme-based and bilingual teaching strategies to strengthen students’ intercultural understanding and global citizenship. The studies emphasize that interdisciplinary co-teaching will be a critical pathway for the future development of ESD [25].

In summary, ESD has transitioned from traditional knowledge dissemination toward the development of students’ practical engagement, action-oriented learning, and interdisciplinary integration capabilities. Blending diverse teaching strategies—including PBL, CBL, and flipped classrooms—can enhance students’ systems thinking, ethical judgment, learning motivation, and practical ability. Real-world tasks and authentic scenarios further facilitate the application of knowledge to social and industrial problems. Interdisciplinary teaching not only helps students grasp the multifaceted nature of sustainability issues but also fosters collaboration, problem integration, and global perspective. Overall, effectively integrating diverse pedagogies with hands-on learning in ESD can promote students’ core competence development and lay a solid foundation for future challenges in environmental and social domains.

2.2. Materials

The instructional setting of this study is a general education course titled “ESG Organization’s Greenhouse Gas Inventory, Decarbonization, and Net-Zero Curriculum.” The course is grounded in the core principles of Education for Sustainable Development (ESD), integrating Problem-Based Learning (PBL) and University Social Responsibility (USR) practices. It aims to cultivate students’ sustainability literacy and practical competencies in addressing climate change and achieving net-zero emissions.

2.2.1. Course Design

The course is divided into three main phases. The first phase, Foundational Knowledge Building, concentrates on helping students understand key concepts like climate change, the greenhouse effect, and carbon neutrality, while highlighting the importance of greenhouse gas (GHG) inventories and relevant international standards (e.g., ISO 14064). Through a mix of lectures and guided class discussions, the instructor assists students in developing a foundational knowledge framework in sustainability, which forms the theoretical basis for later practical work.

The second phase centers on Practical Skill Development. Students explore the three emission scopes (Scopes 1, 2, and 3), conduct materiality assessments, calculate carbon footprints, and plan emission reduction strategies. The curriculum includes simulation exercises such as campus building emission audits and commuting emission modeling. Students also learn how to use the CarbonKeeper software, as shown in Figure 1 through Figure 3, and basic reporting techniques, enabling them to perform simplified GHG inventories and suggest practical improvement strategies.

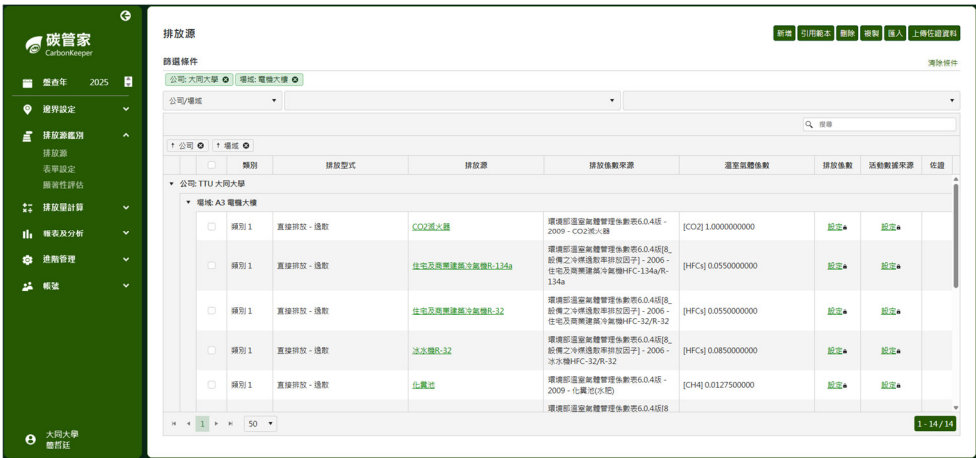


Figure 1. CarbonKeeper Software – Emission Source Identification.

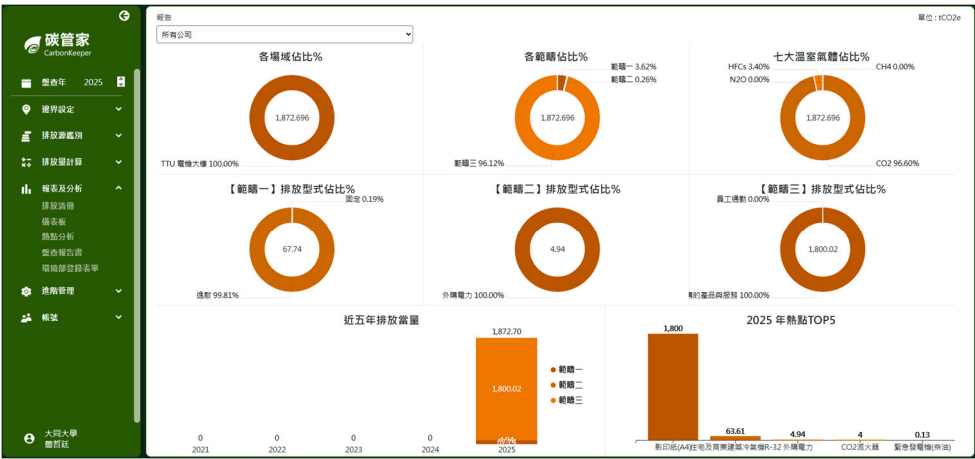


Figure 2. CarbonKeeper Software – Reports and Analysis.



Figure 3. CarbonKeeper Software – Activity Data Collection.

The third phase focuses on Application and Industry Integration. Students compile group data and present their project findings through collaboration across teams. Industry lecturers are invited to provide feedback and share real-world insights into carbon management practices. Students must complete a final group report, document their data, and develop an evidence-based action proposal. Peer evaluations and reflective activities are included to enhance learning. Throughout all phases, task-based learning is the main teaching approach, reinforced by interdisciplinary content and multi-level feedback. This strategy encourages students to “learn by doing” and equips them with the skills needed to tackle complex sustainability issues.

Each phase included targeted topics and learning activities designed to guide students from conceptual understanding to applied learning in the context of ESG and carbon management, as shown in Figure 4.

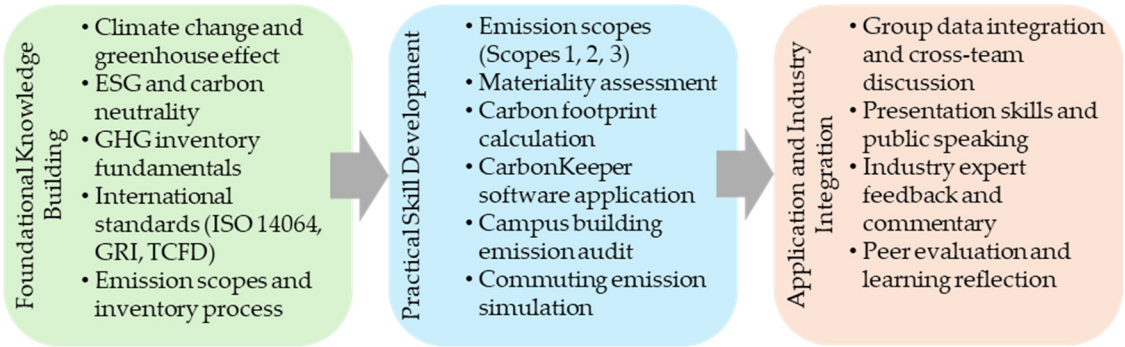


Figure 4. Staged Learning Design from ESG Concepts to Practice.

2.2.2. Lectures and Company Visits

As part of the course design to enhance students’ practical understanding of ESG and carbon neutrality, a series of four industry expert lectures and one corporate site visit were organized. These activities aimed to bridge theoretical knowledge with real-world applications, enabling students to construct a more comprehensive framework of sustainability practice. The guest lectures covered topics such as carbon inventory systems, international sustainability disclosure standards, carbon reduction mechanisms, and interdisciplinary practices—each session strategically building upon the last to deepen students’ conceptual and applied understanding.

The first lecture was delivered by Deputy General Manager Mr. Chang of M-Power Information Co., Ltd., titled “Why Conduct Carbon Inventory?”. This session provided an overview of global ESG development trends and emphasized the necessity of implementing corporate carbon inventory systems. It also addressed the implications of the Carbon Border Adjustment Mechanism (CBAM) and introduced practical case studies on the integration of digital carbon management platforms in industry, as shown in Figure 5.



Figure 5. Why Conduct Carbon Inventory?

Subsequently, a lecture entitled “Value-Added Applications of Carbon Inventory and Practical Sustainability Reporting” was presented by a certified public accountant from a professional accounting firm. This lecture guided students through the ISO 14064 framework and its operational procedures, while also demonstrating how international sustainability disclosure frameworks such as the Global Reporting Initiative (GRI) and Task Force on Climate-Related Financial Disclosures (TCFD) are incorporated into business practices, as shown in Figure 6.



Figure 6. Value-Added Applications of Carbon Inventory and Practical Sustainability Reporting.

To further deepen students’ understanding of carbon reduction project frameworks, a guest lecture titled “ISO 14064-2 Project-Based Carbon Reduction Methods and Taiwan’s Voluntary Emission Reduction Mechanism” was delivered by a specialist from Lin Yuan Property Management Co., Ltd. The session provided a comprehensive overview of Taiwan’s voluntary carbon reduction schemes, the MRV (Monitoring, Reporting, and Verification) system, and additionality assessment procedures, enabling students to develop a systematic understanding of the policy rationale and institutional design behind carbon reduction strategies, as shown in Figure 7.



Figure 7. ISO 14064-2 Project-Based Carbon Reduction Methods and Taiwan’s Voluntary Emission Reduction Mechanism.

The final guest lecture, “Why Carbon Inventory Matters,” was presented by a consultant specializing in environmental and carbon management from ATAX Accounting Firm. Drawing from extensive field experience, the speaker shared practical insights into the challenges and observations of conducting carbon inventories across various industries and organizations. Emphasis was placed on the interdisciplinary nature of carbon inventory work, which requires collaboration among financial, operational, technical, and environmental domains. This lecture further reinforced students’ understanding of the comprehensive skillsets needed to advance ESG practices in real-world contexts, as shown in Figure 8.



Figure 8. Why Carbon Inventory Matters.

In addition to the guest lectures, the course also included a site visit to the Formosa Plastics Group Museum. Through guided tours and on-site observations, students gained firsthand insights

into how corporations implement ESG and CSR strategies in practice. Key topics included the integration of green manufacturing processes, energy-saving and carbon reduction initiatives, and corporate approaches to social engagement. This experiential learning activity effectively complemented the classroom-based instruction and encouraged students to critically reflect on the strategic planning and practical implications of sustainability from a corporate perspective, as shown in Figure 9.



Figure 9. Visit to the Formosa Plastics Group Museum.

2.2.3. Practical Task

To deepen students’ understanding and application of sustainability issues, this course is designed with two practical tasks focusing on transportation carbon emissions and energy usage in campus buildings. Through scenario simulations and field data collection, students were guided to implement carbon inventory techniques, thereby cultivating their systems thinking and interdisciplinary analytical skills.

The first practical task, titled “Simulation and Analysis of Transportation Carbon Emissions”, required students to take public buses to simulate transportation behaviors arising from business-related activities. They recorded parameters such as departure and destination points, travel distance, number of passengers, duration, and average speed. Using emission factors published by DEFRA and the IPCC, students calculated carbon emissions via two methods: the traditional estimation and the advanced estimation (which considers passenger load and delays). Through the analysis process, students were encouraged to explore how travel time and occupancy rates affect carbon intensity, reflect on how commuting, business travel, or academic mobility contribute to the carbon footprint, and propose possible improvements. This task aimed at enhancing students’ critical thinking and data interpretation skills. The results of the students’ practical tasks are shown in Figure 10 through Figure 14.

從民族東路口~羅斯福浦城街口
總距離:5.62公里

路線	從民族東路口~羅斯福浦城街口				
時間轉運方式					
油量(L)=距離(km)×載客量影響×0.004(平均時速油耗率×時速上頂油耗率)+怠速油耗率×延遲時間					
碳排放量(kgCO ₂ e)=油量(L)×油碳係數×CO ₂ 排放係數+(CH ₄ 排放係數×CH ₄ 排放率+NO _x 排放係數×NO _x 排放率)					
單位乘客碳排放量=實際乘客數×碳排放量					
交通工具	燃油	延遲時間 (s)	平均時速 (km/h)	道路時速上限 (km/h)	怠速油耗率 (L/h)
公車			0.013	15.74(2000/125)	50
道路時速上限(200)	實際時間(s)	距離 (km)	平均時速油耗率 (L/km)	道路時速上頂油耗率 (L/km)	油耗量 (L)
0.37	0.297	5.62	0.195	0.125	0.12805
實際乘客數 (人)	最大乘客數 (人)	載客量影響 (%)			
15	40	62.5			
CO ₂ 排放係數 (kg/L)	CH ₄ 排放係數 (kg/L)	NO _x 排放係數 (kg/L)			
2.68	0.0001	0.0002			
GWP CO ₂	GWP CH ₄	GWP NO _x			
1	25	298			
碳排放量 (kgCO ₂ e)	單位乘客碳排放 (kgCO ₂ e/人)				
0.351073525	0.023402825				

Figure 10. Carbon Emission Estimation Table.



Figure 11. Bus Ride Record and Passenger Statistics.



Figure 12. Bus Route Analysis Diagram.

傳統碳排計算法（範疇三）

- 大同大學 → 天母棒球場：6.5 km × 0.102 = 0.663 kgCO₂e
- 天母棒球場 → 劍潭捷運站：3.8 km × 0.102 = 0.3876 kgCO₂e
- 優點：資料取得簡易、計算快速
- 缺點：忽略乘載人數、延誤與實際交通狀況

傳統碳排範疇三（Scope 3）碳排計算（google地圖估算距離）					
公式：碳排量=總行駛距離（km）×公車平均排放因子（kg CO ₂ e/km）					
起點	終點	總距離(km)	交通運輸工具(下拉式)	參考排放因子（DEFRA 2023）	碳排量(kgCO ₂ e)
大同大學	天母棒球隊	6.5	公車	0.102	0.663
天母棒球隊	劍潭捷運站	3.8	公車	0.102	0.3876

Figure 13. Traditional Carbon Emission Calculation Method.

新型vs.傳統碳排計算差異

- 人均碳排比較
 - 新型方法可反映出：回程沒人碳排僅為傳統估算法的1/17
 - 傳統方法無法體現「共乘效益」，可能誤判為高碳排
- 實際乘車觀察
 - 若交通阻塞或載客多，傳統法無法反應影響因素
 - 新型法從油耗推估碳排，較能處理各種變因

Figure 14. Comparison of New and Traditional Emission Calculation Methods.

The second practical task, titled “Campus Building Carbon Inventory and Departmental Energy Structure Comparison,” guided students to conduct a simplified carbon inventory of university department buildings following the ISO 14064-1 framework. The focus was placed on Scope 2 emissions from electricity consumption and the identification and conversion of data related to major energy-consuming equipment.

During the course, students were instructed to investigate the types of teaching and research equipment used in different department buildings, along with their operating hours and energy

consumption characteristics. For example, the Department of Mechanical and Materials Engineering typically houses heavy machinery with high electricity demands; electrical and computer engineering departments may have server rooms requiring a stable and continuous power supply; while chemical and bioengineering laboratories often utilize reaction and ventilation equipment that also consume significant energy.

Students were required to estimate emissions based on the collected data and complete an inventory report. They then compared the energy consumption structures across different faculties and proposed concrete improvement strategies. This task not only deepened their understanding of carbon inventory processes but also enhanced their ability to integrate interdisciplinary knowledge and solve organizational-level sustainability problems. The results of the students’ practical tasks are shown in Figure 15 through Figure 17.

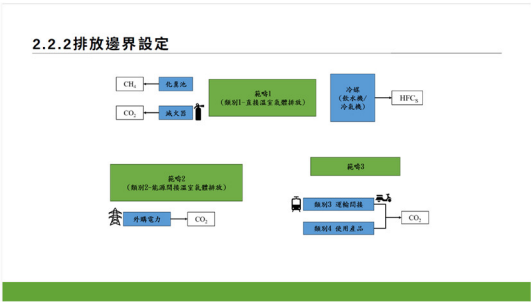


Figure 15. Definition of Emission Boundaries.

本公司依下表進行誤差等級評分，排放源數據誤差等級計算公式為A1×A2×A3

誤差等級	1分	2分	3分
資料來源	資料來源為內部數據庫	資料來源為外部數據庫	資料來源為外部數據庫
資料類型	資料類型為直接測量數據	資料類型為間接測量數據	資料類型為間接測量數據
資料數量	資料數量為1000以上	資料數量為1000以下	資料數量為1000以下
資料準確度	資料準確度為±1%以內	資料準確度為±2%以內	資料準確度為±3%以內
資料完整性	資料完整性為100%	資料完整性為90%以上	資料完整性為80%以上
資料可追溯性	資料可追溯性為100%	資料可追溯性為90%以上	資料可追溯性為80%以上
資料可驗證性	資料可驗證性為100%	資料可驗證性為90%以上	資料可驗證性為80%以上
資料可比較性	資料可比較性為100%	資料可比較性為90%以上	資料可比較性為80%以上

全廠溫室氣體數據品質管理誤差等級評分結果：

等級	第一級	第二級	第三級
評分範圍	X≤10分	10分≤X<19分	19分≤X≤27分
個數	0	0	2
清冊等級總平均分數	26.9	清冊等級	第三級

Figure 16. GHG Emission Source Significance Evaluation Criteria Table.

量化方法

外購電力

電量活動數據說明：因無法取得各樓層之台灣電力公司提供每期電費帳單上之使用電量，故以各設備使用一年電力之電量做計算。

CQ排放量 = (2024總用電量) * 台電公告最新係數 * GWP

- 冷氣 (FT-1102DSR) = 12 (台) * 11 (kW * 9 (hr) * 200 (工作日)) = 237600 (kW)
- 冷氣 (FT-73DYT) = 4 (台) * 7.2 (kW * 9 (hr) * 200 (工作日)) = 51840 (kW)
- 冷氣 (FT-362DQC (新)) = 17 (台) * 5.2 (kW * 9 (hr) * 200 (工作日)) = 159120 (kW)
- 冷氣(FT-452DRC (舊)) = 4 (台) * 5 (kW * 9 (hr) * 200 (工作日)) = 36000 (kW)
- 投影機 = 3 (台) * 0.300 (kW * 9 (hr) * 200 (工作日)) = 1620 (kW)
- 燈管 = 398 (支) * 0.015 (kW * 12 (hr) * 200 (工作日)) = 14328 (kW)
- 電腦 = 7 (台) * 0.3 (kW * 9 (hr) * 200 (工作日)) = 3780 (kW)
- 飲水機(UW313ASR) = 1 (台) * 1.345 (kW * 24 (hr) * 365 (工作日)) = 11782.2 (kW)
- 冰箱(TR-B363HS) = 1 (台) * 0.075 (kW * 24 (hr) * 365 (工作日)) = 657 (kW)

六樓之教學區及辦公室一年總共其電度數 = (516727.2度) → 516727.2 * 0.494 (每度電/噸排kg) = 255263.2 (CQ/kg)

Figure 17. Model Calculation Methods and Results.

Both of the aforementioned practical tasks are explicitly aligned with the UCAN Common Competency Indicators, emphasizing the cultivation of observable and measurable core competencies through task-based learning processes. The transportation carbon emission task requires students to record transport parameters and calculate emission factors, involving substantial data processing and analytical interpretation. This aligns with the indicators of Technological Information Application and Problem-Solving Ability. Moreover, the critical comparison of traditional versus advanced estimation models further enhances students’ Learning Ability and

Innovative Thinking, encouraging them to transcend conventional logic and explore diverse perspectives in assessment.

In the campus carbon inventory task, students must tackle the analytical challenges posed by the heterogeneity of departmental buildings. Through data collection, energy activity conversion, and report writing, they are required to collaborate with peers across teams to complete presentations and project proposals, aligning with the indicators of Interpersonal Interaction and Communication Skills. Furthermore, by integrating the results of their carbon inventory to propose energy-saving strategies, students demonstrate their ability to apply professional knowledge creatively and solve problems effectively.

In summary, the design of these two project-based tasks not only facilitates students’ knowledge construction and technical practice in sustainability issues, but also concretely corresponds to the core competencies emphasized in ESD. By combining pre- and post-course questionnaires and learning process assessments, the course effectively verifies its impact and effectiveness in fostering students’ professional and transferable skills.

2.3. Methods

2.3.1. Research Procedure

This study’s research procedure integrates the actual steps of course implementation with a structured statistical validation framework. It emphasizes the use of quantitative data to examine changes in students’ learning outcomes across six core aspects: First Aspect: Communication, Second Aspect: Continued Learning, Third Aspect: Interpersonal Interaction, Fourth Aspect: Problem Solving, Fifth Aspect: Innovation, and Sixth Aspect: Information Technology Application. By following a systematic approach to data collection and analysis, the study not only rigorously responds to its research questions but also establishes a replicable assessment model for future instructional designs. This model can serve as an empirical reference for evaluating and tracking the effectiveness of similar sustainability-oriented curricula. The research procedure is illustrated in Figure 18.

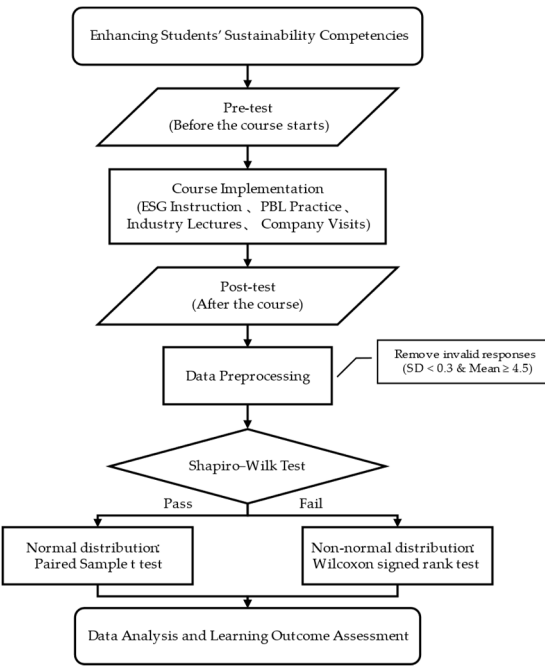


Figure 18. Research procedure.

2.3.2. Participants

The participants of this study were students enrolled in the general education course “ESG Organization’s Greenhouse Gas Inventory, Decarbonization, and Net-Zero Curriculum” offered by the General Education Center at the university. A total of 84 students participated, representing diverse academic backgrounds across engineering, design, management, and humanities and social sciences, thereby reflecting the interdisciplinary nature of the learning context.

2.3.3. Questionnaire

This study adopted the University Career and Competency Assessment Network (UCAN) questionnaire, developed by the Ministry of Education, Republic of China (Taiwan), as the instrument for evaluating students’ learning outcomes. The UCAN questionnaire is a nationally endorsed tool with strong construct validity and reliability, and it has been widely applied in competency-based education programs across universities in Taiwan. It assesses six core aspects: Communication, Continued Learning, Interpersonal Interaction, Problem Solving, Innovation, and Information Technology Application, providing a comprehensive and practical measure for evaluating students’ general competencies in higher education settings.

2.3.4. Data Collection and Analysis Methods

To evaluate the instructional effectiveness of this course in enhancing students’ core competencies, this study adopted a quasi-experimental one-group pretest–posttest design. After collecting the questionnaire responses, the research team performed data cleaning and screening to ensure data quality and analytical accuracy. A total of 32 valid samples were retained based on the following criteria: (1) each student’s response standard deviation in each aspect had to be greater than 0.3, excluding uniform or potentially inattentive answers; and (2) the average score had to be below 4.5, removing cases where students selected the highest rating for all items to reduce the ceiling effect. These criteria ensured that the dataset had sufficient variability and satisfied the assumptions of statistical analysis, thereby enhancing the reliability and validity of the research findings. Although the final sample size of 32 is relatively conservative, it was sufficient to reflect the course’s impact on students’ competency development and provides empirical support for future instructional refinement and promotion.

IBM SPSS was used as the primary tool for data processing and statistical analysis. The analysis included normality testing, paired sample t tests, and Wilcoxon signed rank tests. SPSS, a commonly used software in educational research, supports rigorous quantitative analysis and ensures the reliability and reproducibility of statistical outcomes. Normality of the pretest and posttest data was first examined using the Shapiro–Wilk test. For data following a normal distribution, paired sample t-tests were applied to assess differences in learning outcomes. If the normality assumption was violated, Wilcoxon signed-rank tests were used as a non-parametric alternative[26]. Addressing skewed data appropriately is crucial, as misidentifying distribution characteristics can lead to biased statistical inferences[27]. This analytical procedure ensured that the study’s methodology adhered to statistical standards and yielded robust conclusions.

2.3.5. Ethical Considerations

This study strictly adhered to the principles of research ethics. All data collected were solely used for academic analysis and publication purposes related to this study. At the beginning of the course, students were fully informed about the purpose and content of the questionnaire. Participation in the survey was conducted only after obtaining students’ informed consent, thereby ensuring that the research process complied with ethical standards of respect, transparency, and legality.

3. Results

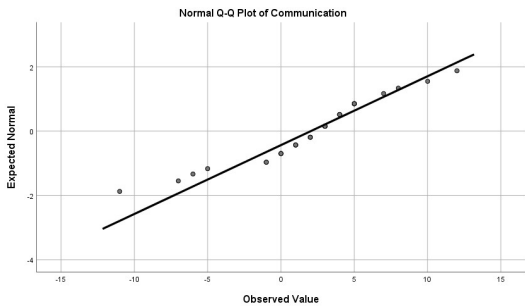
3.1. Results of the Shapiro–Wilk Test

This study performed gain score calculations and normality testing on the pretest and posttest data of the valid samples. The gain score refers to the difference between each student’s posttest and pretest total scores in each aspect, serving as an indicator of competency change after the course intervention.

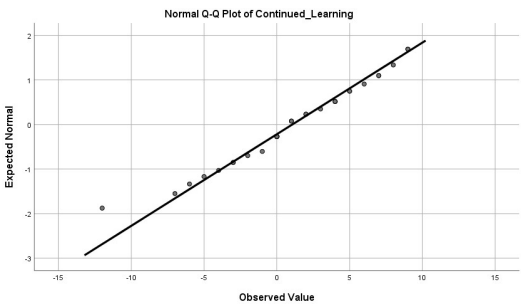
Given the sample size of 32, the Shapiro–Wilk test, known for its high statistical power and suitability for small samples, was employed to assess the normality of the data. A p-value greater than .05 was used as the criterion to determine whether the data followed a normal distribution. If $p > .05$, the result was considered to pass the normality test. The test results are summarized in Table 1, and the Q–Q plots for each aspect are shown in Figure 19.

Table 1. Results of the Shapiro–Wilk Test.

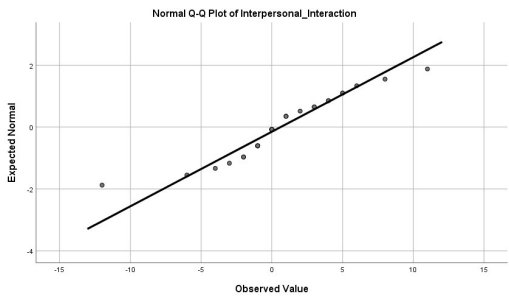
Aspect	Shapiro-Wilk Test ($p > .05$)	Normality Test Result (pass/fail)
First Aspect: Communication	.080	Pass
Second Aspect: Continued Learning	.484	Pass
Third Aspect: Interpersonal Interaction	.049	Fail
Fourth Aspect: Problem Solving	.105	Pass
Fifth Aspect: Innovation	.029	Fail
Sixth Aspect: Information Technology Application	.179	Pass



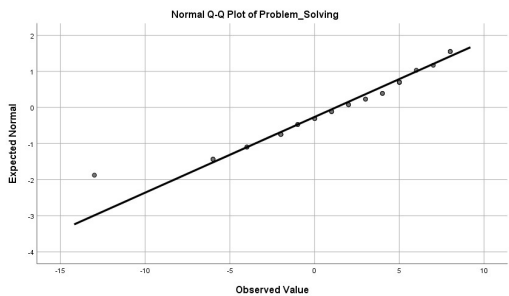
(a)



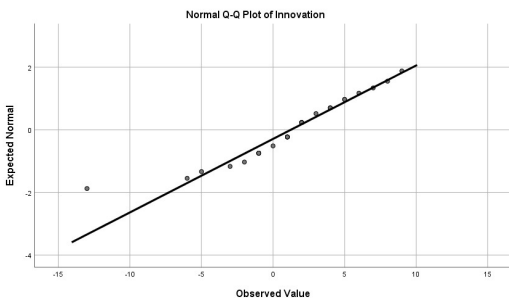
(b)



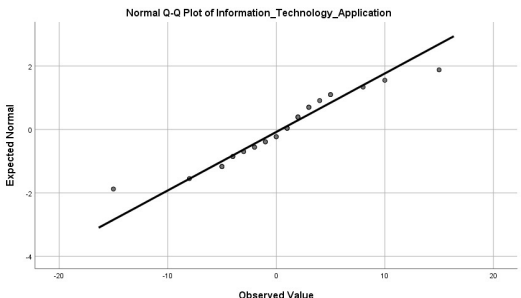
(c)



(d)



(e)



(f)

Figure 19. The Q–Q plots for each aspect. (a) First Aspect: Communication; (b) Second Aspect: Continued Learning; (c) Third Aspect: Interpersonal Interaction; (d) Fourth Aspect: Problem Solving; (e) Fifth Aspect: Innovation; (f) Sixth Aspect: Information Technology Application.

Based on the results of the normality test, the subsequent statistical analysis methods were determined as follows. For the aspects that passed the normality test: Communication, Continued Learning, Problem Solving, and Information Technology Application, paired sample t tests were used. For the aspects that failed the normality test: Interpersonal Interaction and Innovation, the Wilcoxon signed rank test was employed for non-parametric analysis.

3.2. First Aspect: Communication

According to the results of the paired sample t test, as shown in Table 2, there was a statistically significant difference in students’ scores in the Communication aspect between the pre-test and post-test ($t = -2.463$, $df = 31$, $p = 0.020$). The negative mean difference ($M = -2.031$) indicates that post-test scores were generally higher than pre-test scores, suggesting that the course had a positive effect on improving students’ communication skills.

Table 2. Paired sample t test results for Communication.

Comparison	Mean Difference	t	df	p-value
Pre - Post	-2.031	-2.463	31	.020*

Note: * $p < .05$.

This improvement can be credited to the variety of learning activities included in the course, such as group discussions, scenario simulations, and project presentations, which gave students practical chances to practice their verbal expression and logical organization skills. Specifically, the midterm and final ESG case presentations required students to represent their groups in oral reporting and data synthesis, which effectively improved their presentation skills, oral communication, and teamwork. Additionally, industry expert lectures and company visits allowed students to participate in cross-functional communication settings, further deepening their understanding of professional language and interpersonal interactions. Overall, the notable improvement in the “Communication” aspect highlights the effectiveness of combining problem-based and practice-oriented teaching approaches in developing students’ professional language skills and interdisciplinary communication abilities.

3.3. Second Aspect: Continued Learning

According to the results of the paired sample t test, as shown in Table 3, although students’ posttest scores in the aspect of Continued Learning showed an upward trend compared to the pretest, the difference did not reach statistical significance ($t = -1.235$, $df = 31$, $p = .226$). The mean difference was -1.062 , indicating that posttest scores were slightly higher than pretest scores. However, there was considerable variability in student performance. While some students exhibited substantial improvement, others showed minimal change or even a slight decline, leading to greater overall data dispersion and reduced statistical significance.

Table 3. Paired sample t test results for Continued Learning.

Comparison	Mean Difference	t	df	p-value
Pre - Post	-1.062	-1.235	31	.226

Note: * $p < .05$.

Despite the lack of statistical significance, positive trends in students’ learning motivation and engagement were observed. The course employed diverse instructional strategies, such as the integration of sustainability topics, problem-based learning (PBL) tasks, carbon footprint calculation exercises, and ESG case discussions. These approaches progressively fostered students’ active learning attitudes and willingness to explore further.

In the latter part of the course, site visits to companies and interdisciplinary discussion activities were incorporated to help students connect classroom knowledge with real-world professional contexts, thereby enhancing their understanding of future career applications and driving learning motivation. Additionally, industry lectures that shared experiences related to industrial transformation and international net-zero trends helped students link theoretical knowledge to practical development, further strengthening their perceived value of learning and their willingness to engage in lifelong learning.

Overall, although the statistical analysis did not reveal a significant difference, students’ learning trajectories reflected positive behaviors such as continuous exploration, active learning, and cross-disciplinary understanding. Future studies are encouraged to adopt a longer observation period and integrate qualitative data to provide a more comprehensive evaluation of learning effectiveness in this aspect.

3.4. *Third Aspect: Interpersonal Interaction*

According to the results of the Wilcoxon signed rank test, as shown in Table 4, there was no statistically significant difference in the median scores of students’ pretest and posttest in the aspect of Interpersonal Interaction ($p = .329$). Thus, the null hypothesis could not be rejected, indicating that students’ interpersonal interaction abilities did not show statistically significant changes after completing the course.

Table 4. Wilcoxon signed rank test results for Interpersonal Interaction.

Comparison	Test Method	<i>p</i> -value	Statistical Conclusion
Pre vs. Post	Wilcoxon signed rank test	.329	Not statistically significant

Note: * $p < .05$.

Although the course incorporated group discussions, collaborative presentations, and team-based assignments to enhance peer interaction, interpersonal interaction is generally considered a subtle and cumulative competency that often requires prolonged engagement in social contexts and real interpersonal experiences to show measurable improvement. Therefore, it is challenging to observe significant changes within the short duration of a single course.

In addition, the implementation period of this course was only 16 weeks, and some students might have already possessed a solid foundation in interpersonal skills. This limited variance may have also contributed to the lack of statistical significance. Nevertheless, classroom observations and student feedback revealed generally positive attitudes toward group collaboration and the division of labor in ESG case tasks. These findings suggest that the course still holds potential for fostering teamwork and communication. Future iterations could consider extending the duration of group activities or incorporating qualitative interviews to strengthen the evidence base.

3.5. *Fourth Aspect: Problem Solving*

According to the results of the paired sample *t* test, as shown in Table 5, although students’ scores in the Problem Solving aspect showed an upward trend from pretest to posttest, the difference did not reach statistical significance ($t = -1.484$, $df = 31$, $p = .148$). This indicates that the improvement in students’ problem-solving ability after completing the course was not statistically confirmed.

Table 5. Paired sample t test results for Problem Solving.

Comparison	Mean Difference	t	df	p-value
Pre - Post	-1.250	-1.484	31	.148

Note: * $p < .05$.

Despite the lack of statistical significance, students were indeed exposed to a series of complex tasks during the later stages of the course. These included simulations of transportation carbon emissions, campus building carbon inventory analysis, and report writing for ESG cases. These tasks required students to interpret incomplete information and formulate strategies within limited time frames, closely mirroring real-world conditions. Such challenges contributed to the development of logical reasoning and strategic problem-solving skills, helping students gradually establish a systematic approach to tackling problems.

However, the internalization and demonstration of problem-solving abilities typically demand higher-order thinking and long-term training. As such, significant improvement in this area may not be easily reflected in short-term quantitative measures. Future implementations may consider extending the duration of project-based activities, increasing the frequency of decision-making simulations, and incorporating qualitative feedback or process records. These measures can enhance students’ reflection and strategy adjustment, thereby improving both the observability and statistical significance of learning outcomes in this aspect.

3.6. Fifth Aspect: Innovation

According to the results of the Wilcoxon signed rank test ($p = .027$), as shown in Table 6, the posttest median score for the Innovation aspect was significantly higher than the pretest score, indicating a notable improvement in students’ innovation performance after completing the course. Since the normality assumption was not met for this aspect, a non-parametric test was employed. The results demonstrate that the course had a statistically significant positive effect on students’ creative thinking and practical innovation abilities.

Table 6. Wilcoxon signed rank test results for Innovation.

Comparison	Test Method	p-value	Statistical Conclusion
Pre vs. Post	Wilcoxon signed rank test	.027*	Not statistically significant

Note: * $p < .05$.

This improvement can be primarily attributed to the curriculum design, which integrated project-based tasks and problem-based learning activities centered around real-world ESG topics. Regardless of their academic backgrounds, most students had limited prior exposure to sustainability issues, making these topics relatively novel and challenging. Tasks such as estimating transportation-related carbon emissions and conducting campus building carbon audits required students to apply newly acquired methods, construct analytical frameworks, and generate feasible solutions independently. This process encouraged students to move beyond textbook knowledge and adopt diverse perspectives in interpreting sustainability challenges, leading to the development of original and actionable strategies.

While industry experts provided contextual background to support students’ understanding, their guidance ensured that students’ creative interpretations of sustainability issues were grounded in practical relevance and remained on the right track. Overall, the statistically significant improvement in this dimension confirms that the course’s integration of theoretical foundations and hands-on application effectively enhanced students’ capacity for creative thinking, interdisciplinary integration, and innovative problem interpretation.

3.7. Sixth Aspect: Information Technology Application

According to the results of the paired sample t test ($t = -0.456$, $df = 31$, $p = .651$), as shown in Table 7, students’ average post-test scores in the “Information Technology Application” dimension showed a slight increase compared to the pre-test, but the difference did not reach statistical significance. This result indicates that although the course included content related to digital tools and system operations, the students’ ability to apply information technology did not show significant improvement in this assessment.

Table 7. Paired sample t test results for Information Technology Application.

Comparison	Mean Difference	t	df	p-value
Pre - Post	-.437	-.456	31	.651

Note: * $p < .05$.

One possible explanation is that the students enrolled in this course already possessed fundamental digital skills. As a result, the systems and tools adopted in the course, such as Excel and the Carbon Management System, did not present sufficient challenges to facilitate significant skill enhancement. Moreover, the course’s ICT components primarily served as supportive tools and did not focus on cultivating advanced abilities such as information integration, system analysis, or data visualization.

In addition, certain tools required students to manually input numerous parameters, which may have led to difficulties in correct usage due to a lack of familiarity. This highlights a need for future instructional designs to provide predefined parameter settings or guided simulation modules to help students develop a clearer understanding of system functions before actual operation.

Despite these limitations, the inclusion of practical components, such as the hands-on implementation of carbon inventory systems and ESG data organization tasks, still offered students opportunities to apply digital tools in real-world sustainability contexts. Future courses that incorporate more structured training in data analytics, visual representation, and ESG information platforms may further enhance students’ capabilities in Information Technology Application.

3.8. Qualitative Student Feedback

- Improved Understanding of ESG and Carbon Inventory Topics:
Many students reported an enhanced understanding of ESG concepts, carbon inventory methods, and related terminology, including carbon tax, carbon credits, and net-zero emissions. Qualitative student feedback includes: “This course helped me understand the meaning and practice of net-zero carbon and how to conduct carbon inventory,” and “I learned a lot about carbon-related professional knowledge, such as what carbon credits and carbon taxes are, and why net-zero is important across industries.”
- Positive Feedback on Course Design and Instruction
Students generally appreciated the course structure and the efforts of the teaching team, noting that both the instructors and teaching assistants were actively engaged. For example: “The teacher and TA were very dedicated; there were many activities,” and “The guest speakers made the course very rich,” and “The real-world case studies helped me realize that ESG is not just about ethics, but a critical factor for corporate competitiveness.”
- Practical Experience through Practical Tasks and Field Visits:
Several students highlighted that assignments such as carbon emission simulations, transportation tracking, and energy audits deepened their understanding and interest in environmental issues. Feedback included: “Actually doing carbon inventory calculations helped me grasp the concept,” and “I learned a lot from this course, and the company visit enriched the overall experience.”

- **Challenges Faced and Suggestions for Future Improvement:**
A few students expressed difficulty in comprehending some of the more complex course content. For instance: “The classroom atmosphere was relaxed, and I learned useful knowledge, but some deeper topics were hard to understand.” Others suggested that adding more examples of local business sustainability practices or site visits would enhance relevance and engagement.

4. Discussion

The results of this study revealed significant improvements in two of the six core competency aspects, communication and innovation, as evidenced by statistical significance ($p < .05$). These findings are consistent with previous research indicating that problem-based learning (PBL) and authentic project tasks can effectively enhance students' expressive and creative abilities, particularly when embedded within real-world sustainability issues (e.g., SDG-oriented education initiatives)[28–30]. For example, the students' increased performance in communication may be attributed to the inclusion of oral presentations, group discussions, and inter-group proposals, which align with prior studies emphasizing the role of collaborative discourse in strengthening workplace communication skills[31–33].

On the other hand, competencies such as continued learning, interpersonal interaction, problem solving, and information technology application did not reach statistical significance. Nonetheless, all four demonstrated a consistent upward trend, suggesting that the course had a generally positive impact across multiple dimensions[34,35]. These partial gains may be attributed to the limited duration of the course (16 weeks)[36], students' varied academic backgrounds, and the inherent complexity of the subject matter, which encompasses carbon emission calculations, boundary setting, and multi-departmental collaboration.

In light of this, our findings contribute to the growing literature on sustainability education by demonstrating how integrated ESG and PBL frameworks can be applied effectively in a general education setting. Compared with similar studies that reported improvements in innovation and interdisciplinary thinking through active learning methodologies, our results affirm the value of immersive, data-driven projects such as carbon footprint estimation using the CarbonKeeper software and field-based carbon inventory assessments.

Given the technical depth and cross-disciplinary requirements of the course, lower-year students in particular faced challenges in comprehending emission factor systems (e.g., DEFRA and IPCC) and producing data-driven analytical reports. This suggests a need for differentiated instructional design or the incorporation of pre-course foundational modules to better support learners with limited prior exposure. These insights resonate with studies that underscore the importance of scaffolding and long-term experiential learning to foster higher-order problem-solving and sustained engagement[37–39].

Future research could explore the course's long-term effects on student behavior, career orientation, and sustainability literacy[40,41]. It may also be worthwhile to incorporate mixed-method approaches, such as follow-up interviews or classroom observations, to deepen the understanding of students' cognitive and affective development[42]. Furthermore, the course structure could be adapted for cross-institutional deployment, allowing comparative studies across contexts[43] and helping to formulate a more unified pedagogical framework for sustainability education in higher education.

5. Conclusions

This study implemented a general education course that integrated problem-based learning and practical tasks focused on ESG and carbon inventory, aiming to enhance students' sustainability competencies. The results of the paired sample t test and Wilcoxon signed rank test revealed significant improvements in the Innovation and Communication Aspects, while other areas, such as

Continued Learning and Problem Solving, showed positive, though statistically non-significant, trends.

Despite the limited significance across all aspects, qualitative feedback demonstrated that students gained a clearer understanding of ESG-related topics and became more engaged through hands-on project tasks such as carbon footprint estimation, data collection, and campus site analysis. These findings suggest that the incorporation of real-world sustainability challenges can foster students' creativity, critical thinking, and motivation to engage with emerging global issues.

Furthermore, the combination of classroom instruction, practical task design, expert insights, and field-based activities contributed to a learning environment that bridged theoretical content with real-world application. While industry experts provided contextual background, students were encouraged to independently explore complex sustainability challenges and transform their ideas into actionable solutions thereby strengthening their innovation skills.

To further enhance the educational impact, future courses may consider extending the duration of project implementation, incorporating advanced digital analysis tools, and reinforcing interdisciplinary collaboration. These improvements could help students consolidate their problem-solving abilities and information technology competence while deepening their engagement with sustainability topics. Overall, this research supports the potential of combining PBL with ESG-focused content to cultivate essential 21st-century competencies and sustainability literacy among students from diverse academic backgrounds.

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Institutional Review Board Statement: Ethical review and approval were waived for this study due to its nature as a non-clinical educational research project involving human participants through anonymous and voluntary participation. Although the study involved interaction and data collection from identifiable individuals or groups, it was conducted under the guidance of institutional policies requiring prior submission of recruitment and informed consent documentation. These documents included the name of the research institution and funding source, research objectives and methods, contact information of the principal investigator, protection mechanisms for participants' rights and personal data, data retention and usage plans, and participants' right to withdraw consent at any time.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study. Written informed consent has been obtained from the participants to publish this paper.

Data Availability Statement: The data that supports the findings of this study are available on request.

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