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Team-based projects incorporating eco-friendly packaging and conservation principles to improve students' sustainability awareness in environmental chemistry courses

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ABSTRACT
It's clear that understanding sustainability is super essential for dealing with the environmental problems we face now and will face later. But we still don't know how to teach it in colleges, mainly in environmental science and chemistry education classes. This study tries to create a lecture program for environmental chemistry using team projects focused on eco-friendly packaging and saving resources. This is because we need better ways to teach sustainability. The study uses a research and development method, following the ADDIE model (which is just a way to plan how to prepare something). They got info from 124 college students in environmental chemistry, and the program they made has lesson plans, how the team projects should work, and ways to grade them. The effectiveness of the program was assessed using normalized gain (N-Gain) and paired sample t-test analysis. While the program demonstrated high validity (92.5%) and practicality (95%), and produced a moderate improvement in students' sustainability awareness (N-Gain = 0.6, $p < 0.05$), certain limitations remain. The research was conducted within a single institution and over a relatively short period, limiting the generalizability and long-term insights of the findings. Future research should explore the scalability of this approach across diverse educational settings and investigate the sustained impact of such programs on students' attitudes and behaviors towards sustainability.

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Introduction

As is known, plastic, which started being used around 50 years ago, has now become an inseparable part of human life. It is estimated that between 500 million and 1 billion plastic bags are used each year globally, amounting to around 1 million bags per minute. To produce them, 12 million barrels of oil are needed annually, and 14 million trees are cut down. Excessive plastic consumption results in vast amounts of plastic waste. As it is not made from biological compounds, plastic is non-biodegradable. It is estimated that plastic takes 100 to 500 years to fully decompose (Putra & Wahid, 2021; Maida et al., 2020).

Plastic bag waste pollutes the soil, water, oceans, and even the air. Plastic bags are made from ethylene, a gas produced by distilling oil. Oil, gas, and coal are non-renewable natural resources, so increasing plastic use depletes these resources faster. Plastic is mostly made of polyvinyl polymers. These polymers come from polychlorinated biphenyls (PCBs), which look a lot like DDT. It takes anywhere from 100 to 500 years for plastic to break down in the ground (Febrianta & Yuwono, 2022; Enfrin et al., 2021; Kik et al., 2020).

Plastic waste management requires a mix of policy, technology, and behavior change, with education for sustainable development (ESD) as a key driver in developing the right attitudes and skills. It will help the individual gain the ability to be able to act and take decisions that can help in ensuring environmental integrity through means such as minimizing the use of plastics, encouraging recycling, and finding new ways of managing waste. Through inclusion of the concepts of sustainability in educational curriculum, it will help the individual assess their daily decisions which may have an effect on the environment such as the use of plastics, hence being able to effect change in their environment. Therefore, education regarding the environment and conservation plays a vital role in addressing the issue of pollution, climate change, and resource management (Khairina et al., 2020; Amin et al., 2020).

Environmental chemistry focuses on the interactions between chemicals and their environment, whether naturally occurring or artificial. At present, as global connections strengthen and sustainability is prioritized, it is increasingly essential for students of chemistry and related disciplines to become acquainted with environmental chemistry and the principles of ESD (Agbedahin, 2019; Bascopé et al., 2019).

ESD is a way of teaching that includes subjects on keeping things going, such as environmental, social, and financial issues, as part of learning (Sinakou et al., 2019; Kioupi & Voulvoulis, 2019). Education based on ESD aims to help students develop their understanding, knowledge, attitudes, and skills so they can address issues and build a future that lasts. For instance, in an environmental chemistry course, group projects on using eco-friendly packaging and conservation can help students learn more about sustainability.

Sustainability awareness is what people know, how they feel, and what they do to keep environmental, economic, and social systems going strong (Wamsler, 2020; Rieckmann, 2018). It encompasses three areas: cognitive (sustainability issue and solution knowledge), affective (attitude, values, and concern for sustainability), and behavioral (actual or planned sustainable behavior) (Evans, 2019; Bascopé et al., 2019). It consists of several indicators, including knowledge of sustainability principles, positive attitude, behavioral intentions, and critical thinking for solving sustainability-related problems.

Learning about sustainability awareness is imperative for students, as they are future leaders, entrepreneurs, and decision-makers who will shape society and address ongoing global challenges (Abulibdeh et al., 2024; Khan, 2023; Motzer et al., 2021). Sustainability awareness educates students about intertwined environmental, social, and economic challenges, cultivating responsibility and willingness to act (Ningsih & Akhyar, 2024). Sustainability awareness empowers students to adopt sustainable practices, make informed decisions, and develop solutions that support the sustainable development and conservation of natural resources. Sustainability awareness also equips students to contribute to a world that will increasingly focus on sustainable goals, preparing them for their individual growth, employability, and potential to introduce constructive changes in society (Rieckmann, 2018; Wamsler, 2020; Evans, 2019). Teamwork that integrates eco-friendly packaging and conservation in environmental chemistry can help mitigate the adverse effects of plastic packaging that doesn't break down (Moshkbid et al., 2024; Matarazzo et al., 2020).

To meet the requirement of enhanced awareness of sustainability in environmental chemistry education, there is a need for innovative methods of learning. The current research centers on team-based projects (TBPs), which engage students in solving problems and performing practical activities like designing environment-friendly packaging and formulating conservation strategies. Contemporary studies encourage the application of learning and project-based approaches to facilitate understanding of sustainability by students.

Several important questions are investigated in the study. First, what level of improvement in students' understanding of sustainability can be achieved using a team-based lecture course on environmental chemistry with an emphasis on the design of environmentally friendly packaging and conservation? Secondly, what is the students' reaction to implementation of the proposed instruction approach that is team-based projects in environmental chemistry education?

Course development research for an Environmental Chemistry course on eco-friendly packaging technology will be done to integrate environmental chemistry concepts, conservation concepts, and eco-friendly packaging technologies within the higher education syllabus. The motivation to integrate eco-friendly packaging technology comes from its multi-disciplinary characteristics as well as its applicability towards addressing practical environmental issues. Eco-friendly packaging technology will serve as a real-world means of imparting chemical concepts such as biodegradation, green synthesis, and life cycle analysis while sensitizing students about the concept of sustainability and innovation in everyday practice.

There have been previous endeavors that have touched on various aspects pertinent to such integration. Pratiwi et al. (2023) and Mitarlis et al. (2023), for instance, have noted the salutary impacts of conservation-themed chemistry education on students' pro-environmental behavior and cognitive understanding of sustainability. Maidou et al. (2019) and Man et al. (2023) have summarized the application of green chemistry principles and project-based learning to enhance sustainability competencies. So too, Anthony Jnr (2021) has highlighted the role of sustainability thinking towards responsible innovation, while Kanapathy et al. (2020) and Janakiraman et al. (2021) have briefly touched on eco-innovation in packaging and its role towards environmental literacy. What, however, has yet to be accomplished despite such valuable endeavors is to bring together all of environmental chemistry, conservation values, eco-friendly packaging technology, and Education for Sustainable Development (ESD) into a single, systematically conceived course program.

Thus, the novelty and latest contribution of this study lie in its holistic integration of science content knowledge, sustainability values, and technological breakthroughs, encapsulated within the context of environmentally friendly packaging in a framed environmental chemistry course. It not only addresses the cognitive aspects of learning chemistry but also enhances students' affective and behavioral abilities relevant to ESD targets.

There has been particular emphasis on universities in preparing leaders and professionals who are sustainability aware (Abulibdeh et al., 2024; Khan, 2023; Motzer et al., 2021). Interdisciplinary, project-based methods are increasingly advised for integrating sustainability across curricula, encouraging active participation and deeper understanding (Sinakou et al., 2019; Kioupi & Voulvoulis, 2019). Empirical research indicates that they lead to transformative learning and broader implementation of sustainable behaviors (Wamsler, 2020; Bascopé et al., 2019). In spite of all the progress, most science curricula, including environmental chemistry, are poorly represented by holistic models that incorporate team-based tasks, conservation values, and practical work, such as environmentally friendly packaging, explicitly (Mitarlis et al., 2023; Kanapathy et al., 2020; Man et al., 2023).

The concept of eco-friendly packaging is a natural platform for teaching sustainability because it combines environmental problems with the use of scientific knowledge in practice. There are a number of recent research results indicating that bioplastics and biodegradable materials, such as starch, cellulose, chitosan, alginate, and biomass-based materials, can serve as good substitutes for traditional plastic products provided that their environmental impact depends on their performance, manufacturing process, and life cycle (Khalid & Arif, 2022; Van Roijen & Miller, 2022; Wang et al., 2022). Project and cooperative learning methods used in higher education are capable of transforming sustainability problems in reality into educational experience, which is associated with students' teamwork and sustainability skills development (Birdman et al., 2022; Guerra et al., 2022). Thus, projects of eco-friendly packaging are not only product development activities but also can be considered as interdisciplinary educational platforms.

The concept of sustainability awareness is not limited to student awareness of environmental concerns but involves student attitudes, values and readiness to apply such awareness in sustainable practices. Recent research in higher education suggests that students may have strong sustainability knowledge, but less effective attitudes and behaviors which point to the importance of learning approaches that integrate awareness and practice (Farliana et al., 2024; Ovais, 2023). For effective sustainability education, it is important to focus on experiential and practice-based learning methods, rather than traditional teaching, since sustainable knowledge is related to developing specific sustainability competencies such as systems thinking, critical thinking, collaboration and solving of sustainability problems (Lozano et al., 2022; Brundiers et al., 2021; Kioupi & Voulvoulis, 2022). Thus, it would be relevant to implement sustainability awareness in team-based projects such as sustainable packaging.

Team-based projects provide a structured pedagogical approach for engaging students in authentic sustainability problems through shared responsibility, collaboration, and collective problem-solving. Research in higher education shows that well-designed project-based learning can strengthen collaboration, student autonomy, real-world application, and sustainability competencies (Birdman et al., 2022; Konrad et al., 2021). Effective teamwork also depends on meaningful peer interaction and appropriate instructor facilitation, which support communication, interpersonal competence, and the integration of diverse perspectives (Konrad et al., 2021; Bolstad et al., 2023). In sustainability-oriented projects, interdisciplinary collaboration enables students to connect scientific knowledge with complex environmental problems and develop feasible solutions through inquiry and reflection (Paristiowati et al., 2022; Domingues, 2025). Thus, team-based projects centered on eco-friendly packaging can provide an integrated mechanism for connecting sustainability awareness, environmental chemistry, collaborative inquiry, problem-solving, and sustainable action.

Although the above possibilities have been identified, very little research has actually focused on incorporating team-based project learning along with conservation and environmental chemistry through eco-friendly packaging in environmental chemistry education. This calls for developing an instruction model which will involve students in solving real-world environmental issues by incorporating scientific investigation, collaboration, conservation, and sustainability. Therefore, this paper will focus on developing and evaluating an integrated instruction model, which involves all of the above-mentioned concepts along with environmental chemistry, conservation, eco-friendly packaging technology, and sustainability awareness in an integrated team-based project model. What makes the proposed research unique is its explicit integration of these concepts, which have been approached separately in most cases in previous research. This is especially true because of the continued environmental challenges caused by plastic packaging technology due to its non-biodegradable nature.

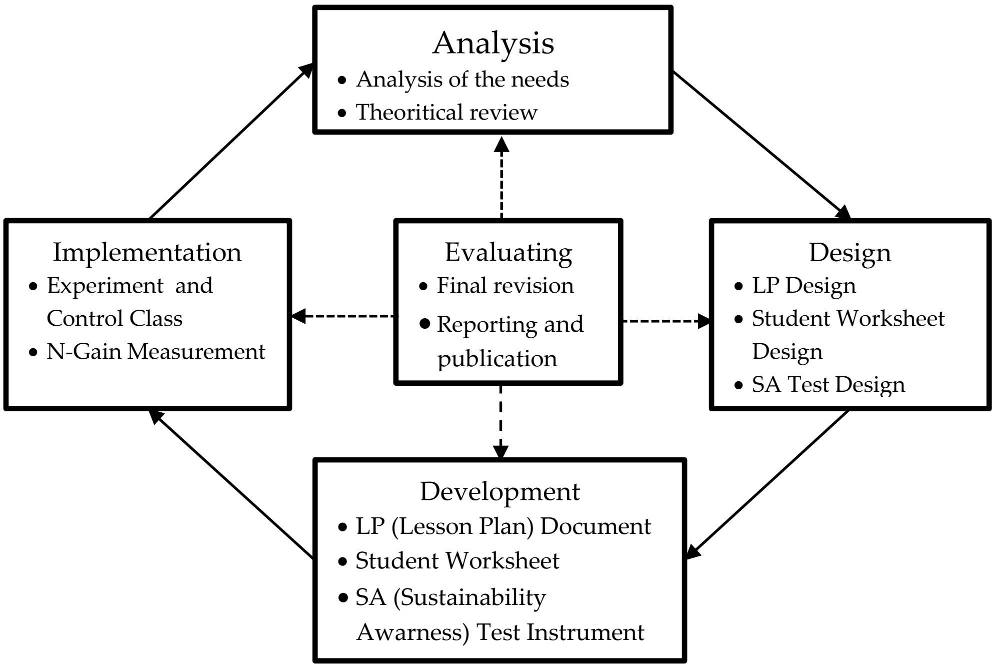
Higher education, particularly courses such as environmental chemistry, is crucial for equipping students with scientific knowledge and sustainability awareness. Therefore, this study aims to contribute to learning innovation by embedding eco-friendly packaging technology as a contextual entry point to help students critically understand and address the negative environmental impacts of plastics while cultivating their competencies in Education for Sustainable Development (ESD).

Method

Research and development methods using the ADDIE model (Analysis, Design, Development, Implementation, and Evaluation), according to Branch (2009), have been carried out to develop an environmental chemistry lecture program that provides insight into environmentally friendly packaging technology and conservation to improve students' ESD competencies. The subjects of this study were students in the Chemistry Education and Environmental Science Study Program at the Faculty of Mathematics and Natural Sciences, Semarang State University.

Figure 1

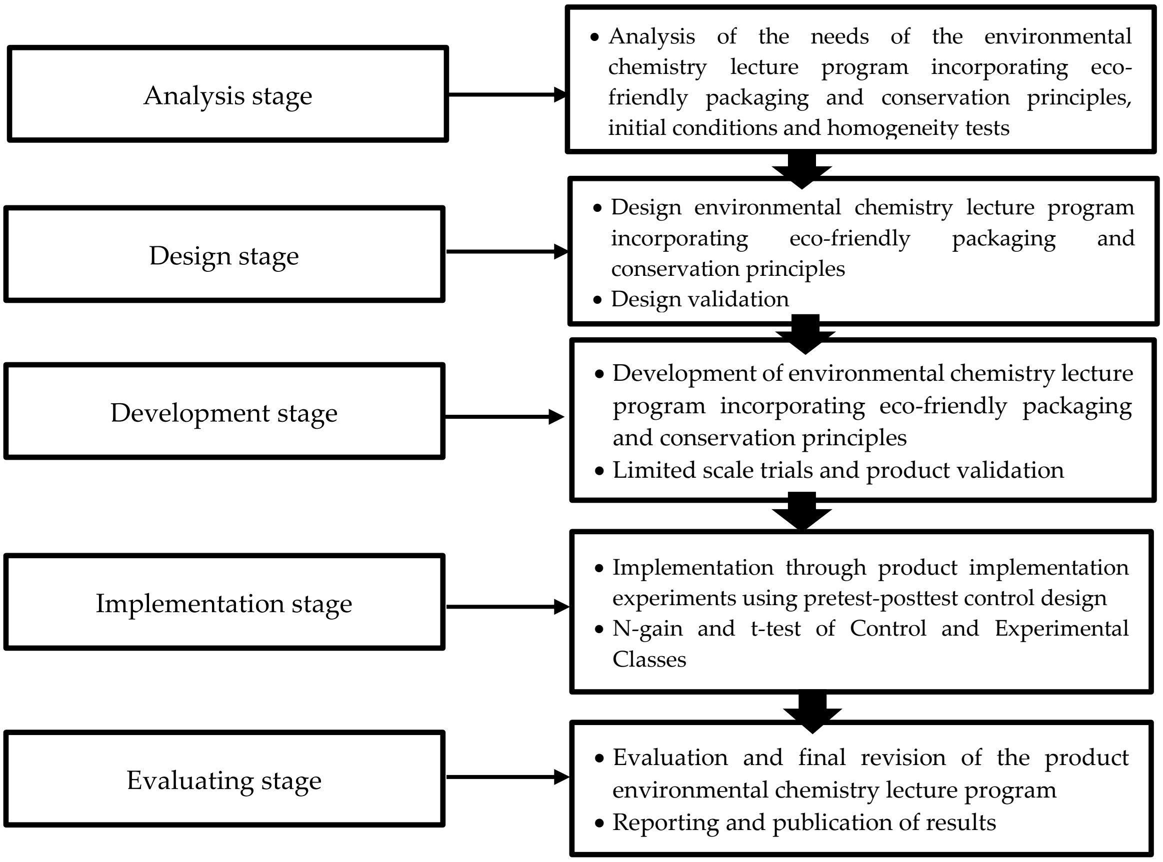
The ADDIE model adapted from Branch (2009)



This development procedure follows the ADDIE instructional research and development procedure, which aims to produce an environmental chemistry lecture program product that provides insight into environmentally friendly packaging technology and conservation to improve students' ESD competencies. ADDIE is a development model consisting of five stages, namely Analysis, Design, Development, Implementation, and Evaluation. The R and D stages with the ADDIE model in this study are shown in Figure 2.

Figure 2

ADDIE Design Implementation Flow for Lecture Program Development



The stages in developing an environmentally conscious environmental chemistry course program focused on eco-friendly packaging technology to enhance sustainability awareness include the following: Analysis, this stage involves conducting a needs analysis, identifying problems (needs), carrying out task analysis, and determining the research sample. At this stage, the environmentally conscious environmental chemistry course program, focused on eco-friendly packaging technology to enhance sustainability awareness, is created. The design is then evaluated and improved before being realized in the final product. At this stage, the product design is still conceptual and will form the foundation for the next development process.

The development phase translates the conceptual design into a complete environmentally conscious environmental chemistry course program centered on eco-friendly packaging technology and sustainability awareness. Development involves developing such components as the course syllabus, learning outcomes, teaching materials, project instructions, student worksheets, assessment tools, and learning resources. Learning activities will be planned according to the nature of the topic of environmental chemistry where chemical concepts will be linked with practical environmental issues especially regarding plastic pollution, material selection, biodegradability, waste handling, and environmental consequences of packaging. Implementation of the course will involve group projects where students will have to identify environmental issues concerning packaging, study the chemical and environmental properties of other materials, develop environmentally friendly packaging prototypes, and evaluate the properties and the environmental aspects of the solutions. After that, the developed course program will be tested in a limited scale within the classroom environment in order to check the feasibility and practicability of the course program as well as its compliance with the specified learning outcomes.

The process of evaluation is done systematically to gauge the validity, practicality, and preliminary success of the newly designed course program. Firstly, an FGD of experts is carried out to evaluate whether the course program, its objectives, environmental chemistry knowledge, conservation knowledge, eco-friendly packaging project, the learning activities, and the assessment tools conform to the theoretical framework and the nature of higher education. Expert feedback is analyzed and the course program revised prior to its actual implementation. Secondly, survey responses of the students are collected after completion of the learning activities to gauge student perceptions about the clarity, relevancy, feasibility, level of engagement, collaborative learning, and contribution of project activities to awareness of sustainability. Evaluation results based on the experts' and student feedbacks are triangulated to establish areas of strength as well as areas needing revision of the course program. The revisions made represent the final environmentally conscious environmental chemistry course program design.

Participants

The sample consists of four classes, two classes from the Chemistry Education program and two from the Environmental Science program, comprising a total of 124 undergraduate students enrolled in the Environmental Chemistry course during the even semester of 2024. These students are in their 4th semester and have previously completed prerequisite courses in general chemistry and basic environmental science, making them pedagogically and cognitively prepared for the integration of eco-friendly packaging technology in the course. The sample was selected purposively based on key considerations, including student academic background, learning objectives, and the thematic relevance of sustainable packaging to their respective fields. This selection aims to ensure that the program implementation can optimally foster students' sustainability awareness, scientific understanding, and application of environmentally responsible practices.

Data Collection Tools

The data collection tools in this study were systematically developed based on the stages of the ADDIE model to ensure alignment with the research objectives. During the Analysis phase, data were collected through three main instruments: (1) a student needs analysis questionnaire to assess students' prior knowledge and perceptions related to environmental chemistry and sustainability, (2) semi-structured interview guidelines for lecturers to explore their perspectives on integrating eco-friendly packaging technology in the course, and (3) a literature review checklist to identify gaps in existing curricula and instructional practices.

In the Design phase, instruments were developed to support instructional development and to measure students' initial competencies in practice. These included (1) lesson plan and lecture module validation sheets, which experts reviewed to ensure alignment with sustainability principles in a practical context, and (2) a pretest instrument on sustainability awareness, designed using validated items that measure dimensions such as students' understanding of environmental issues, attitudes toward sustainability, and knowledge of eco-friendly packaging. This pretest served as a practical baseline for students' sustainability awareness prior to their participation in the course.

Before implementing the environmental chemistry course program, which incorporates team-based projects on eco-friendly packaging and conservation principles, a pretest was administered to assess students' initial sustainability awareness. Pretest was made up of 20 multiple choice questions, where five of them covered each of four indicators, which included knowledge of sustainability concepts, attitude towards sustainability practices, behavioral intention of sustainability, and critical thinking and problem solving. The questions were created in accordance with the operational definitions of the four indicators and were rated by five experts in a five-point scale. Content validity was assessed using Aiken's V coefficient, with item-level values ranging from 0.85 to 0.95 ($M = 0.90$), indicating satisfactory content validity. The instrument was subsequently pilot-tested with 30 students with characteristics comparable to those of the target sample. Item analysis showed point-biserial correlations ranging from 0.35 to 0.61, difficulty indices ranging from 0.53 to 0.73, and discrimination indices ranging from 0.37 to 0.60. Each of the 20 items fulfilled the pre-set requirements and remained included, while reliability was calculated using the KR-20 coefficient which gave the value of 0.89. Students were allowed 60 minutes for testing, and the results from the pretest formed the quantitative baseline that will be compared with the posttest performance of the students to measure their improved knowledge on sustainability.

Quantitative data from the surveys and pretests were analyzed descriptively and inferentially, while qualitative data from interviews were analyzed thematically. These combined instruments and methods provided a comprehensive understanding of the learning context and the impact of the course design.

For the developmental and implementation phases, the instructional learning materials, multimedia and activities were created and tested. Post-tests and surveys were also used to evaluate the degree to which students learned and the level of their engagement with the program. Feedback from experts was also obtained for improving the learning materials. At last, numerical and feedback instruments were used to measure the success of our program. The number-oriented data comprised test scores to evaluate students' knowledge of sustainability issues. On the other hand, feedback from surveys and group discussions helped assess the effectiveness and usefulness of the lecture program.

Data Analysis

We analyzed the data using both quantitative and qualitative methods. The number-based part assessed how well students understood sustainability. We did this by comparing their scores before and after the teaching, using a formula by Hake (2002a, 2002b).

$$\text{N-Gain}=\frac{Posttest\ Scor-Pretest\ Scor}{Maximum\ Scor-Pretest\ Scor}$$

Where:
Posttest Score: The score obtained after learning.
Pretest Score: The score obtained before learning.
Maximum Score: The highest possible score
Here is the N-Gain Interpretation Categories:

Table 1

The N-Gain interpretation categories

Category	N-Gain Range
High	N-Gain ≥0.7
Medium	0.3≤ N-Gain <0.7
Low	N-Gain <0.3

We used a paired-samples t-test to compare average grades before and after the program to determine whether our green lecture series made a real difference. This test works well when looking at two sets of data connected, like pre-and post-test results, to see if a teaching method is any good (Creswell & Creswell, 2017).

We ran a t-test on the pre- and post-test scores to determine whether the lecture series increased students' awareness of sustainability. We set our cutoff for a real difference (alpha) at 0.05, which is standard for education research (Fraenkel, Wallen, & Hyun, 2012). To better understand how much the lecture series changed things, we also figured out the effect size using Cohen’s d. This indicates whether the change was small (0.2), medium (0.5), or large (0.8), according to Cohen (1988). The t-test results and the effect size give us a clearer idea of what the program did.

Thematic analysis was applied to the student feedback and discussions within the groups. Thus, we were able to identify the themes associated with students' experiences and impact on their perception of the issue of sustainability (Braun & Clarke, 2006). We analyzed, categorized, and interpreted the feedback in order to find out how effective the instruction process was and how motivated students were towards the packaging.

Several sources of data were used to ensure the credibility of the research findings. We analyzed surveys, group discussions, and expert opinions (Creswell & Poth, 2018). Such an approach provides for credibility and reliability of the research findings. A combination of numbers and narratives provided us with a better insight into the effectiveness of the lecture program.

Results and Discussion

This research was a collaborative project on eco-friendly packaging and conservation for an environmental chemistry class. The goal was to raise students' awareness of sustainability, and the project was meticulously planned using the ADDIE model, with each team member contributing their expertise.

At each stage of the ADDIE model, we developed tools to gather data. The initial phase involved a comprehensive student needs analysis facilitated through surveys, lecturer interviews, and group discussions. These discussions were instrumental in identifying gaps in current teaching methods and in shaping the program to meet students' educational needs.

During the group discussions, considerations on the choice of the appropriate sample for the program tests were discussed. Among the aspects considered during the sample choice included the nature of the students, their learning requirements, and the relevance of the packaging technology to the environment. The choice of sample made in this regard would mean that the program will make the learners more sustainable. This is in line with current trends on the need for sustainability-oriented higher education programs that are linked to students' competencies and learning needs as sustainability competencies develop better through learning that addresses practical real-life issues (Redman & Wiek, 2021; Bianchi et al., 2022; Leal Filho et al., 2023; Yakar-Pritchard et al., 2024).

Aside from the sample determination, the FGD was also used to measure the initial conditions of the students who will be used as the subjects for this study. Initial conditions of the students include their basic knowledge about ESD and environmentally friendly packaging technology. This information was used to serve as the basis for developing an appropriate learning strategy. Homogeneity test of the sample has also been done and based on the results, it can be seen that the samples possess relatively homogeneous characteristics and thus it will be easy to determine the outcome of the implementation of the program. The need to assess the sustainability knowledge of the students is further emphasized by the recent studies which state that even though university students have positive environmental attitude, they lack sustainable knowledge (Alvarez-Risco et al., 2022; Redman & Wiek, 2021; Farliana et al., 2024; Aquan et al., 2025).

From the test carried out on the homogeneity on the sample classes within the Chemistry and Environmental Science Education Study Programmes, the findings were that the data satisfied the homogeneity requirement. The test was carried out to ensure that the variables measured within the sample classes shared similar fundamental characteristics such as the level of knowledge about the concepts of education for sustainable development (ESD) and the environmentally friendly packaging technology. The test results showed that there was a probability of 0.45 ($p > 0.05$). The result is significant since the comparable characteristics allow for a better interpretation of differences within the sample classes as a result of the instruction programme and not because of significant differences before carrying out the test as recommended by other researchers (Redman et al., 2021; Kioupi & Voulvoulis, 2022; Xiao et al., 2024; Null et al., 2024).

These findings prove that the selected classes are relatively homogeneous in terms of the variables that were analyzed. Therefore, they can be considered an appropriate proxy for the full-scale program. Such homogeneity will help prevent external factors from affecting the effectiveness of the learning process. It will also contribute to ensuring that the outcome will be more relevant. Consequently, the assessment of homogeneity is one of the crucial steps that should be done prior to implementing the full-scale program (Braithwaite et al., 2018; Kraft, 2020).

Moreover, the homogeneity analysis found out that such characteristics as educational background, age, and learning experience were not statistically significant in terms of the differences among the sample classes. This finding is methodologically important because establishing comparable baseline characteristics can strengthen the interpretation of changes in sustainability-related outcomes by reducing concerns that observed differences are primarily attributable to pre-existing differences among the participating groups (Redman et al., 2021; Kioupi & Voulvoulis, 2022; Xiao et al., 2024). Because of these results, we could proceed to the next stage of the program with greater confidence in interpreting the outcomes of the intervention.

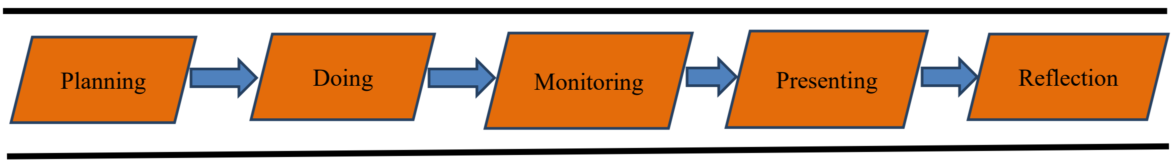
The FGD results indicated that two classes from the Chemistry and Environmental Science Education Programs at the Faculty of Mathematics and Natural Sciences, Universitas Negeri Semarang, were selected as the test groups. This choice was based on an assessment of the program requirements and the students' initial conditions. With the homogeneity test completed, the selected classes were considered sufficiently comparable to support the implementation and evaluation of the ESD program. Such alignment between students' initial conditions, intended learning outcomes, and instructional design is consistent with recent higher-education ESD research emphasizing that sustainability programs should be systematically designed and evaluated according to students' competencies and learning needs (Brundiers et al., 2021; Kioupi & Voulvoulis, 2022; Hammer & Lewis, 2023). This provides a reasonable basis for evaluating the program outcomes and assessing their potential relevance to the broader target population.

During the planning stage, we developed lesson plans and class modules that incorporate eco-friendly packaging technology and sustainability ideas. We used tools like pretests to gauge where students stood with their sustainability smarts. These pretests gave us a starting point for seeing how well the program works. Putting these learning tools to use meant using a variety of resources, like videos and interactive activities that engage people. In bringing all of these elements together, there is a lot that has been done in ensuring that the learning of the students improves. In doing so, this is in line with current science education studies which suggest that contextualized project-based learning and systematically organized environmental learning projects could lead to improved analytical and engagement abilities, as well as helping students make connections between their scientific knowledge and sustainability concerns in the world (Syawaludin et al., 2022; Lutfauziah et al., 2023).

We designed team projects for the environmental chemistry lectures that use eco-friendly packaging and focus on conservation. The goal was to get students more aware of how to be sustainable. We call this the environmentally friendly packaging technology conservation-focused environmental chemistry lecture program. You can see the design in Figure 3.

Figure 3

The design of the environmental chemistry lecture program team-based projects incorporating eco-friendly packaging and conservation principles to improve students' sustainability awareness



During the design stage, we created team projects for the environmental chemistry lecture series that incorporated eco-friendly packaging and conservation principles. This was all done to get students thinking more about sustainability. We ended up with a semester plan, a step-by-step guide for the team projects, teaching stuff for the chemistry course, and a way to evaluate the lectures. This design is consistent with recent evidence that sustainability-oriented chemistry education benefits from student-centered, project-based, and contextually relevant learning strategies that connect disciplinary knowledge with authentic environmental problems (Aydin Gunbatar et al., 2025; Yakar-Pritchard et al., 2024; Wan Nor Azmi et al., 2024).

In the course of development and implementation of our project, we have been working hard to test it and make improvements to it. We gave post-tests to find out what knowledge the students have gained and evaluate the effectiveness of the approach used. In addition, we carried out surveys among the students to get their feedback and learn about their engagement in the program. The expert groups helped us improve the teaching material and ensured that it is correct and serves its purpose. All these results of the testing and the feedback provided have helped us evaluate the progress of our project. The combination of cognitive measures and feedback is supported by the latest reviews of green and sustainable chemistry education (Aydin Gunbatar et al., 2025; Ginting & Budiasih, 2025; Suiirbay, 2025).

We created an environmental chemistry lecture program based on the use of eco-friendly packaging technology. We did this by designing a framework for team project work in class, a semester learning schedule, process of conducting team projects, teaching materials for the course, and an assessment scheme. Integration of packaging technology and environmental chemistry is conceptually relevant because current literature on green chemistry education highlights the need for embedding chemical ideas into environmental issues and application of active learning techniques to foster students' knowledge of both science and sustainability (Ginting & Budiasih, 2025; Aydin Gunbatar et al., 2025).

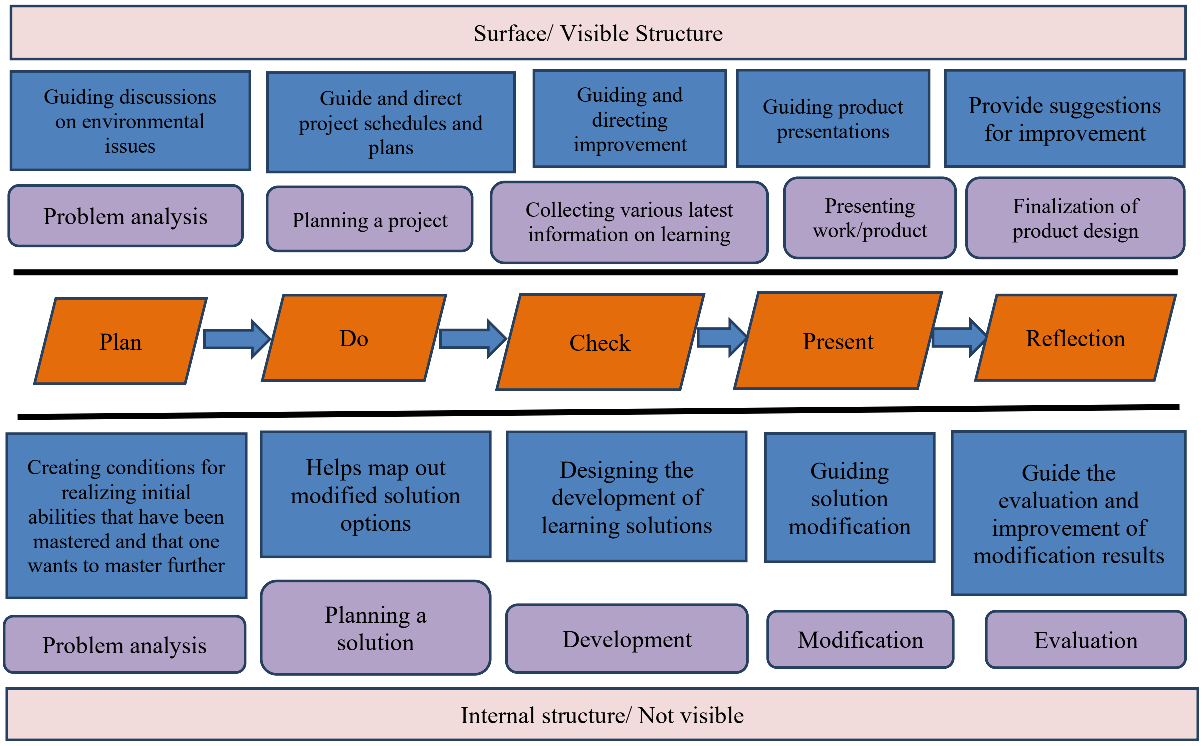
Next, the program's feasibility, in terms of its suitability for teamwork on sustainable packaging and protection, was assessed. The objective was to ensure that the program met all criteria required for it to be efficient and useful in the classroom. This assessment was conducted by three experts in environmental chemistry, sustainable education, and green technologies who verified if the information provided was accurate, the learning approach was appropriate and the program had potential for wider usage. Participation of the experts in multiple related fields corresponds with the modern research on sustainability education, which stresses the importance of alignment between disciplinary content, pedagogical approach, sustainability skills, and assessment methods in designing an ESD curriculum (Brundiers et al., 2021; Aydin Gunbatar et al., 2025; Wan Nor Azmi et al., 2024).

The results revealed that the course is very reliable and valuable. It scored 92.5% for appropriateness, which means that it correlates highly with student learning outcomes. In addition, it earned a 95% score for usability, which means that the course is easy to apply in practice. Taking all the scores into account, we expect that the lectures on environmental chemistry will contribute to the development of protection and green technology skills among students. This result is in line with the findings of recent systematic reviews, according to which properly constructed sustainability and green chemistry curricula could serve as an excellent basis for combining environmental awareness, active learning, and sustainability competencies in chemistry courses (Yakar-Pritchard et al., 2024; Suiirbay, 2025).

This experiment took place in the autumn of 2024/2025 among 124 students enrolled in the environmental chemistry course at Semarang State University. This pilot test aimed to assess the newly designed lecture course integrating group work and emphasis on environmental packaging and protection concepts. The experiment was based on the application of a one-shot case study approach using the method of structured experimental activities implemented into the existing curriculum. Semarang State University was selected as a research institution due to the commitment of this educational organization to the sustainability issue and its reputation as an innovator in environmental studies in Indonesia. Furthermore, Semarang State University is known to provide its students with an Environmental Chemistry course within its Chemistry Education program.

Figure 4

Development of syntax in the environmental chemistry lecture program team-based projects incorporating eco-friendly packaging and conservation principles to improve students' sustainability awareness



The outcome of the pretest will later be employed in assessing the N-Gain of students' awareness of sustainability in environmental chemistry lectures. The environmental chemistry lecture program involving team-based projects, which included eco-friendly packaging and conservation concepts, was applied after the pretest. The delivery of the lecture took place through the team-based project approach based on the previously validated PDCPR (Plan Do Check Present and Reflection) syntax. Conducting a pretest followed by a team-based project is in line with the latest sustainability education studies highlighting the need for determining the students' starting point and then assessing their learning outcomes after the interventions (Yakar-Pritchard et al., 2024; Widyantoro et al., 2025; Jusniar et al., 2025).

At the plan (P) stage, students work in groups to plan and design their sustainable packaging technology projects. The process comprises ideation, preliminary research, and formulation of project objectives. Students develop project plans that incorporate the elements of sustainability and technology. The project designs are then presented in the class for feedback from fellow students and instructors in order to improve their designs. The planning process is essential in teaching and learning because sustainability-focused project learning involves students' interaction of knowledge, negotiating ideas, and connecting the concepts of disciplines to solve sustainability challenges (Hidayah et al., 2025; Yakar-Pritchard et al., 2024; Widyantoro et al., 2025).

Figure 5

Team based project lecture activities at the plan stage (students plan and present environmentally friendly packaging technology development project design)

Figure 6

Students present the implementation of the environmentally friendly packaging technology project

Figure 7

Students presenting at monitoring activities or progress reports on environmentally friendly packaging technology projects

During the do (D) stage, students carry out active learning in their assigned groups as they design their environmentally friendly packaging technology projects. Each group chooses an individual topic to investigate, such as packaging made from banana stems, antimicrobial packaging, or biodegradable plastic films. In this phase, the focus on teamwork and practical application of ESD principles becomes crucial, as the students engage in problem-solving, troubleshooting, and improving their designs. This practical and collaborative aspect of the phase is justified by contemporary findings of chemistry education research revealing that project-based and experiential learning can improve students' environmental sensitivity, conceptual learning, teamwork, and connection of chemistry knowledge with sustainability issues (Jusniar et al., 2025; Hidayah et al., 2025).

At the implementation stage, students are split into eight groups. Each group comes up with environmentally friendly packaging technology design based on ESD. During the C phase, students are involved in monitoring activities, where they share their progress and early results. This phase provides students with the chance to be accountable as well as gives them the chance to have feedback on their project, helping them improve their project further. This collaborative monitoring and feedback process is consistent with recent research showing that sustainability-oriented project-based learning can facilitate knowledge exchange, collaborative problem solving, and iterative improvement as students work together to address authentic sustainability challenges (Castaño et al., 2025; Widyantoro et al., 2025).

Right now, after projects wrap up, each group gives a final presentation showcasing their eco-friendly packaging tech. They show prototypes, explain the science and technology behind them, and discuss how their ideas can be used. These presentations show they get sustainability and can turn ideas into real-world solutions. The presentation and reflection of project outcomes are pedagogically significant because experiential and project-based approaches enable students to connect disciplinary knowledge with authentic environmental problems while communicating and justifying sustainability-oriented solutions (Jusniar et al., 2025; Yakar-Pritchard et al., 2024).

Figure 8

The examples of student project results or products, a. Biopack made from dry leaf waste and fruit peel; b. Bioplastic made from cassava; c. Biopack made from banana peel and fiber waste. Biofoam made from rice straw waste; and e. Biofoam made from sugarcane pulp and starch

Figure 9

Students presenting the results of environmentally friendly packaging technology projects

At the reflection (R) stage, after the presentations, students engage in reflective activities to evaluate their learning experiences. This stage focuses on identifying challenges faced, lessons learned, and potential improvements for future projects. Students also assess the impact of their work on environmental sustainability and their understanding of sustainable awareness and ESD principles, consolidating their knowledge and skills for future applications. However, this process is highly significant in sustainability education since structured reflection will allow students to reflect on their experiences and analyze any difficulties that they have faced and link project results to broader aspects of sustainability (O'toole et al., 2026; Lo-Iacono-Ferreira et al., 2024).

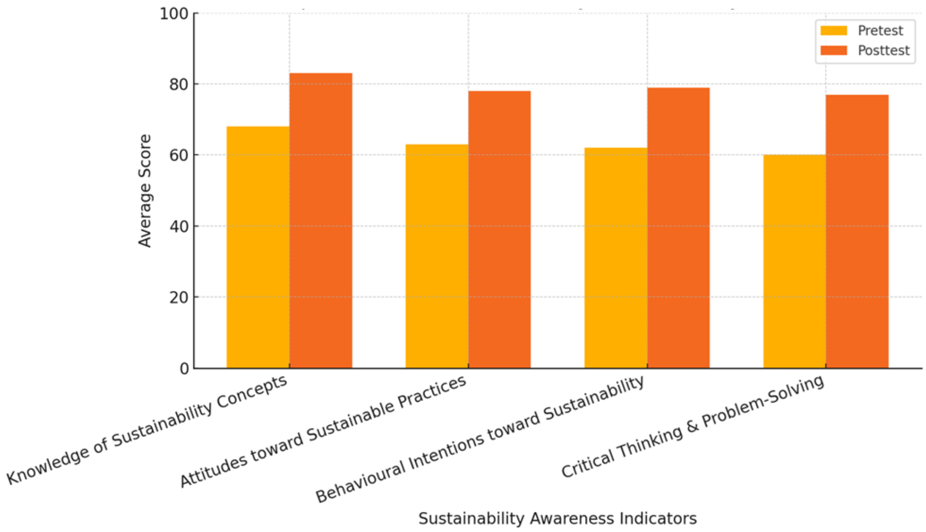
For the purpose of the evaluation of the success of the program, both quantitative and qualitative analyses were used. As for the quantitative approach, it was directed at evaluating the changes in students' awareness about sustainability. The results of limited implementation show that the implementation of the environmental chemistry lecture program team-based projects incorporating eco-friendly packaging and conservation principles to improve students' sustainability awareness. The N-Gain value of the average value of the pre-test and post-test of students is 0.6, indicating that there is an improvement on the students' sustainability awareness in the moderate criteria. This moderate gain is consistent with recent empirical evidence showing that sustainability-oriented and green chemistry learning interventions can produce measurable improvements in students' sustainability-related knowledge and awareness, particularly when learning involves active, contextual, and project-based experiences (Daulay et al., 2025; Null et al., 2024).

We used a paired sample t-test to see if the environmentally-conscious lecture program made a real difference in scores. The findings indicated a significant increase in the students' sustainability awareness, with a mean pretest score of 65 increasing to a post-test score of 80, confirming the program's effectiveness at a significance level of $p < 0.05$. This improvement is consistent with recent evidence that sustainability-oriented and green chemistry learning can strengthen students' environmental knowledge and sustainability-related competencies when instruction combines contextual problems, active learning, and opportunities to apply scientific knowledge to real-world sustainability challenges (Carvalho da Silva et al., 2026; Gorito & Morais, 2026; Kusuma et al., 2026).

Besides students knowing more about sustainability in general, a close look at each part of what makes up sustainability awareness shows big gains in all areas. In addition to the overall increase in students' sustainability awareness, a detailed analysis of each indicator of sustainability awareness shows substantial improvements across domains. Figure 10 below compares students' pre-test and post-test scores for four key indicators: knowledge of sustainability concepts, attitudes toward sustainable practices, behavioural intentions toward sustainability, and critical thinking and problem solving. This chart shows how well the course helped students get better at understanding different parts of sustainability. This multidimensional improvement is consistent with recent sustainability-education research indicating that sustainability learning should integrate knowledge, values and attitudes, behavioral orientation, and competencies for critical and solution-oriented thinking rather than treating environmental awareness as a single cognitive construct (Brundiers et al., 2021; Farliana et al., 2024; Xiao et al., 2024).

Figure 10

Improvement in Sustainability Awareness by Indicator



The environmentally-conscious chemistry lecture program led to better scores in sustainability awareness. This shows students have a better understanding of what sustainability means for the environment, society, and the economy. The Attitudes toward Sustainable Practices scores also went up, from 63 to 78 (a 24% increase). This means students are more willing to support sustainability in their lives. The biggest change was in Behavioural Intentions toward Sustainability, which went up from 62 to 79 (a 27% increase). This suggests the program inspired the students to live in a more sustainable way. Lastly, the Critical Thinking and Problem-Solving Related to Sustainability scores increased from 60 to 77, a 28% increase. This result means the program assisted students to think about sustainability problems and come up with new ideas. The increases show that the lecture program gave students the information, mindset, and skills to help with sustainability. This multidimensional improvement is consistent with recent research showing that sustainability learning should address interconnected dimensions of knowledge, attitudes, behaviors, and higher-order competencies, rather than treating sustainability awareness as a single cognitive outcome (Liu et al., 2026; Aquan et al., 2025; Jintalan, 2025; Widyantoro et al., 2025).

The results indicated that students were well-informed about the concept of sustainability and committed to it. The interviews and journals provided supporting evidence of students' understanding of the problem and their willingness to become more sustainable. These findings indicate that there is an opportunity for educating students on sustainability through school programs. Students' comments revealed their experience of working within the program. The key themes of student experience are the increased awareness of environmental issues and the applicability of the lectures to reality. The current finding is also supported by the contemporary research stating that experiential and context-based chemistry education can help learners link scientific concepts to authentic sustainability challenges, and collaborative knowledge exchange can improve students' sustainability knowledge, affective involvement, and learning-to-action capability (Tantayanon et al., 2025; Koulougliotis et al., 2024; Yakar-Pritchard et al., 2024; Chen et al., 2020).

In general, this research focused on examining the lecture program on eco-friendly packaging and sustainability education. It became apparent that the participants' level of knowledge regarding sustainability was higher compared to their initial one, since there was an improvement of test scores in such categories as knowledge, attitude, intention, and problem-solving. Thus, the use of group work and application of practical examples allowed improving knowledge and positive attitudes towards sustainability. As for the collected feedback, it revealed increased participation, motivation, and understanding of the importance of sustainability education in schools and everyday life. In particular, students stated that group work on real-life problems contributed to improved problem-solving and personal responsibility in relation to environmental issues. The obtained results are consistent with the latest research which indicates that the use of experiential and project-based approaches in chemistry and sustainability education may help develop students' environmental awareness, critical thinking skills, collaboration abilities, and integration of scientific knowledge into practical sustainable development problems (Nugroho & Dewi, 2025; Widyantoro et al., 2025; Jusniar et al., 2025; Yakar-Pritchard et al., 2024). The success of this teaching method suggests that other similar programs could raise awareness about sustainability and offer life-changing learning in different schools. Still, this study only looked at one school over a short time. More research is needed to see the long-term on students' eco-friendly actions and if the findings hold true in different schools to validate these discoveries.

Conclusion

In conclusion, this research conducted was successful in increasing the awareness of sustainable packaging among the students. It was done using a learning program designed using the ADDIE model. Gathering data using surveys, interviews, and focus groups indicated several gaps in the existing teaching program. In this way, it was possible to develop a program based on the needs of students. This research indicated that students' knowledge, attitudes, willingness to behave and think in a critical manner regarding sustainability had been improved. The results of the research indicate that not only the program enhanced students' perception of sustainability but also encouraged them to make actions that are environmentally friendly.

The research conducted in this paper is useful in incorporating sustainability education in schools mostly through programs that are well-designed and based on practical issues such as sustainable packaging. Due to significant changes achieved in all aspects studied, it is clear that such educational measures can contribute towards building sustainable behaviors and skills of thinking among the students. This will make them more prepared to handle environmental challenges on the global level.

However, there are several weaknesses in this research. First, it was conducted based on students of only one educational institution and from the programs of Chemistry and Environmental Science Education. It means that the findings cannot be easily generalized to other populations. Besides, most of the impacts were studied short-term, and more research is needed to examine long-term impacts of the program on students' sustainable practices.

Based on these findings, future research should verify the applicability of this program in different learning environments and across various disciplines. Furthermore, future longitudinal studies may reveal the long-term effects that the sustainable education program has on the lives of students in a personal and professional environment. Additionally, the application of technology-based methods, such as webinars and computerized simulations, may increase accessibility and attractiveness of the program.

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Declaration of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

Some Sample of the Sustainability Awareness Test

Instructions: Read each question carefully and select **one best answer** from the four alternatives (A–D).

A. Knowledge of Sustainability Concepts

1. In the context of Environmental Chemistry, sustainable development emphasizes the use of resources and chemical processes that ...
   A. maximize production without considering waste
   B. meet present needs while minimizing impacts on future generations
   C. eliminate the use of all chemical substances
   D. use only natural materials regardless of their production processes
2. A student compares conventional plastic packaging with starch-based packaging. From a life-cycle perspective, sustainability should be evaluated by considering ...
   A. raw materials only
   B. product price only
   C. raw materials, production, use, and end-of-life management
   D. the visual appearance of the packaging

B. Attitudes Toward Sustainable Practices

3. During an Environmental Chemistry laboratory activity, you learn that single-use plastic can be reduced by using reusable equipment when appropriate. Which response best reflects a sustainability-oriented attitude?
   A. Continue using single-use plastic because it is more convenient
   B. Use reusable equipment whenever it is safe and appropriate
   C. Leave all responsibility for plastic waste management to laboratory staff
   D. Assume that laboratory plastic use has no significant environmental consequences
4. After learning that improperly managed laboratory plastic waste can contribute to environmental pollution, a student with a sustainability-oriented attitude would most likely ...
   A. regard waste management as solely the responsibility of laboratory staff
   B. regard appropriate waste management as part of their academic and environmental responsibility
   C. dispose of all laboratory waste in a general waste container
   D. avoid discussing the environmental consequences of laboratory waste

C. Behavioural Intentions Toward Sustainability

5. **After** learning about plastic pollution, you have the choice between single-use and reusable packaging. You intend to ...
   A. always choose single-use packaging because it is more convenient
   B. choose reusable packaging when it adequately meets the intended purpose
   C. choose packaging primarily based on its colour
   D. make no distinction between different types of packaging

6. If **you** notice unnecessary single-use plastic consumption in a university activity, you would most likely ...
   A. ignore it because it is not your personal responsibility
   B. continue using the plastic without considering alternatives
   C. suggest or choose an alternative that can reduce unnecessary plastic use

D. dispose of the plastic after use without further consideration

D. Critical Thinking and Problem-Solving

7. A **biomass**-based packaging material degrades more rapidly than conventional plastic but requires substantially more energy during production. Which conclusion is most appropriate?
   A. The material is definitely more sustainable
   B. The material is definitely not sustainable
   C. Its sustainability should be evaluated by considering impacts across its life cycle
   D. Biodegradability is irrelevant to sustainability
8. A **team** identifies two packaging alternatives. Packaging X uses locally available materials but requires more energy during production, whereas Packaging Y requires materials transported from outside the region but uses less energy during production. To determine which alternative is more sustainable, the team should ...
   A. select X because locally sourced materials are always more sustainable
   B. select Y because energy consumption is the only relevant factor
   C. systematically compare relevant environmental, social, and economic considerations
   D. select the alternative preferred by the majority of team members