Is higher education curriculum prepare to support sustainable environmental chemistry learning?

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Abstract

Global environmental challenges such as climate change, pollution, and ecosystem degradation require urgent responses, and education plays a strategic role in building environmental literacy. This study aimed to evaluate the readiness of higher education curricula in supporting sustainable learning in Environmental Chemistry courses and their alignment with the Sustainable Development Goals (SDGs). The research used a descriptive approach involving curriculum and lesson plan analysis, student surveys, and interviews with lecturers and program heads at a state university in Aceh Province, Indonesia. The findings show that while the curriculum includes relevant topics such as pollution and climate change, the integration of emerging issues and practical learning methods remains limited. Students demonstrated positive attitudes and awareness toward environmental sustainability, but their active involvement in practical actions was still low. Recommendations include the explicit integration of SDGs in course plans, diversification of teaching strategies through fieldwork and case studies, and fostering interdisciplinary collaboration. Overall, the study concludes that the curriculum provides a strong foundation but requires strategic improvements to enhance its relevance and impact. Aligning academic programs with global and local environmental challenges will enable higher education to prepare students as proactive agents of sustainable development.

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1. Introduction

The increasingly complex global environmental changes, such as global warming, pollution, and ecosystem degradation, demand a rapid and effective response from various sectors, including education. Higher education plays a strategic role in producing graduates who are not only technically skilled but also have a deep environmental awareness. One highly relevant course is Environmental Chemistry, a branch of science focused on understanding chemical processes in nature and the impact of human activities on these processes. This course examines the interactions between chemicals and the environment, both naturally and due to pollution. Environmental Chemistry plays a crucial role in understanding various issues such as water, air, and soil pollution, as well as the management of hazardous waste. Furthermore, it supports the development of technologies to minimize the negative impacts of human activities on the environment (Ali & Khan, 2017; Prajapati & Pandya, 2024).

Environmental Chemistry has a strategic role in addressing global challenges, including climate change, water pollution, and soil degradation (Awewomom et al., 2024; Sillanpää, 2020). Climate change, for example, is influenced by chemical reactions in the atmosphere, particularly greenhouse gas emissions that cause global warming (Cronan, 2023; Farmer & Prather, 2020; Peachey & Maeda, 2024). This course helps identify solutions, such as the use of clean energy and environmentally friendly waste management. Water pollution from industrial and household waste can also be addressed through technologies developed from Environmental Chemistry research. In terms of soil degradation, this field supports the monitoring of the impact of agricultural chemicals on soil fertility and the environment. Therefore, Environmental Chemistry courses are highly relevant in equipping students with the knowledge and skills needed to contribute to the mitigation and adaptation of environmental issues.

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A well-designed curriculum is key to achieving learning objectives (Hays & Reinders, 2020; Wijngaards-de Meij & Merx, 2018). The curriculum must integrate learning goals with student needs and real-world challenges. This includes developing relevant content, innovative teaching approaches, and comprehensive assessment of learning outcomes. An effective curriculum not only emphasizes the mastery of scientific concepts but also develops critical thinking skills, environmental awareness, and problem-solving abilities for real-world issues. In the context of Environmental Chemistry education, a well-structured curriculum will motivate students to understand complex environmental issues and create innovative solutions that support the Sustainable Development Goals (SDGs).

The evaluation and assessment of curriculum implementation are important steps in ensuring the effectiveness of Environmental Chemistry education. This evaluation aims to identify the extent to which the curriculum meets learning needs, develops 21st-century skills, and prepares students to face global environmental challenges (Mellyzar et al., 2022; Mulyani et al., 2023; Tindowen et al., 2017). This study focuses on the curriculum evaluation at a state university in Aceh Province, covering aspects of planning, implementation, and its impact on student understanding and skills. In addition, students' responses to the curriculum are also evaluated to provide a comprehensive picture of the success of the learning process and areas for improvement. Thus, this evaluation is expected to contribute to the development of a more effective and relevant curriculum in Environmental Chemistry education.

Therefore, the research question addressed in this study is to what extent is the Environmental Chemistry curriculum in higher education prepared to support sustainable learning and the achievement of the SDGs?. In line with this question, the main objective of the study is to evaluate the curriculum readiness, its implementation, and its impact on students' understanding, attitudes, and skills, thereby ensuring that the research remains focused and relevant.

2. Method

This research uses a descriptive approach, focusing on curriculum evaluation and its implementation in Environmental Chemistry courses at higher education institutions. The research subjects were 26 students enrolled in the Environmental Chemistry course, 2 lecturers teaching the Environmental Chemistry course, and the head of the Chemistry Education program at a state university in Aceh Province during the even semester of the 2024/2025 academic year. Data collection techniques included document analysis and surveys.

The curriculum and lesson plan analysis process was conducted using indicators developed by the author, including topic alignment with national and international curriculum standards, topic relevance to current environmental issues such as pollution, waste management, and climate change, integration of the SDGs into course content, the diversity of teaching methods applied (lectures, discussions, project-based learning, practicums, fieldwork), and alignment with the program's vision, mission, and graduate learning outcomes. These indicators ensure that the curriculum and lesson plan are systematically evaluated to identify strengths and areas for improvement.

The effectiveness of Environmental Chemistry learning was evaluated using a 15-item questionnaire grouped into several dimensions: teaching methods, material relevance, interaction and feedback, learning support activities, and environmental literacy improvement. Each statement was rated using a 4-point Likert scale, and the data were analyzed using descriptive statistics, such as frequencies, percentages, and average scores, to provide a comprehensive overview of the learning process. The analysis of students' environmental literacy on the affective dimension was based on a 15-item questionnaire developed by Fang et al. (2023) and Hungerford & Volk (1990), with indicators covering environmental awareness and sensitivity, environmental values, and decision-making attitudes toward environmental issues. A 7-point Likert scale was used to capture more detailed variations in student responses. Similarly, the analysis of students' environmental literacy on the behavioral dimension involved a 15-item questionnaire with indicators covering responsible environmental behavior, environmental action strategies and skills, and intention to act, which were also measured using a 7-point Likert scale.

Respondents comprised all 26 students enrolled in the Environmental Chemistry course, making the sample representative of the target group in this case study, although the findings are not intended to be generalized to other institutions. Additionally, interviews with lecturers and program heads were included to triangulate the survey results, thus strengthening the validity of the data. The survey data analysis technique relied on descriptive statistics supported by qualitative interpretation, allowing for the presentation of numerical trends and contextual insights.

The research procedure followed three systematic stages: (1) preparation, including the development and validation of instruments such as document analysis sheets, questionnaires, and interview guides; (2) implementation, including curriculum and lesson plan analysis, survey distribution, and interviews with students, lecturers, and program heads; and (3) interpretation, consisting of analyzing the survey results using descriptive statistics, conducting thematic analysis of the interviews, and mapping the results of the curriculum and lesson plan analysis against the SDGs and dimensions of environmental literacy. These stages are illustrated in a revised flowchart (Figure 1) (Czaja et al., 2014; Groves et al., 2011) to provide a clearer picture of the research steps.

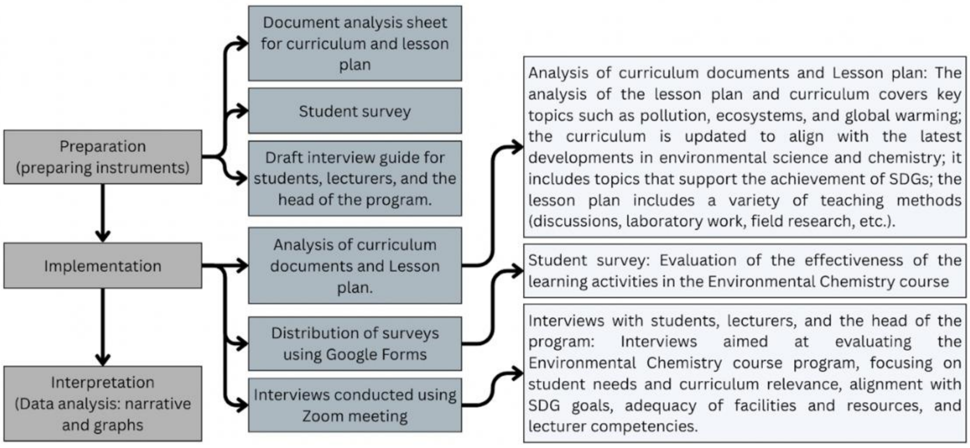

Figure 1. Research Implementation Step

3. Results and Discussion

3.1. Curriculum and Lesson Plan Analysis

The curriculum analysis aims to ensure that the structure and content of the study program align with the applicable educational standards (Jonnaert & Therriault, 2013; Tezcan-Unal et al., 2019), both at the national and international levels. By meeting these standards, the study program can ensure that graduates possess competencies that are widely recognized. Additionally, this analysis focuses on the relevance of the curriculum to the latest developments in science and technology, as well as labor market needs, ensuring that the courses offered prepare graduates for careers in relevant fields, such as environmental management or the chemical industry, while providing the necessary skills for the workforce, such as innovation and research.

Curriculum analysis supports the achievement of educational goals by ensuring that the curriculum reflects the vision, mission, and objectives of the study program. The implementation of the curriculum should integrate innovative teaching methods, such as project-based learning (PBL), interdisciplinary collaboration, and the use of technology, to enhance the quality of learning (Dwiputra et al., 2023). As a result, students not only gain theoretical knowledge but also practical skills that can be directly applied in the professional world. Furthermore, the curriculum should address global issues and sustainability developments, such as climate change, circular economy, and SDGs, to ensure that the education provided remains relevant and valuable in addressing contemporary challenges.

The goal of the lesson plan analysis is to ensure that the semester lesson plan aligns with the graduate learning outcomes of the program and supports the gradual development of competencies. The analysis also aims to evaluate whether the teaching methods, assessments, and materials taught can develop skills needed in the workforce, such as critical thinking, teamwork, and problem-solving. This analysis ensures that the learning materials each semester connect theory with relevant practice, such as waste management, the use of renewable energy, or green technology innovations so that students can apply the knowledge gained in real-world contexts. Additionally, the lesson plan analysis assesses whether the allocated time, teaching methods, and evaluations are optimal for achieving the expected learning outcomes and identifies whether any materials or methods need to be updated to better align with advancements in knowledge and student needs. Thus, lesson plan analysis helps lecturers improve the learning design to be more effective, engaging, and in line with student needs and learning outcomes.

The key components analyzed include the alignment of the main topics with the curriculum, relevance to current issues in Environmental Chemistry, integration of SDGs into the curriculum, and the teaching methods used. The analysis of the curriculum and lesson plan for the Environmental Chemistry course shows that the vision, mission, and objectives of the Chemistry Education Program align with the developments in science, technology, and societal needs. This program emphasizes research based on local potential that is internationally recognized, allowing it to contribute to global challenges. The Lesson plan is designed to meet learning needs by including key topics such as waste management, climate crisis, and environmental pollution, which are relevant to current global issues. These topics provide students with a deep understanding of urgent environmental problems and prepare them to contribute to their resolution. Although the integration of SDGs has not been explicitly mentioned, this Lesson plan supports sustainability through natural resource management, climate action, and environmental awareness development. The structured teaching methods outlined in the lesson plan, such as scientific and problem-based approaches, allow students to gain in-depth theoretical insights while developing practical skills that are relevant to the workforce. Therefore, this curriculum not only builds academic competence but also fosters holistic environmental awareness.

While the curriculum and course plan analysis demonstrate an emphasis on aligning learning outcomes with the vision of the study program and the needs of the community, the scientific aspects of environmental chemistry need to be further strengthened to foster more meaningful learning. Several fundamental subtopics should therefore be explicitly incorporated into the curriculum. For instance, the curriculum could address the relationship between biogeochemical cycles and global phenomena, such as climate change, as well as local phenomena, such as eutrophication caused by excessive fertilizer use in Aceh. Students may enhance their understanding through experiential learning activities, such as quantifying nitrate and phosphate concentrations in water samples collected within the university environment. In the context of chemical toxicology, the curriculum should highlight the mechanisms of heavy metal toxicity (e.g., Hg, Pb, Cd) and persistent organic pollutants, which are relevant to potential pollution from the local fertilizer industry. Practicum activities, such as toxicity testing using bioindicators (e.g., Daphnia species), can facilitate the integration of theoretical concepts with real-world environmental issues. Furthermore, the overarching theme of waste mitigation and remediation technologies may be integrated through project-based learning, where students design strategies for liquid or solid waste treatment. Examples include neutralizing acidic waste, adsorption using activated carbon, and phytoremediation with local plant species. Such approaches may also instill a circular economy perspective through the study of waste-to-energy processes.

Moreover, the curriculum analysis highlights the importance of local contextualization. Environmental issues in Aceh such as groundwater contamination near fertilizer industries due to excess nitrogen and phosphate, and declining air quality caused by SO_2 and NO_x emissions—serve as relevant case studies within teaching and learning activities. In project-based assessments, students may engage in collecting water samples and conducting laboratory analyses of key parameters, including pH, DO, BOD, COD, and nitrate–phosphate concentrations. The results are then compared against national water quality standards, enabling students to connect theoretical knowledge with real-world applications. Through this process, environmental chemistry is understood not only within a global framework but also in relation to local needs. Such systematic integration supports the curriculum analysis finding that environmental chemistry instruction should extend beyond pedagogical considerations to explicitly build students' scientific capacity for addressing both global and regional environmental challenges (Šebej & Urík, 2024; Araripe & Zeidler, 2024).

Recommendations based on the document analysis include that the Environmental Chemistry Lesson plan has covered relevant main topics, but it can be enhanced by diversifying and contextualizing it to local conditions. Adding topics such as international environmental policy changes, including the Paris Agreement or regional regulations on hazardous waste, could broaden students' perspectives on global challenges. The integration of local case studies, such as water quality analysis or the impact of industry on air pollution in Indonesia, would help students understand the application of Environmental Chemistry concepts in real-world contexts. To strengthen the relevance with current issues, it is recommended to include materials on new technologies, such as biofiltration for water treatment or green catalysts for air pollution control. These adjustments could also be complemented with discussions on global trends, such as the circular economy, using the latest literature, and collaboration with faculty or student research. Webinars or discussions with experts could also provide practical insights that enrich students' learning experiences.

The integration of SDGs in the lesson plan can be emphasized with explicit steps, such as adding a column linking materials to specific SDG targets, for example, the relationship between environmental sanitation and SDG 6 (Clean Water and Sanitation). Additionally, SDG-based projects that encourage students to design sustainable local solutions will enhance their understanding of how the curriculum is related to global development. From a teaching methods perspective, improvements could be made by adding field practicum, such as visits to waste management sites or virtual simulations using environmental analysis software. Multidisciplinary discussions involving lecturers from environmental policy or public health fields could also enrich students' perspectives on the social impacts of environmental chemistry. Project-based evaluations, such as scientific papers or poster presentations, would strengthen students' analytical and communication skills in developing innovative solutions for environmental challenges. The results of the overall analysis are presented in Table 1.

Table 1. Analysis of Curriculum Documents and Lesson Plan

Analyzed component	Document source	Assessment criteria	Analysis results	Conclusions/ recommendations
Relevance of main topics to curriculum	Curriculum/ lesson plan	The curriculum and lesson plan cover main topics	The lesson plan includes main topics such as air pollution, water pollution, land pollution,	The lesson plan has covered relevant main topics; however, here are

Analyzed component	Document source	Assessment criteria	Analysis results	Conclusions/ recommendations
		such as pollution, ecosystems, and global warming	global warming, and other environmental chemistry issues. These topics align with the environmental chemistry curriculum, which generally covers chemical aspects in analyzing and mitigating environmental problems. Relevance to the curriculum of the study program. *Connection of vision, mission, and objectives of the study program with the environmental chemistry lesson plan.* The vision of the chemistry education study program is "to become an excellent study program in the field of chemistry education at the international level based on local potential." Relationship with Vision**:** a. The environmental chemistry lesson plan supports the study program's efforts to produce competent graduates in the field of analysis and mitigation of environmental issues. Topics such as air, water, and land pollution, as well as global warming, demonstrate a focus on solving real problems relevant to sustainable development and support students' competencies in understanding and addressing environmental issues. b. This aligns to produce excellent graduates with the academic ability to apply environmental chemistry knowledge in both global and local contexts. Mission: "to provide quality education and research based on local potential." Relationship with mission**:** a. The Lesson Plan supports quality learning by providing topics relevant to real challenges in the environmental field, such as pollution mitigation and hazardous waste management. b. The material allows students to connect chemistry theory with practical solutions in local-based environmental management. Objective: "to produce competent and professional graduates" Relationship with Objective**:**	recommendations for improvement: Topic Diversification: Add more specific topics related to international environmental policy changes, such as the Paris Agreement or regional regulations on hazardous waste. Local contextualization: Include case studies based on local issues to help students understand how Environmental Chemistry concepts are applied in Indonesia, such as water quality analysis in specific areas or the local impact of air pollution.

Analyzed component	Document source	Assessment criteria	Analysis results	Conclusions/ recommendations
			a. Topics in the lesson plan equip students with relevant scientific analysis skills to generate solutions to environmental problems, supporting the achievement of high graduate competencies.	
Relevance to Current Issues in environmental chemistry	Curriculum/ lesson plan	The curriculum is adjusted to the latest scientific developments related to the environment and chemistry	The lesson plan is already relevant to current issues, such as greenhouse effects, hazardous waste management, and air and water pollution. This indicates that the curriculum has been adjusted to the latest scientific developments relevant to the environment and chemistry. *Connection of vision, mission, and objectives of the study program with the environmental chemistry lesson plan.* Vision: "To Excel at the International Level." Relationship with vision: a. The lesson plan includes global issues such as greenhouse effects, global warming, acid rain, and environmental degradation. This shows that the learning material is designed to equip students with knowledge relevant to international standards. Mission: "To enhance academic capabilities with national and international recognition." Relationship with Mission**:** a. Material on waste management, air pollution, and environmental sanitation is relevant to best practice standards in global environmental education. b. Scientific references in the lesson plan support the development of students' capabilities to contribute to the advancement of science at both national and international levels. Objective: "To produce scientific works and creative works with international reputation." Relationship with objective**:** a. The lesson plan provides a strong foundation for environmental-based scientific research, enabling students to produce creative works that can be recognized internationally.	Current issues have been discussed, but could be strengthened with the following steps: Adjustment to new technologies: add materials discussing the latest technologies in pollution mitigation, such as biofiltration for water treatment or the use of green catalysts in air pollution control. Inclusion of global trends: include discussions on global trends such as the circular economy focused on recycling chemicals. Use of current literature: add recent international journal references on climate change mitigation, waste management, or environmentally friendly technologies. Webinars or expert discussions: organize discussions with experts in the field of environmental chemistry to provide students with direct insights. Collaboration with research: involve faculty or student research findings in learning to connect material with the latest findings.
Integration of SDGs in the curriculum	Curriculum/ lesson plan	Curriculum includes topics that support the	Some topics in the lesson plan support the achievement of SDGs, such as environmental	The integration of SDGs can be further emphasized with the following steps:

Analyzed component	Document source	Assessment criteria	Analysis results	Conclusions/ recommendations
		achievement of SDGs.	sanitation (SDG 6), air quality (SDG 13), and waste management (SDG 12). However, the integration of SDGs is not explicitly mentioned in the lesson plan description, so it can still be improved by linking each topic to relevant SDG targets. *Connection of vision, mission, and objectives of the study program with the environmental chemistry lesson plan* Vision: "Based on Local Potential." Relationship with Vision: a. Topics such as environmental sanitation and hazardous waste management can be linked to SDG 6 (clean water), SDG 12 (sustainable consumption and production), and SDG 13 (climate action), even though they are not explicitly mentioned. Mission: "to implement community service." Relationship with mission: a. The material in the lesson plan provides a foundation for students to develop practical solutions that support the goals of the SDGs, particularly in improving the quality of life through environmental management. Objective: "to apply research to improve community living standards." Relationship with objective: a. Knowledge about pollution mitigation and biogeochemical cycles can be applied by students to raise community awareness about the importance of sustainability.	Link topics to SDGs: Explicitly add a column in the Lesson Plan to connect each course material to specific SDG targets. For example, material on environmental sanitation can be linked to SDG 6 (clean water and sanitation). SDG-based projects: conduct group assignments or projects that focus on achieving one of the SDGs, such as designing sustainable local waste management solutions. Impact-based assessment: Add assessment criteria that evaluate how students understand the relevance of topics to the achievement of SDGs.
Structured teaching methods	Lesson plan	Lesson plan includes a variety of teaching methods (discussions, practicals, field research, etc.)	This lesson plan employs various teaching methods, such as lectures, discussions, presentations, reflections, and quizzes. Additionally, the problem-based learning approach provides a structured teaching method that encourages critical thinking and problem-analysis skills. This reflects a structured and comprehensive teaching methodology. *Connection of vision, mission, and objectives of the study program with the environmental chemistry lesson plan.*	The teaching methods are well-structured, but here are some suggestions for improvement: Add field practical: for example, visits to waste management sites or environmental laboratories to understand processes directly. This will strengthen students' analytical skills through real-life experiences. Interactive collaboration: use modern learning technologies, such as virtual simulations or software for environmental pollution analysis.

Analyzed component	Document source	Assessment criteria	Analysis results	Conclusions/ recommendations
			Vision: "to become an excellent study program." Relationship with vision: a. The learning methods that include scientific and problem-based approaches support the achievement of high-quality education.	Integration of multidisciplinary Discussions: invite lecturers or practitioners from other fields, such as environmental policy or public health, to enrich discussions about the social impacts of environmental chemistry issues.
			Mission: "to provide quality education." Relationship with mission: a. Structured teaching through lectures, discussions, presentations, reflections, and quizzes reflects efforts to provide efficient and effective education. b. However, there has not been an explicit emphasis on laboratory practical or field research that could strengthen students' practical competencies. Objective: "to realize efficient and transparent educational governance." Relationship with objective: a. The neat and well-planned structure of the Lesson Plan supports the effectiveness of educational implementation, in line with the principles of efficiency, transparency, and accountability.	Creative evaluation: add a project-based assessment component that integrates environmental chemistry solutions, such as writing scientific papers or poster presentations.

The integration of the SDGs in the current curriculum documents remains largely implicit. As a result, students may recognize the general relevance of the SDGs but often struggle to explicitly link the studied material with global sustainability targets. UNESCO emphasizes the importance of an explicit connection between educational content and global agendas, including SDG 4 (Quality Education), SDG 6 (Clean Water and Sanitation), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action). Without such explicit integration, the SDGs risk being perceived as abstract ideals rather than actionable frameworks relevant to students' professions and daily lives. To address this, SDG integration should be implemented in two phases. First, markers or columns could be incorporated into the lesson plan, mapping each subject area to relevant SDGs for example, water contamination to SDG 6 and greenhouse gas emissions to SDG 13. Second, project-based assessments should be designed around SDG-oriented solutions, such as group assignments to develop plastic waste reduction strategies (SDG 12) or to monitor local air quality (SDG 13). In this way, environmental chemistry instruction extends beyond theoretical knowledge to foster the internalization of global sustainability values within students' learning experiences. This perspective aligns with David (2005) and Kurniawan et al. (2025), who highlight the value of feedback oriented towards broader objectives, enabling students to connect their academic achievements with the global development agenda.

A closer examination of the curriculum and course plan documents indicates a relatively comprehensive material structure covering water, air, and soil pollution, climate change, and waste management. However, survey and interview findings suggest that classroom implementation has not fully realized this design. Current learning activities in environmental chemistry remain predominantly lecture-based, with limited opportunities for experiential learning through field practice, collaborative projects, or mini-research initiatives. Such experiential opportunities are critical for deepening learning and addressing the existing gaps in the curriculum. This observation is consistent with Akhtar et al. (2024) and Børe (2024), who stress the importance of curriculum alignment ensuring consistency between planning documents and classroom practices to achieve optimal learning outcomes. The discrepancy can be further explained through hidden curriculum theory, which posits that the values and objectives articulated in documents do not always manifest in daily practice (Nakamura et al., 2024; Behmanesh, 2025). Consequently, while students acquire a theoretical understanding of environmental concepts, their practical competencies in analyzing and addressing real-world issues remain underdeveloped. In summary, this implementation gap may undermine the curriculum's effectiveness in cultivating comprehensive competencies.

3.2. Evaluating Learning Effectiveness and Students' Environmental Literacy in Affective and Behavioral Dimensions of Environmental Chemistry

3.2.1. Evaluation of the Effectiveness of Environmental Chemistry Learning

The evaluation of learning activities in the Environmental Chemistry course is conducted to ensure the effectiveness of teaching methods, the relevance of the material, and its impact on students' understanding and awareness of environmental issues. The goal of Environmental Chemistry learning is not only to provide theoretical knowledge but also to foster critical attitudes, practical skills, and concern for environmental problems. Through this evaluation, the strengths and weaknesses of learning activities can be identified, including teaching methods, lecturer–student interactions, and supporting activities such as practicals and field learning. The results of this evaluation are expected to serve as a basis for improving the quality of learning to make it more relevant to students' needs and the global challenges in the environmental field. The questionnaire items employed in this study are presented in Table 2.

Table 2. Questionnaire Statements for Evaluating the Effectiveness of Environmental Chemistry Learning

	Statements
S-1	The teaching methods used (e.g., discussion, lectures, experiments) help me understand Environmental Chemistry concepts.
S-2	The lecturer provides clear and easily understandable explanations in every session.
S-3	The practical sessions support my understanding of the topics taught in lectures.
S-4	The materials presented are related to environmental issues relevant to daily life.
S-5	Class or group discussions help me become more active and engaged in learning.
S-6	The lecturer provides useful feedback after assignments or presentations.
S-7	The time allocated for each activity (discussion, practice, presentation) is sufficient to achieve the learning objectives.
S-8	The technology or teaching media used (projector, e-learning, etc.) helps me understand the material better.
S-9	The interaction between the lecturer and students in the Environmental Chemistry course is effective.
S-10	The materials presented are aligned with the principles of SDGs.
S-11	I feel capable of applying the concepts learned in class to real-life issues, especially environmental ones.
S-12	The learning activities encourage me to think critically about global environmental problems.
S-13	Fieldwork (if any) greatly helps me understand environmental conditions directly.
S-14	The lecture materials are always relevant to recent developments in the field of chemistry and the environment.
S-15	I feel that learning in this course is effective in enhancing my environmental literacy.

The group of 15 statements from the evaluation instrument is categorized into several dimensions to assess the effectiveness of learning in the Environmental Chemistry course. The Teaching Method dimension includes statements 1, 5, and 8, focusing on how approaches such as discussions, lectures, project-based learning, and learning technologies help students understand the concepts of Environmental Chemistry. The Relevance of Material dimension involves statements 4, 10, and 14, which evaluate the connection between course material and everyday environmental issues, the principles of the SDGs, and recent developments in the fields of chemistry and the environment. The Interaction and Feedback dimension encompasses statements 2, 6, and 9, which assess the quality of interactions between lecturers and students, as well as the extent to which feedback provided by lecturers is beneficial for the learning process. The Supporting Learning Activities dimension consists of statements 3, 7, and 13, focusing on the effectiveness of activities such as practicals, the allocation of time for each activity, and field learning in supporting student understanding. The Environmental Literacy Improvement dimension includes statements 11, 12, and 15, evaluating how learning encourages students to think critically about global environmental issues and enhances their environmental literacy. This grouping helps identify strengths and weaknesses in each aspect of learning, providing a more comprehensive picture of the effectiveness of learning in the course.

The results of the questionnaire analysis indicate that the learning in the Environmental Chemistry course is generally rated effective by students. In the teaching method dimension, the majority of students feel that the approaches used, such as discussions, lectures, and experiments, help them understand the concepts of Environmental Chemistry well. About 46.15% of students agree and 46.15% strongly agree that these teaching methods support their understanding. Group discussions are also considered beneficial in increasing student engagement. This aligns with statements from Idsardi (2020), Prince (2004), and Ribeiro-Silva et al. (2022), which emphasize the importance of interaction between students and lecturers, as well as among students themselves, in creating a dynamic learning environment. Additionally, research by Hattie & Timperley (2007) highlights the importance of feedback in the learning process. In the context of Environmental Chemistry learning, the use of diverse teaching methods, such as lectures, discussions, and experiments, provides students with opportunities to receive constructive feedback, which in turn can enhance their understanding of the material. Meanwhile, learning technologies such as projectors and e-learning provide additional support for understanding course material. The integration of technology in learning can enhance student motivation and engagement. Thus, the applied teaching methods are deemed capable of creating a positive and profound learning experience (Bhat, 2023; Hwang et al., 2015; Nhleko et al., 2024; Timotheou et al., 2023).

The relevance of course material to everyday environmental issues and current developments is also rated very positively by students. About 61.54% of students strongly agree and 34.62% agree that the material presented is closely related to relevant environmental issues. This material is also considered aligned with the principles of the SDGs, although the percentage of students who strongly agree is still low, at 7.69%. Additionally, 57.69% of students agree and 38.46% strongly agree that the material is always relevant to the latest developments in chemistry and the environment. This indicates that the curriculum successfully integrates global issues and supports students' awareness of sustainability needs.

In terms of interaction and feedback, the majority of students assess that lecturers provide clear, helpful, and easy-to-understand explanations. About 50% of students agree and 42.31% strongly agree that the interaction between lecturers and students is effective. The feedback given after assignments or presentations is also considered helpful for students in enhancing their understanding. Furthermore, supporting learning activities, such as practicals and field learning, received fairly positive responses, although there is room for improvement. About 50% of students strongly agree that practicals support their understanding, but only 23.08% of students recognize field learning as very helpful. This indicates the need to optimize field activities to make them more beneficial for students. In the dimension of environmental literacy, the learning is deemed capable of enhancing students' awareness and ability to apply the concepts learned in real life. About 57.69% of students agree and 26.92% strongly agree that the learning encourages them to think critically about global environmental issues. Additionally, 53.85% of students agree and 38.46% strongly agree that this course is effective in improving their environmental literacy. Thus, learning in this course not only succeeds in providing theoretical understanding but also in building environmental awareness and students' ability to contribute to sustainability issues. Nevertheless, improvements in time allocation and field activities could further enhance the effectiveness.

From the results of the questionnaire analysis, several aspects of learning have been carried out very well, including teaching methods such as discussions, lectures, and the use of learning technologies, which effectively help students understand the concepts of Environmental Chemistry. The material presented is also considered relevant to current environmental issues and the principles of the SDGs, demonstrating a strong integration between theory and global needs. Additionally, the interaction between lecturers and students, as well as the feedback provided by lecturers, has created a conducive learning environment. However, there are several aspects that require improvement, such as the allocation of time for learning activities, which some students feel is not yet optimal. Field learning also needs to be maximized to provide more meaningful hands-on experiences, as some students feel that the benefits have not yet been fully realized. Improvements in these two aspects could further optimize the overall effectiveness of learning. Therefore, clarifying the connection between environmental chemistry and the SDGs is essential to enable students to recognize the global relevance of each topic studied. Emphasizing SDG-oriented projects and assessments may enhance environmental literacy and foster proactive attitudes, thereby equipping students with the capacity to address local and global challenges simultaneously. The summarized results of the evaluation of Environmental Chemistry instruction are presented in Figure 2.

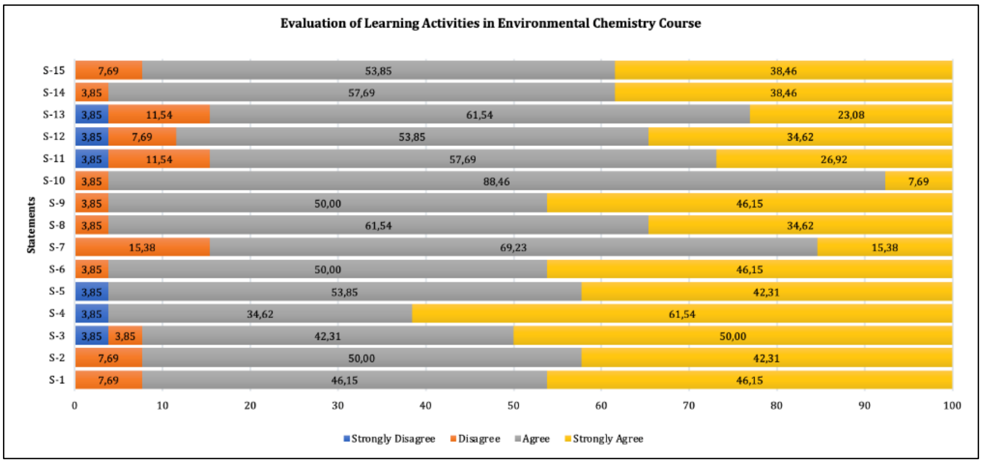

Figure 2. Student Responses to Environmental Chemistry Learning

Preliminary analysis suggests that student responses to Environmental Chemistry instruction are predominantly positive, with an average score approaching 4 on a maximum scale. The highest-rated dimension was interaction and feedback (M = 3.40; SD = 0.21), indicating that students perceived strong lecturer–student interaction and adequate feedback throughout the learning process. This finding is consistent with constructivist theory, which highlights the importance of dialogue and interaction in constructing knowledge and enhancing motivation to learn. Teaching methods (M = 3.35; SD = 0.04) and the relevance of learning materials (M = 3.31; SD = 0.04) also received favorable ratings with low standard deviations, suggesting that instructional strategies were regarded as effective and that course content was perceived as relevant and applicable to real-world problems.

By contrast, supporting learning activities (M = 3.14; SD = 0.25) and concern for the environment (M = 3.19; SD = 0.12) were rated lower. This indicates that students view activities such as practicums, projects, and problem-based discussions as not yet fully optimized. According to principles of problem-based and experiential learning, such activities are critical for strengthening conceptual understanding and cultivating 21st-century skills. Similarly, the relatively modest score for environmental concern suggests that affective dimensions have not been fully internalized, despite students' cognitive comprehension of environmental concepts. This mirrors broader challenges in environmental education, where attitudes and actions often lag behind knowledge acquisition.

These findings carry several practical implications for instructional design. Greater variability and applicability in learning activities are needed, including field research, environment-based projects, and awareness campaigns. Such initiatives are essential not only for deepening conceptual understanding but also for fostering authentic concern for environmental issues. In addition, integrating global perspectives through the Sustainable Development Goals, specifically SDG 6 (Clean Water and Sanitation), SDG 12 (Sustainable Consumption and Production), and SDG 13 (Climate Action) is imperative. Meanwhile, the strong performance in interaction and feedback should be sustained through enhanced feedback mechanisms that go beyond correction to include reflection, guidance, and critical discussion. This approach resonates with the framework of Brooks et al. (2024), who emphasized the value of feedback directed at overarching objectives (feed up), current performance (feedback), and future improvement (feed forward) in enhancing learning effectiveness. The overall distribution of student responses is presented in Figure 3.

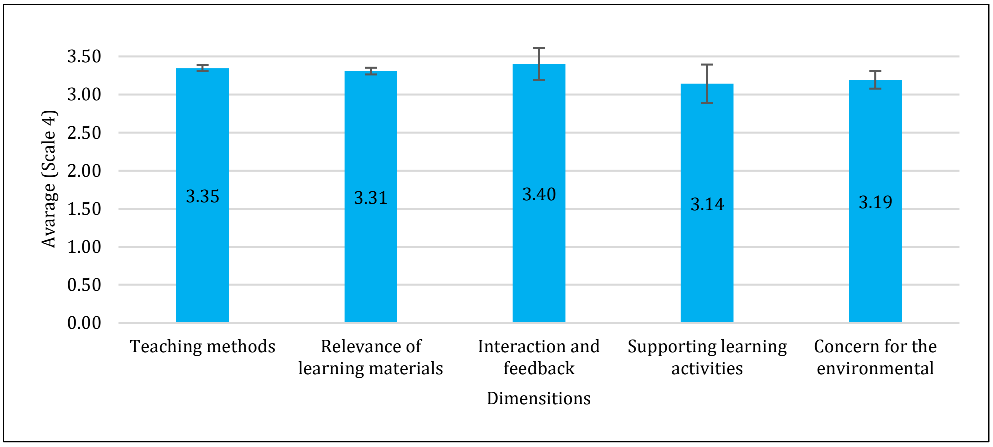

Figure 3. Student Responses to Environmental Chemistry Learning

The findings of the learning effectiveness evaluation indicate that, although students perceive the course material as relevant to real-life concerns, the incorporation of environmental chemistry topics remains largely descriptive and theoretical. For example, issues such as water, air, and soil pollution are often discussed through literature reviews rather than through local case studies or environmental quality analyses. Similarly, green technologies including biofiltration, environmentally friendly catalysts, and the circular economy are presented as supplementary knowledge rather than as problem-based projects that encourage critical engagement. This observation resonates with Ferns (2024) argument that an effective curriculum should integrate theoretical concepts with real-world contexts to foster problem-solving and knowledge transfer skills. The socio-scientific issues (SSI) approach is also highly relevant, as it has been shown to enhance both scientific literacy and environmental awareness (Çalik & Wiyarsi, 2024). Accordingly, environmental chemistry instruction should prioritize contextualized strategies. For instance, students could be tasked with analyzing local river pollution data or designing waste management solutions informed by green chemistry principles. Such approaches not only provide conceptual knowledge but also promote reflective, analytical, and applied competencies that contribute directly to sustainable development.

3.2.2. Analysis of Student Environmental Literacy in the Affective and Behavioral Dimensions in the Environmental Chemistry Course

In 1969, William Stapp, a professor at the University of Michigan, School of Natural Resources and Environment (SNRE), first defined environmental education as a process that produces citizens knowledgeable about the biophysical environment and related issues, aware of how to help solve these problems, and motivated to work toward solutions (Stapp, 1969). In 1990, the United Nations declared the "International Year of Literacy" which called for "human environmental literacy" to strengthen basic knowledge, skills, and motivation to learn for sustainable development (Fang et al., 2023; Mellyzar et al., 2025). As people emphasize sustainable development and intergenerational justice, the right attitudes toward the environment, concepts of control, and a sense of personal responsibility have resulted in a strong intention to behave in an environmentally friendly manner, involving environmental education and learning motivation, awareness, sensitivity, values, skills, and experiences (Law, 2019; McCauley et al., 2024).

The analysis of student environmental literacy in the affective and behavioral dimensions is crucial to assess the extent to which learning in the Environmental Chemistry course can enhance awareness and pro-environmental actions. The affective dimension encompasses students' awareness, values, and attitudes toward environmental issues, including their concerns about pollution and sustainable resource utilization. By analyzing this dimension, lecturers can evaluate the success of learning in fostering students' concern for environmental issues and encouraging them to adopt positive attitudes toward environmental preservation. The results of this analysis provide insight into how well students understand the importance of maintaining the environment as part of sustainable living, which is a preliminary step in shaping pro-environmental behavior. The behavioral dimension includes students' actual actions, such as their involvement in environmental activities, environmental action strategies, and skills to contribute actively. This dimension provides insights into how students' attitudes and awareness are applied in daily life, including tangible actions such as recycling, reducing plastic waste, or participating in environmental conservation activities. This analysis is important to evaluate whether classroom learning has successfully encouraged students to act more actively and responsibly regarding environmental issues. Assessment is conducted using a questionnaire with a 7-point scale, which offers a greater variety of response options, thereby better representing objective reality. This scale allows participants to express their motives and levels of awareness in more detail, resulting in more accurate and relevant outcomes (Chang, 1994).

Analysis of Student Environmental Literacy in the Affective Dimension

Environmental education should include the affective dimension to build awareness and positive attitudes toward the environment (Leimbach et al., 2022; Lovren & Jablanovic, 2023).The questionnaire statements were developed based on indicators of environmental awareness and sensitivity, environmental value, and decision-making attitudes on environmental issues. The full set of items is presented in Table 3.

Table 3. Questionnaire Statements for Analyzing Student Environmental Literacy in the Affective Dimension

Indicator	Statements
Environmental Awareness and Sensitivity	S-1. I feel concerned about the environmental conditions around me
	S-2. I feel disturbed when I see actions that harm the environment
	S-3. I actively seek information about environmental issues.
	S-4. I am aware of the negative impacts of various forms of pollution on the environment.
	S-5. I feel that protecting the environment is a shared responsibility.
Environmental Value	S-6. Preserving the environment is a top priority for me.
	S-7. I believe that natural resources should be used wisely.
	S-8. I trust that individual actions can contribute to environmental preservation.
	S-9. Maintaining biodiversity is very important.
	S-10. I appreciate the effoS-9rts of others who strive to protect the environment.
Decision-Making Attitude on Environmental Issues	S-11. I always consider environmental impacts before making decisions.
	S-12. I feel the need to learn more about environmental policies.
	S-13. I support policies aimed at reducing pollution and environmental damage.
	S-14. I am open to changing my habits to be more environmentally friendly.
	S-15. I feel responsible for making decisions that do not harm the environment.

The indicators were developed based on the research by (Fang et al., 2023) which was modified from the works of Hungerford & Tomera (1985), Hungerford & Volk (1990), Hungerford et al. (1990), Liu et al. (2015), Liang et al. (2018), dan Cherdymova et al. (2018)

Awareness and sensitivity to the environment are important indicators in the affective dimension of environmental literacy. This indicator reflects the extent to which students possess emotional and cognitive sensitivity to environmental issues around them. Statements such as concern for environmental conditions, disturbance caused by destructive actions, and awareness of the impacts of pollution serve as a basis for evaluating their level of concern. Additionally, active efforts to seek information about environmental issues and the belief that environmental protection is a shared responsibility demonstrate students' understanding of the importance of sustainability. Through this questionnaire, it can be analyzed whether the Environmental Chemistry course has successfully enhanced students' awareness of their collective responsibility in protecting the environment. The analysis results for the Environmental Awareness and Sensitivity indicator can be seen in Figure 4.

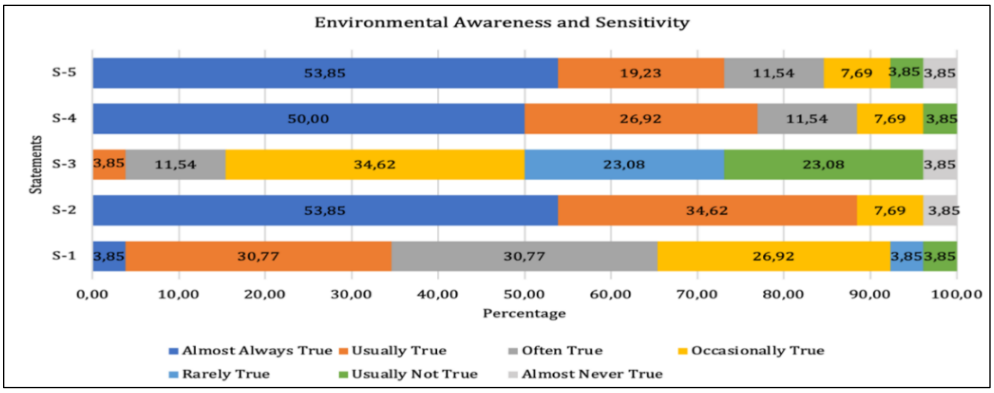

Figure 4. Student Opinions on the Affective Dimension of the Environmental Awareness and Sensitivity Indicator

The affective dimension analysis of environmental literacy revealed varied responses across student levels. At the undergraduate level, most responses were classified as usually true (30.77%) or often true (30.77%), with only 3.85% categorized as almost always true. This pattern suggests that students' concern for environmental conditions has begun to form but has not yet reached consistent strength. At the master's level, the trend was more pronounced, with the majority of responses rated as almost always true (53.85%) and usually true (34.62%), indicating a relatively high degree of emotional sensitivity toward environmentally harmful actions. These findings are consistent with prior studies showing that environmental education can enhance awareness and sensitivity (Bergman, 2016; Muhammad, 2020; Mellyzar et al., 2025).

In contrast, doctoral students exhibited the weakest affective responses. The predominant category was occasionally true (34.62%), followed by usually not true (23.08%), while only 3.85% reported almost always true. This pattern suggests that although doctoral students expressed emotional concern regarding environmental issues, they were less proactive in seeking related information. Previous research emphasizes that both knowledge and attitudes are critical predictors of pro-environmental behavior, and that improving access to relevant information can foster more proactive engagement (Bamberg & Möser, 2007; Burgos-Espinoza et al., 2024).

In S-4, 50.00% of respondents chose almost always true, indicating a high awareness of the negative impacts of pollution, although there were respondents who chose occasionally true (7.69%). This aligns with findings by Gifford (2011), which explain various psychological barriers that prevent individuals from taking proactive actions on environmental issues. Statement S-5 also showed positive results, with 53.85% of respondents choosing almost always true, although a small portion chose usually not true (3.85%). Research by Schultz (2001) indicates that environmental awareness is closely related to individuals' concerns for themselves and others. Overall, this data shows that students possess a good level of environmental awareness and sensitivity, but there are indications that proactive actions, such as seeking information about environmental issues, still need to be improved. Research by Kollmuss & Agyeman (2002) identifies factors influencing pro-environmental actions and provides recommendations to address these barriers. To enhance students' proactive actions in seeking information about environmental issues, integration of research-based assignments related to local and global issues into learning can be implemented. Additionally, providing access to reliable information sources, such as journals or environmental portals, can encourage students' interest. Research by Zelezny (1999) shows that environmental education can significantly enhance sustainable behavior among students. Routine thematic discussions about environmental issues can also motivate more active engagement.

The measurement of Environmental Value aims to describe the extent to which students hold values and principles that support environmental preservation in their daily lives. The statements in this indicator highlight students' priorities regarding environmental sustainability, the wise use of natural resources, and their belief in individual contributions to preservation. Furthermore, the importance of maintaining biodiversity and appreciation for others' efforts in environmental protection are also evaluated. The data generated through this questionnaire provides an overview of the level of internalization of environmental values by students. The results of the questionnaire can be seen in Figure 5.

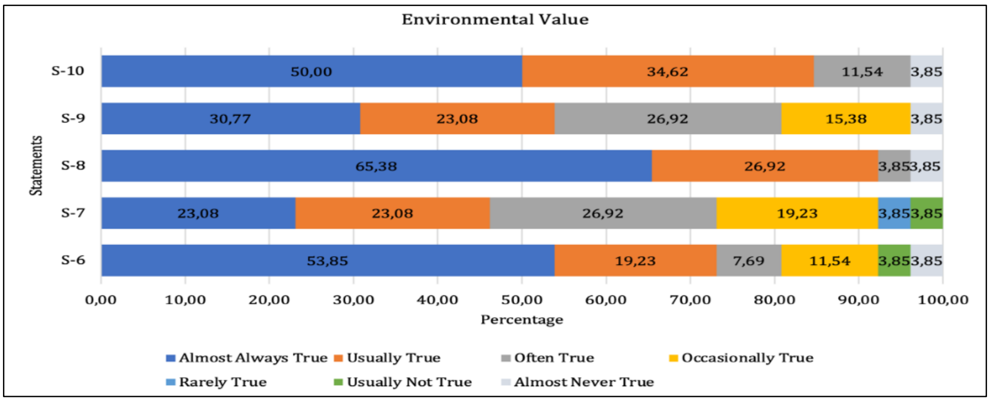

Figure 5. Student Opinions on the Affective Dimension of the Environmental Value Indicator

The analysis results indicate that students exhibit relatively strong environmental values, particularly with regard to conservation (S-6; 53.85% of respondents indicated that this statement is almost always true) and the belief in the contribution of individual actions (S-8; 65.38% of respondents indicated that this statement is almost always true). This finding aligns with the conclusions of Alfirević et al. (2024), who posited that conservation values promote student engagement in sustainable practices. Conversely, awareness of the wise use of resources (S-7; 23.08% of respondents indicated that this statement was almost always true) and the importance of biodiversity (S-9; 30.77% of respondents indicated that this statement was almost always true) indicate a discrepancy between knowledge and practice. These findings are consistent with the results reported by Concina and Frate (2023), who concluded that environmental literacy in higher education still faces obstacles in translating knowledge into concrete action. Concurrently, the acknowledgment of others' contributions (S-10; 50% almost always true, 34.62% usually true) signifies a shared awareness, aligning with the notion of "collective environmental literacy," which underscores the significance of collective action in engendering sustainable change (Ardoin et al., 2023). The affective dimension of students is robust in the context of conservation and individual action. However, further development is necessary through real-world and collaborative learning strategies to strengthen the internalization of environmental values, attitudes, and actions.

The Decision-Making Attitude Indicator on Environmental Issues reflects the extent to which students consider environmental aspects in every decision they make. This questionnaire is designed to measure students' awareness of the environmental impacts of their actions, both in their personal and social lives. Additionally, this indicator evaluates students' willingness to support environmental policies and adopt more eco-friendly habits. Responsible attitudes in decision-making are one of the essential pillars in shaping pro-environmental behavior. The percentage of student responses can be seen in Figure 6.

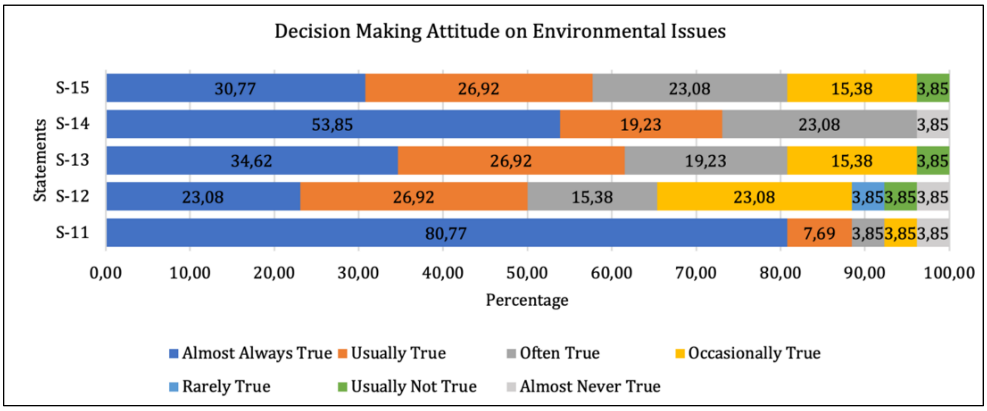

Figure 6. Student Opinions on the Affective Dimension of the Decision Making Attitude on Environmental Issues Indicator

The results of the analysis demonstrate that students generally hold a favorable attitude toward decision-making processes related to environmental issues. Regarding the consideration of environmental impacts in decision-making (S-11), the majority of respondents (80.77%) reported that they almost always take this into account. This finding reinforces the notion that critical awareness is an integral component of every action taken, consistent with Zhou et al. (2024), who highlighted that awareness of environmental impacts is a strong predictor of sustainable decision-making behavior in students.

In terms of the necessity of acquiring further knowledge about environmental policies (S-12), the responses were more varied, with 26.92% selecting usually true and 23.08% selecting almost always true. This suggests an emerging interest in environmental policy issues, albeit with noticeable variation among individuals. Student support for policies to reduce pollution and environmental damage (S-13) was relatively strong, with 34.62% indicating almost always true and 26.92% indicating usually true. This aligns with Lu et al. (2025), who demonstrated that students with strong environmental values often support public policies that promote conservation and pollution reduction. Concerning eco-friendly habits (S-14), 53.85% of respondents indicated almost always true, suggesting readiness to adopt a more sustainable lifestyle. This finding highlights that openness to behavioral change is a key indicator in shaping students as agents of environmental change at the university level. In relation to responsibility for making environmentally sound decisions (S-15), 30.77% reported almost always true and 26.92% usually true, reflecting the emergence of moral awareness and ethical alignment with environmental concerns.

Overall, these findings suggest that students possess a solid foundation in decision-making related to environmental issues. Nevertheless, reinforcement is needed to strengthen their comprehension of environmental policies, ensuring that these favorable attitudes translate into tangible engagement in policy advocacy and sustainable practices. The results of the questionnaire analysis on the affective dimension of environmental literacy are presented in Figure 7.

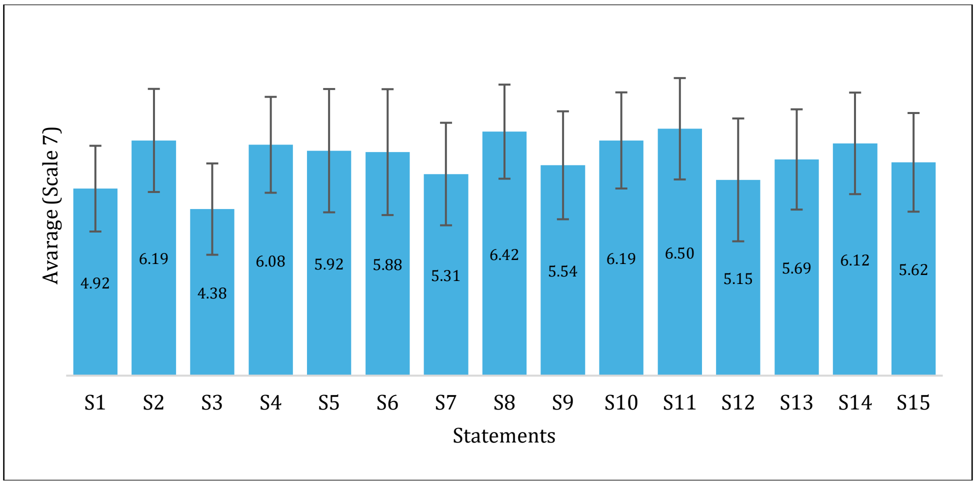

Figure 7. Student Opinions on the Affective Dimension on Environmental Issues Indicator

The analysis indicates that students demonstrate a strong level of environmental awareness, particularly in decision-making processes that consider environmental impacts (S-11, mean = 6.50, SD = 1.33) and in their belief that individual actions can contribute to environmental protection (S-8, mean = 6.42, SD = 1.24). These findings are consistent with previous studies emphasizing the importance of the affective dimension in environmental literacy, where environmental affect—such as ecological concern and empathy significantly contributes to pro-environmental behavior (Coelho et al., 2017; Miller et al., 2022; Strömbäck et al., 2025). In addition, research demonstrates that student involvement in citizen science-based educational activities can substantially increase environmental awareness (Araújo, 2023). This underscores that affective engagement with the environment provides a crucial foundation for sustainable actions aligned with SDG 13 (Climate Action) and SDG 15 (Life on Land).

Conversely, other indicators reveal notable gaps in students' environmental literacy, particularly regarding their tendency to actively seek environmental information (S-3, mean = 4.38, SD = 1.20) and their spontaneous awareness of surrounding environmental conditions (S-1, mean = 4.92, SD = 1.13). These findings suggest that although students exhibit strong emotional concern, progressive elements such as proactivity and knowledge-driven ecological literacy remain underdeveloped. Meta-analytical evidence indicates that environmental knowledge is positively correlated with environmental attitudes (Wulandari et al., 2021), suggesting that strengthening the cognitive dimension could deepen affective commitment. Accordingly, pedagogical strategies such as socio-scientific issue (SSI) approaches, case-based discussions, research-oriented assignments, and citizen science projects are recommended to enhance proactivity while fostering an integrated development of both affective and cognitive dimensions, thereby equipping students to respond more holistically to SDG challenges. The results of the interviews with the head of the study program and lecturers show that the implementation of Environmental Chemistry courses has referred to the SDGs, although not explicitly stated. Discussions on environmental pollution issues caused by large industrial activities around the campus area have become one of the focuses of learning. However, the implementation of pollution reduction projects has not been possible due to limitations in funding, facilities, equipment, and practical tools. Additional support is needed to optimize project-based learning related to environmental issues.

Analysis of Environmental Literacy of Students in the Behavioral Dimension

The questionnaire statements were developed based on the indicators of involvement in responsible environmental behavior, environmental action strategies and skills, and intention to act. The complete set of items is presented in Table 4.

Table 4. Questionnaire Statements for the Analysis of Environmental Literacy of Students in the Behavioral Dimension

Indicator	Statements
Involvement in Responsible Environmental Behavior	S-1. I participate in activities or organizations that care about the environment.
	S-2. I always strive to reduce plastic usage in my daily life.
	S-3. I avoid littering and try to recycle waste.
	S-4. I get involved in tree planting or cleanup activities.
	S-5. I feel happy when participating in activities aimed at protecting the environment.
Environmental Action Strategies and Skills	S-6. I know how to recycle waste properly.
	S-7. I know how to conserve energy and water in daily life.
	S-8. I have the ability to plan simple environmental actions or campaigns.
	S-9. I understand techniques to reduce my personal carbon footprint.
	S-10. I can identify practical ways to preserve the environment.
Intention to Act	S-11. I plan to stay actively involved in environmental conservation activities.
	S-12. I am committed to adopting an environmentally friendly lifestyle in the future.
	S-13. I intend to participate regularly in environmental movements.
	S-14. I want to further improve my understanding of environmental issues.
	S-15. I am committed to reducing the use of environmentally harmful products.

The indicators were developed based on the research by (Fang et al., 2023) which was modified from the works of Hungerford & Tomera (1985), Hungerford & Volk (1990), Hungerford et al. (1990), Liu et al. (2015), Liang et al. (2018), dan Cherdymova et al. (2018).

The results of the questionnaire regarding involvement in responsible environmental behavior show a diverse picture of student behavior in actions that support environmental sustainability. The statement that received the highest "almost always true" response is S-5, with a percentage of 23.08%, indicating that most students tend to be consistent in maintaining environmental cleanliness. However, for S-4, only 19.23% provided a similar response, suggesting that students' active involvement in environmental activities still needs improvement.

On the other hand, the percentage of responses indicating "rarely true" and "almost never true" that appeared in several statements, such as 15.38% in S-4, shows that some students have not fully engaged in responsible environmental activities. This indicates a need to facilitate more programs that encourage active participation, such as environmental volunteer activities or community-based projects, to enhance student involvement. The importance of active student engagement in environmental activities can be reinforced by research from Khatibi et al. (2021) and Xie et al. (2023), which shows that participation in environmental activities can increase individual awareness and commitment to environmental issues. Additionally, research by Husamah et al. (2022) and Yalçınkaya & Çetin (2018) reveals that hands-on experiences in environmental activities, such as tree planting and clean-ups, can foster positive attitudes and sustainable behavior among students. Details of student responses can be seen in Figure 8.

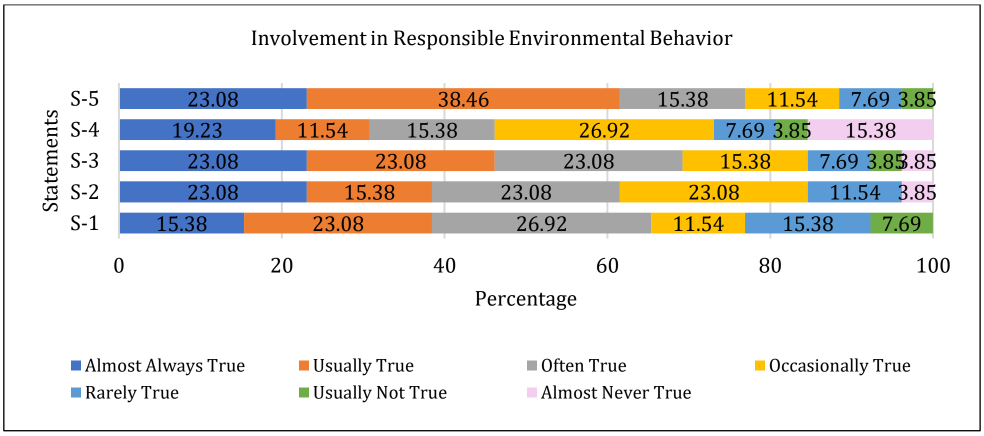

Figure 8. Student Opinions on the Behavioral Dimension Indicator of Involvement in Responsible Environmental Behavior

The environmental action strategies and skills indicator has been developed to evaluate students' ability to design, implement, and apply pro-environmental actions in practice. The results of the questionnaire indicate that the majority of students possess a satisfactory comprehension of S-7, with 34.62% of respondents reporting that aspects such as energy and water efficiency are to a reasonable extent recognized. However, for S-6 and S-8, only 3.85% of students reported a consistently high level of mastery, suggesting that knowledge and skills in these areas remain limited. A significant proportion of students also selected the mid-level response category, particularly for S-8 (38.46%) and S-10 (23.08%), which reflects partial knowledge that has not yet translated into fully optimized environmental strategies. These findings underscore the necessity to fortify students' proficiencies in environmental action skills through experiential learning, field activities, or collaborative projects that can cultivate more profound environmental literacy. The percentage distribution of student responses for the Behavioral Dimension Indicator of Environmental Action Strategies and Skills is presented in Figure 9.

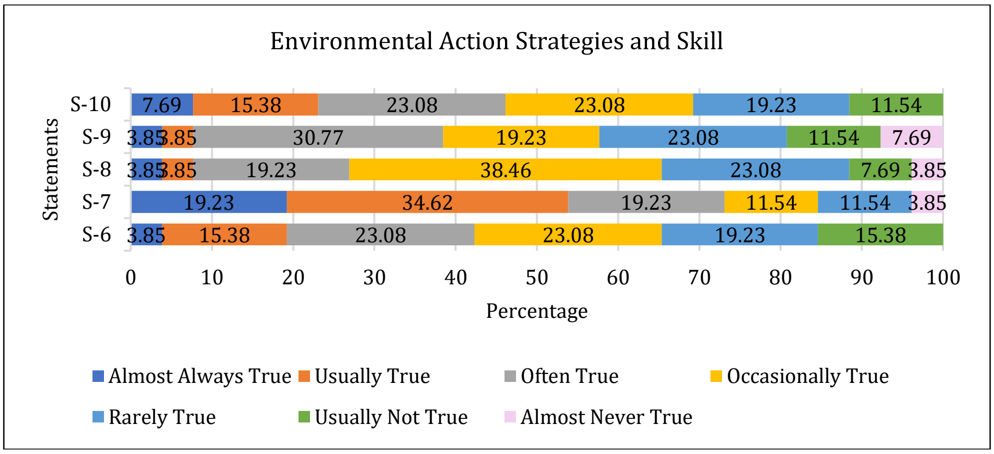

Figure 9. Student Opinions on the Behavioral Dimension Indicator of Environmental Action Strategies and Skills

The assessment of intention to act aims to measure students' commitment and plans to contribute to environmental preservation in the future. Based on the results of the questionnaire, the majority of students show a good intention, especially on S-12, with 30.77% choosing almost always true. This indicates that students are aware of the importance of adopting a lifestyle that supports sustainability. However, for S-11 and S-13, the almost always true responses only reached 15.38% and 19.23%, respectively. The relatively high occasionally true responses for several statements, such as 30.77% in S-11, indicate that students' intentions have not yet been fully internalized. These findings provide a valuable basis for designing learning strategies that can strengthen commitment and encourage students to be more consistent in acting pro-environmentally. The percentage distribution of student responses for the Behavioral Dimension Indicator of Intention to Act is presented in Figure 10.

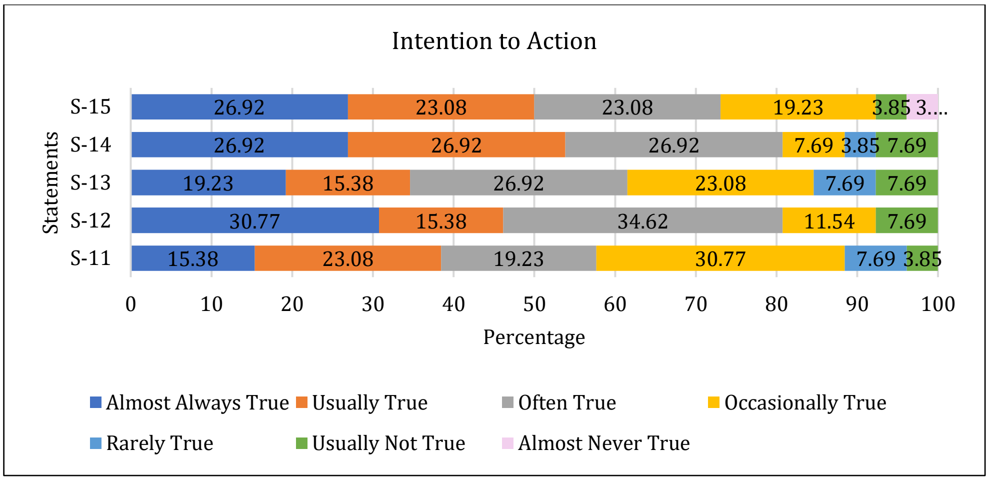

Figure 10. Student Opinions on the Behavioral Dimension Indicator of Intention to Action

The results of the questionnaire indicate that although the majority of students have good intentions to contribute to environmental preservation, there is a gap between intention and the expected actions. With only 15.38% of students showing strong commitment on S-11 and 19.23% on S-13, this suggests that despite awareness, further efforts are needed to internalize sustainability values into students' daily behaviors (Ajzen, 2020; Alas & Kurthan, 2024; Kirby & Zwickle, 2021). Therefore, it is important to develop educational programs and practical activities that not only enhance knowledge but also build motivation and habits that consistently support pro-environmental actions.

4. Conclusion

This study concludes that the Environmental Chemistry curriculum in higher education has established a solid foundation by addressing key topics such as pollution, waste management, and climate change, yet its potential to fully support sustainable learning and the achievement of the SDGs remains underutilized. The findings suggest that more explicit integration of SDGs, increased use of experiential learning strategies, and stronger contextualization to local environmental issues are necessary to strengthen both affective and behavioral dimensions of students' environmental literacy. A new hypothesis emerging from this research is that embedding project-based, interdisciplinary, and SDG-oriented learning will not only enhance students' scientific capacity but also foster their readiness to act as proactive agents of sustainable development. Therefore, higher education institutions are recommended to redesign Environmental Chemistry courses by emphasizing real-world problem solving, interdisciplinary collaboration, and policy-linked case studies to ensure graduates are prepared to address both global and local environmental challenges effectively.

Author Contributions

All authors have equal contributions to the paper. All the authors have read and approved the final manuscript.

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Declaration of Conflicting Interests

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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