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Developing contextual biology curriculum for natural resource conservation and SDG-oriented learning

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ABSTRACT

This study aims to design, develop, and test a contextual biology curriculum focused on natural resource conservation, aligned with Sustainable Development Goals (SDGs), particularly SDG 4 (Quality Education) and SDG 15 (Life on Land). The Research and Development (R&D) method, using a modified 4D model (define, design, develop, disseminate), was employed to create a practical and effective curriculum. The Define stage identified gaps in the existing high school biology curriculum, particularly the lack of integration of local environmental issues and SDGs. The Design stage resulted in the development of syllabi, lesson plans, modules, and conservation-based teaching materials, systematically linking biological concepts such as ecosystems, biodiversity, and the life cycle of organisms with local conservation topics. Project-based learning and field activities were incorporated to enhance student engagement and promote environmental responsibility. The Develop stage involved expert validation and classroom trials, confirming the feasibility and effectiveness of the curriculum. The results showed significant improvement in students' understanding of biological concepts and conservation, as well as positive changes in their pro-environmental attitudes and behaviors. This research provides a new framework for integrating sustainability into the biology curriculum, addressing local and global environmental challenges. The implications of this study are significant for curriculum development, offering a model for educators to foster environmental literacy and contribute to the achievement of the SDGs through practical, real-world learning experiences.

INTRODUCTION

Global environmental degradation has become an urgent problem due to increasing human activities, such as deforestation, pollution, and unsustainable resource exploitation (Xu & Zhao, 2023). These environmental challenges threaten biodiversity, ecosystem services, and the sustainability of natural resources vital to human life. Based on Zhang & Cao (2025) research, overcoming this problem requires immediate action at the policy and industry levels, as well as through education that can shape the attitudes and behavior of the younger generation towards environmental conservation. Education plays a strategic role in fostering environmental awareness and sustainability literacy. The integration of environmental education into the formal curriculum helps students understand the interconnection between natural systems and human activities (Gebrekidan & Gebremedhin, 2024). Specifically, biology education offers a unique platform to teach scientific concepts and environmental responsibility because it is directly related to living organisms, ecosystems, and conservation principles.

Although it has great potential, the current biology curriculum in many schools tends to be theoretical, emphasising the memorisation of concepts rather than practical application. This condition limits students' understanding of how biological knowledge can be applied in real conservation efforts. As a result, students often lack the skills and motivation to engage in pro-environmental behaviour outside the classroom (Semilarski & Laius, 2021). The Sustainable Development Goals (SDGs) emphasise the role of education in achieving a sustainable future. SDG 4 (Quality Education) promotes inclusive and equitable learning, while SDG 15 (Life on Land) emphasises the preservation of ecosystems and biodiversity. Based on research results Schneiderhan-Opel & Bognern (2020), linking biology education to these goals can contribute to broader social outcomes by preparing students to actively participate in environmental conservation.

The contextual curriculum approach is very important for bridging theory and practice. The contextual biology curriculum integrates local environmental issues, case studies, and practical activities, allowing students to connect scientific concepts with their surrounding environment (Wicaksono et al., 2025). Research by Kowasch et al. (2022) indicates that this curriculum promotes experiential learning and improves students' problem-solving abilities in real-world conservation contexts. Natural resource conservation is a fundamental theme that can be integrated into the biology curriculum. Instruction on the sustainable use of forests, water, soil, and biodiversity can cultivate ecological awareness and a sense of responsibility. The integration of conservation topics into the curriculum not only provides knowledge about environmental issues but also encourages real actions at the community level. Direct learning experiences, such as fieldwork, laboratory experiments, and activity-based projects, are essential for developing practical skills and environmental competence (Ardoin et al., 2020a). By directly engaging with natural resources and local ecosystems, students gain experiential knowledge that reinforces theoretical understanding and encourages active participation in conservation efforts (Morales et al., 2025).

Previous research by Lestari et al. (2023) showed that although the biology curriculum has great potential to instil environmental awareness, the results show that the curriculum in Indonesia is still theoretical and emphasises memorisation, making it difficult for students to apply biological knowledge to real-world conservation efforts. Furthermore, Lasekan et al. (2024) research indicates that the integration of local environmental issues and the Sustainable Development Goals (SDGs) into learning materials remains minimal, so students rarely see the relevance of their learning to the environmental challenges around them. Classroom observations also show that learning activities tend to be teacher-centred, reducing active student participation in practical activities and conservation-based projects.

Previous research by Fajri et al. (2025) showed there is limited empirical evidence supporting the effectiveness of contextual biology in improving students' understanding of conservation concepts and sustainable behaviour. Teachers also identified the need for learning modules and guides that are more applicable, contextual, and integrated with the SDGs, so that students not only understand biological concepts but can also apply them in real-world actions to conserve natural resources. This gap emphasises the importance of developing a biology curriculum that is contextual, experience-based, and aligned with the SDGs to effectively improve students' environmental literacy and pro-environmental behaviour.

This research offers an innovation the development and trial of a contextual biology curriculum that integrates natural resource conservation, SDG goals, and experiential learning. This approach not only emphasises theory but also practice and measurable outcomes, thereby presenting a new and relevant curriculum model for conservation education. Academically, this research fills a gap in the literature by providing a validated curriculum framework that can be adopted or adapted by other educators and researchers. This contribution adds to the literature on curriculum development, environmental education, and SDG-based pedagogy and offers evidence-based strategies for integrating sustainability into science teaching. The Research and Development (R&D) method provides a systematic framework for designing, developing, and testing educational innovations. The application of R&D to curriculum development enables iterative design, validation, and refinement of teaching materials and strategies (Widyastuti & Susiana, 2019). This approach ensures that the resulting curriculum is not only pedagogical but also effective in enhancing students' environmental literacy.

Practically, this research provides ready-to-use guides and teaching materials for teachers and schools. This curriculum offers a structured approach to engage students in conservation education, foster environmental awareness, and support the achievement of SDGs through classroom learning practices. The formulation of the research problem is (1) how to design a contextual biology curriculum that emphasizes natural resource conservation?, (2) is the developed curriculum effective in increasing students' knowledge and behavior towards conservation?, (3) how to develop a curriculum implementation guide that can support the achievement of SDGs, especially quality education and ecosystem preservation?. The main objectives of this research are (1) to design a contextual biology curriculum that emphasizes the conservation of natural resources, (2) to test the curriculum in a school setting to evaluate its effectiveness in enhancing students' knowledge and behavior toward conservation, and (3) to develop a curriculum implementation guide that can support the achievement of SDGs, particularly quality education and ecosystem preservation.

METHODS

Research Design

This research uses the Research and Development (R&D) method, with a modified 4D curriculum development model (define, design, develop, disseminate) (Irawan et al., 2018), to design and test a contextual biology curriculum on environmental conservation that supports the achievement of the SDGs. The design of this research is iterative and cyclical, where each stage includes analysis, development, validation, testing, evaluation, and revision, resulting in a valid and effective curriculum (figure 1).

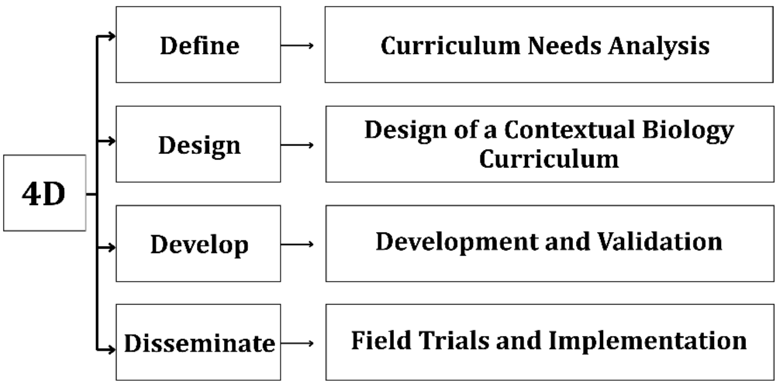

Figure 1. The 4D Research and Development Model for Designing a Contextual Biology Curriculum.

Figure 1 shows the 4D development model's stages: define, design, develop, and disseminate. The define stage involves analyzing curriculum needs, particularly in the context of natural resource conservation. A Research and Development (R&D) design was employed, utilizing a modified 4D model consisting of define, design, develop, and disseminate stages. This model was chosen for its systematic framework, which facilitates the identification of curriculum needs, the design of instructional products, the validation of developed curricula, and the assessment of practicality and effectiveness in classroom settings. In this context, the 4D model functioned as an iterative curriculum inquiry process, with each stage generating evidence to inform subsequent revisions. During the define stage, curriculum analysis was conducted to identify gaps between the existing senior high school biology curriculum and the anticipated learning needs for natural resource conservation and Sustainable Development Goals (SDG)-oriented education. Curriculum documents, biology syllabi, learning objectives, lesson plans, textbooks, and teaching materials used by biology teachers were examined. The analysis addressed five key aspects: (1) inclusion of biology concepts related to ecosystems, biodiversity, organism interactions, and natural resources; (2) representation of local conservation issues in learning materials; (3) integration of SDG-related themes, particularly SDG 4 and SDG 15; (4) availability of experiential, inquiry-based, project-based, or field-based learning activities; and (5) alignment among learning objectives, instructional activities, and assessment tasks. Teacher interviews and classroom observations supplemented the analysis to provide insight into curriculum implementation and to identify constraints encountered by teachers and students. This procedure aligns with established curriculum development studies, which emphasize curriculum mapping, contextual needs analysis, stakeholder involvement, and alignment between learning goals, activities, and assessment (Jóhannesson et al., 2011; Lei & Tang, 2023).

The results of the curriculum analysis informed the design stage. At this stage, relevant biology topics were mapped to local conservation issues and SDG targets. For instance, ecosystem and biodiversity topics were connected to local environmental degradation, habitat conservation, sustainable resource use, and community-based conservation practices. Subsequently, the curriculum structure, syllabus, lesson plans, student modules, project-based activities, field observation tasks, and assessment instruments were developed. The design process adhered to the principle of constructive alignment, ensuring coherence among learning objectives, instructional strategies, learning experiences, and assessment indicators (Adams et al., 2023; Fekih Zguir et al., 2021; Lasekan et al., 2024b). During the development stage, the curriculum draft underwent validation by education and environmental experts. This validation assessed content feasibility, scientific accuracy, contextual relevance, SDG integration, learning activity design, assessment clarity, and module readability. Revisions were made based on expert feedback prior to classroom implementation(Ardoin et al., 2020b; Børresen et al., 2023a). In the disseminate stage, the revised curriculum was tested in selected grade 11 biology classes to evaluate practicality and effectiveness. Data collected from observation sheets, knowledge tests, questionnaires, and interviews were analyzed to determine improvements in students' biology knowledge, conservation understanding, pro-environmental attitudes, and behaviors. This research design facilitated progression from curriculum diagnosis through development, validation, implementation, and final revision(Collado et al., 2020a).

Population and Samples

The population and sample in this study were teachers and students selected using purposive sampling. Explanations of the population and sample are provided in Tables 1 and 2.

Table 1.
Population and Sample of Biology Teachers

School Name	Population	Sample
State Senior High School 1 Cilegon	10	3
State Senior High School 2 Cilegon	8	2
State Senior High School 3 Cilegon	9	2
State Senior High School 4 Cilegon	9	2
State Senior High School 5 Cilegon	9	3
Total	**45**	**12**

Table 1 shows that the study teacher population consisted of 45 teachers: 10 from State Senior High School 1 Cilegon, 8 from State Senior High School 2 Cilegon, 9 from State Senior High School 3 Cilegon, 9 from State Senior High School 4 Cilegon, and 9 from State Senior High School 1 Cilegon. The sample of 12 teachers was selected for having at least 2 years of biology teaching experience and for their willingness to participate in training and to try the new curriculum.

Table 2.
Population and Sample of 11th-Grade Students

School Name	Population	Sample
State Senior High School 1 Cilegon	120	36
State Senior High School 2 Cilegon	100	36
State Senior High School 3 Cilegon	110	36
State Senior High School 4 Cilegon	105	36
State Senior High School 5 Cilegon	115	36
Total	**550**	**180**

Table 2 shows that the student population in the study amounted to 550 students who will be used for the large class and small class trial with the distribution of State Senior High School 1 Cilegon 120 students, State Senior High School 2 Cilegon 100 students, State Senior High School 3 Cilegon 110 students, State Senior High School 4 Cilegon 105 students, and State Senior High School 1 Cilegon 115 students. Meanwhile, the sample of 180 students is diverse in terms of academic performance and gender distribution. In addition to teachers and students, this study used expert validation with 5 experts (3 education specialists and 2 environmental specialists) who provided assessments of the material's feasibility, integration of conservation issues, alignment with SDG goals, and the effectiveness of the applied teaching methods. By involving teachers, students, and experts, this research can produce a curriculum that is academically validated, applicable, and responsive to learners' needs and the local context (Mpuangnan & Ntombela, 2024; Voogt et al., 2016; Zeivots et al., 2025).

Instrument

The research instruments used in this study consist of several measurement tools to comprehensively collect quantitative and qualitative data. First, the teacher observation sheet is used to assess the quality of material delivery, the use of learning media, student interaction, integration of SDG issues, and the provision of evaluation and feedback (Table 3) (Farah & Chandler, 2018; Jentsch & Senden, 2025; Kohake, 2024).

Table 3.
Indicators for Teacher Observation Sheet

Measured Aspect	Indicators
Quality of Material Delivery	1. Clarity and accuracy in presenting biological concepts. 2. Logical sequencing of topics. 3. Use of examples and real-life cases to illustrate concepts.
Use of Learning Media	1. Effective use of visual aids (diagrams, slides, videos). 2. Integration of digital or interactive media to enhance learning.
Student Interaction	1. Encouragement of student participation and discussion. 2. Facilitation of collaborative learning activities. 3. Promotion of peer learning and engagement.
Integration of SDG Issues	1. Inclusion of relevant SDG goals in lesson content. 2. Linking biological concepts to real-world sustainability challenges.
Provision of Evaluation and Feedback	1. Use of formative assessments during and after lessons. 2. Timely and constructive feedback on students' work.

Table 3 presents the indicators from the Teacher Observation Sheet utilized to evaluate the quality of teacher learning implementation. The observed aspects include the quality of material delivery, the use of learning media, student interaction, the integration of Sustainable Development Goals (SDGs), and the provision of evaluation and feedback. Regarding material delivery, teachers were evaluated on the clarity and accuracy of their explanations of biological concepts, their ability to organize topics logically, and their use of real-life examples or cases to enhance students' comprehension and relevance. Second, the student observation sheet is used to monitor students' active participation, practical skills, conceptual understanding, pro-environmental attitudes, and ability to cooperate in learning activities, see Table 4 (Ndihokubwayo et al., 2022).

Table 4.
Indicators for Student Observation Sheet

Measured Aspect	Indicators
Active Participation	1. Students respond actively to teacher questions. 2. Students voluntarily contribute ideas during discussions.
Practical Skills	1. Ability to perform experiments or practical tasks accurately. 2. Correct use of laboratory tools and materials.
Conceptual Understanding	1. Ability to explain biological concepts in own words. 2. Application of concepts to solve simple problems or case studies.
Pro-Environmental Attitudes	1. Shows interest in environmental topics discussed in class. 2. Demonstrates concern for conservation issues.
Cooperation in Learning Activities	1. Works effectively in group tasks. 2. Shares responsibilities and supports peers in learning activities.

Table 4 presents the indicators included in the Student Observation Sheet, which is designed to assess student engagement and behavior during the learning process. The observed aspects comprise active participation, practical skills, conceptual understanding, pro-environmental attitudes, and cooperation in learning activities. Active participation is demonstrated by students' responses to teacher questions and their willingness to contribute ideas during discussions. According to Machaba & Mangwiro (2024) research, responding to teacher questions and sharing ideas during discussions are key indicators of active participation. These behaviors make students' thinking visible, allow teachers to provide targeted feedback, and promote conceptual understanding and higher-order thinking skills.

Third, biology and conservation knowledge tests are used to measure students' understanding of biological concepts, the principles of natural resource conservation, the application of these concepts in real-world cases, and the connection of the material to SDG goals (Table 5). These tests are designed as multiple-choice questions, case studies, and essays to assess factual knowledge, conceptual understanding, and application skills.

Table 5.
Indicators for Biology and Conservation Knowledge Tests

Measured Aspect	Indicators
Factual Knowledge (Biology Concepts)	1. Recall of key biological terms and definitions. 2. Identification of organism structures and functions.
Conceptual Understanding	1. Explanation of ecological principles and interactions. 2. Understanding relationships between human activities and ecosystem changes.
Application Skills (Conservation Principles)	1. Ability to analyze case studies on natural resource management. 2. Propose solutions for sustainable resource use in real-world scenarios.
Connection to SDG Goals	1. Link biological and conservation concepts to relevant SDGs.

Table 5 presents the indicators utilized in the Biology and Conservation Knowledge Tests to evaluate students' mastery of biology and conservation concepts. The assessment encompasses factual knowledge, conceptual understanding, application skills, and the capacity to relate content to the Sustainable Development Goals (SDGs). Factual knowledge is assessed through students' recall of key terms and definitions, as well as their identification of organism structure and function. This component establishes a foundation for understanding biological concepts, which is essential prior to undertaking more advanced

Fourth, the pro-environmental attitude and behavior questionnaire is used to collect data on students' awareness of the environment, motivation to engage in environmentally friendly actions, actual behavior at school and home, and social attitudes related to conservation. The questionnaire uses a 1–5 Likert scale to facilitate quantitative analysis (Table 6).

Table 6.
Indicators for Pro-Environmental Attitude and Behavior Questionnaire.

Measured Aspect	Indicators
Environmental Awareness	1. Awareness of current environmental issues. 2. Understanding the importance of biodiversity and ecosystem preservation.
Motivation for Environmentally Friendly Actions	1. Willingness to participate in recycling and waste reduction. 2. Interest in engaging in environmental activities at school.
Actual Behaviour	1. Implementation of eco-friendly practices at school. 2. Implementation of eco-friendly practices at home.
Social Attitudes Related to Conservation	1. Encourages peers or family to adopt environmentally responsible behaviours. 2. Participates in community initiatives or projects related to conservation.

Table 6 presents the indicators of the Pro-Environmental Attitude and Behavior Questionnaire, which measures students' attitudes and behaviors toward the environment. The questionnaire evaluates environmental awareness, motivation to engage in environmentally friendly actions, actual behavior, and social attitudes related to conservation. Environmental awareness is assessed based on students' understanding of current environmental issues and the importance of preserving biodiversity and ecosystems. This dimension reflects the degree to which students possess foundational knowledge and sensitivity to environmental issues within their surroundings. Fifth, semi-structured interviews are used to obtain in-depth qualitative data from teachers, students, and environmental experts. These interviews asked about experiences during curriculum implementation, students' understanding of conservation materials, the obstacles and challenges faced, and suggestions for curriculum improvement (Table 7).

Table 7.
Indicators for Semi-Structured Interviews

Measured Aspect	Indicators
Experiences During Curriculum Implementation	1. Teachers' perspectives on the feasibility of implementing the new curriculum. 2. Students' experiences and engagement during lessons.
Students' Understanding of Conservation Materials	1. Students' comprehension of biological and conservation concepts. 2. Ability to relate lessons to real-world environmental issues.
Obstacles and Challenges	1. Difficulties faced by teachers in delivering the curriculum. 2. Challenges students encounter in understanding or applying conservation materials.
Suggestions for Curriculum Improvement	1. Recommendations from teachers for enhancing lesson design and delivery. 2. Suggestions from students and experts to increase relevance, engagement, or integration with SDG goals.

Table 7 presents the indicators utilized in the semi-structured interviews to collect qualitative data on experiences, understanding, obstacles, and feedback related to curriculum implementation. The aspects examined included experiences during curriculum implementation, students' comprehension of conservation materials, identified obstacles, and recommendations for curriculum development. These interviews enabled an exploration of teachers' perspectives on the feasibility of implementing the new curriculum as well as students' experiences and engagement throughout the learning process.

In addition to observation, testing, and questionnaires, this stuso used validation instruments and analytical frameworks to assess the feasibility and effectiveness of the developed curriculum. Expert validation instruments were used to assess the quality of the curriculum before implementation (Table 8), while pre-test and post-test measurement formats and paired-samples t-test analysis formats were used to obtain quantitative data on changes in student knowledge, attitudes, and behavior after the curriculum was implemented (Table 9).

Table 8.
Expert Validation Instrument Indicators

Assessment Aspect	Indicator
Content Feasibility	Material is relevant to biology concepts and conservation
SDGs Integration	Material and activities clearly relate to SDG goals
Learning Activities	Practical activities and projects align with student abilities
Assessment Guidelines	Competency indicators are clear and measurable
Module Readability	Module is easy to understand for teachers and students

Table 8 presents the indicators included in the Expert Validation Instrument, which is designed to assess the feasibility of a module or learning tool before its implementation in the educational process. The instrument validates several aspects, including content feasibility, integration of Sustainable Development Goals (SDGs), learning activities, assessment guidelines, and module readability. Content feasibility is determined by the material's relevance to biology and conservation concepts, whereas SDGs integration is evaluated by the clarity of the relationship among the material, learning activities, and sustainable development goals.

Additionally, the Expert Validation Instrument assesses the alignment of learning activities with student abilities, with particular attention to practical and project-based tasks. Assessment guidelines are reviewed for the clarity and measurability of competency indicators, which facilitate objective evaluation of learning outcomes. Module readability requires that teaching materials be organized for clear comprehension by both teachers and students. Consequently, the instrument ensures that the developed module is feasible, relevant, measurable, and suitable for use in biology learning that incorporates conservation and SDG principles.

Table 9.
Measurement Grid for Students' Pre-Test and Post-Test Assessment

Measured Aspect	Indicators
Biology Knowledge	1. Ability to define key biological concepts related to ecosystems and biodiversity. 2. Understanding the structure and function of organisms and their interactions. 3. Application of biological principles to explain natural phenomena. 4. Ability to solve problems or answer questions based on biological data or case studies.
Conservation Knowledge	1. Understanding principles of natural resource conservation. 2. Awareness of human impacts on ecosystems. 3. Ability to propose strategies for sustainable resource management.
Pro-Environmental Attitude	1. Awareness of environmental issues and their importance. 2. Motivation to engage in environmentally friendly actions. 3. Positive perception of conservation practices. 4. Willingness to participate in school or community environmental activities.
Pro-Environmental Behavior	1. Actual participation in environmentally responsible actions at school and home. 2. Implementation of waste reduction, recycling, or energy-saving practices. 3. Engagement in conservation-related projects or initiatives. 4. Sharing and encouraging pro-environmental behavior among peers.

Table 9 presents the Measurement Grid for Students' Pre-Test and Post-Test Assessments, which evaluates changes in students' knowledge, attitudes, and behavior before and after the instructional intervention. The measured aspects include biological knowledge, conservation knowledge, pro-environmental attitudes, and pro-environmental behavior. Biological knowledge is assessed through students' ability to define key concepts related to ecosystems and biodiversity, comprehend the structure and function of organisms and their interactions, apply biological principles to explain natural phenomena, and solve problems using biological data or case studies. Conservation knowledge is evaluated based on students' understanding of natural resource conservation principles, awareness of the impact of human activities on ecosystems, and ability to propose strategies for sustainable resource management.

Data collection techniques were conducted in a combined manner (triangulation) to enhance the validity of the research results. Quantitative data from tests and questionnaires were collected before and after the curriculum implementation to analyse changes in students' understanding and attitudes. Observational data were recorded during the learning process to assess teacher-student participation and engagement. Meanwhile, interview data were thematically analysed to gain insights into the curriculum's effectiveness, participants' experiences, and the factors that supported and hindered its implementation. With this combination of instruments and techniques, the research can produce comprehensive, valid, and relevant data for the evaluation and development of a conservation-based contextual biology curriculum.

Validity and Reliability of Instruments

The instrument's validity was evaluated by five experts: three in biology education and two in environmental studies. They reviewed the indicators, content relevance, language clarity, and measurability. All instruments were found valid and suitable. Empirical validity for the knowledge test and questionnaire was assessed using item-total correlation; items were valid if the correlation exceeded the r-table at 0.05 significance. Instrument reliability was measured using KR-20 for the knowledge test and Cronbach's Alpha for the questionnaire and observation sheet. Reliability was confirmed if the coefficient was above 0.70 (Yusup, 2018). Results showed all instruments met reliability standards, and interview validity was ensured through source triangulation and member checks.

Table 10.
Results of the Validity and Reliability Tests of the Instrument

Research Instrument	Validity Test	Reliability Test	Category
Teacher observation sheet	Content validity	Cronbach's Alpha	Valid and reliable
Student observation sheet	Content validity	Cronbach's Alpha	Valid and reliable
Biology and conservation knowledge test	Content validity and item-total correlation	KR-20	Valid and reliable
Pro-environmental attitude and behaviour questionnaire	Content validity and item-total correlation	Cronbach's Alpha	Valid and reliable
Semi-structured interview guide	Content validity	Source triangulation and member checking	Credible
Expert validation instrument	Content validity	Cronbach's Alpha	Valid and reliable

The results of the validity and reliability tests indicate that all research instruments are appropriate for assessing the implementation and effectiveness of a contextual biology curriculum based on conservation and the Sustainable Development Goals (SDGs). Consequently, data collected through observations, tests, questionnaires, and interviews offer a valid, consistent, and methodologically robust foundation for measurement.

Procedure

This development research uses a 4D model: define (curriculum needs analysis), design (a contextual biology curriculum), develop (development and validation), and finally disseminate (field trial and implementation). The stages are shown in Figure 2.

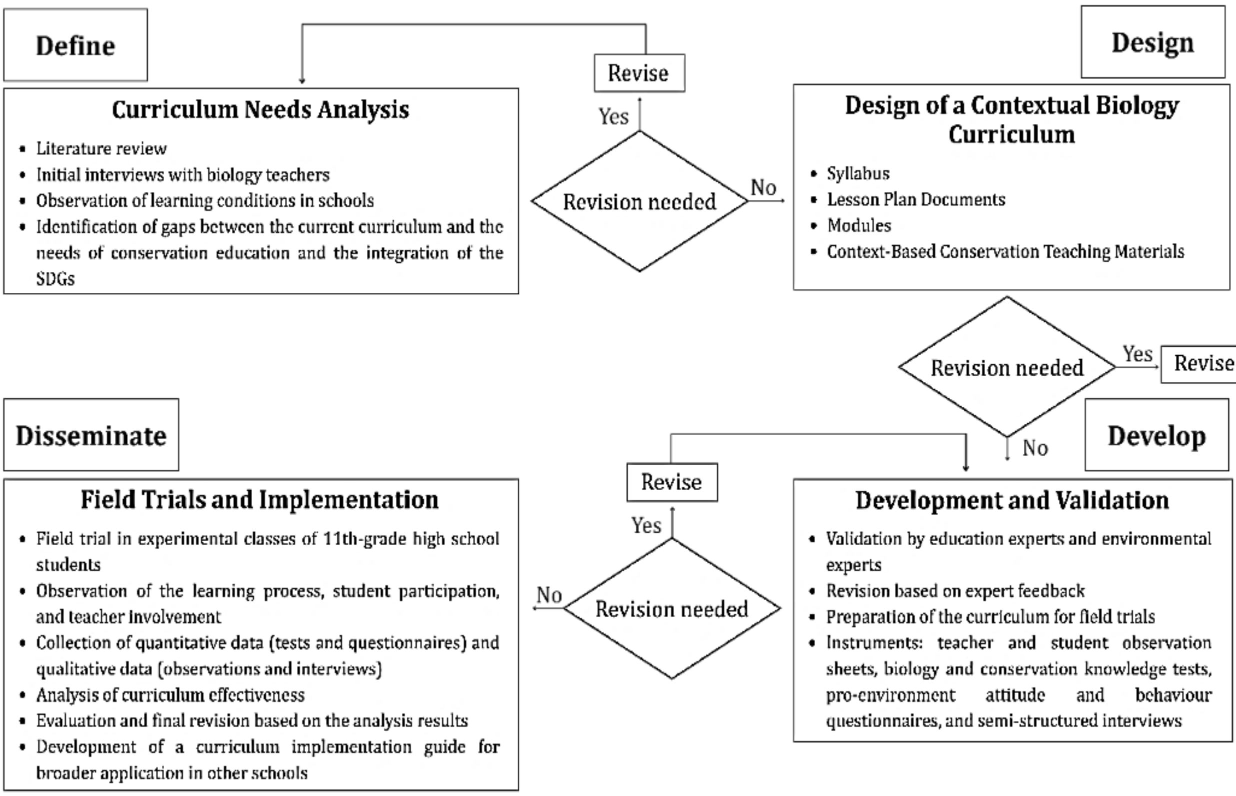

Figure 2. The 4D Research and Development Model for Contextual Biology Curriculum Integrating Local Conservation Issues and SDG Goals

The first stage, define, is conducted through a curriculum needs analysis that includes a literature review, initial interviews with biology teachers, and observations of learning conditions in schools. This analysis aims to identify the gaps between the current curriculum and the needs of conservation education and the integration of the SDGs (Martínez-Borreguero et al., 2024). The second stage, design, includes preparing syllabi, learning plan documents, modules, and context-based conservation teaching materials. At this stage, learning indicators, practical activities, and the relationship between the material and local environmental issues, as well as the SDGs, are systematically integrated.

The third stage, develop (development and validation), is carried out through expert validation (education and environmental experts) to assess the feasibility and suitability of the curriculum. Subsequently, revisions are made based on expert input so that the curriculum is ready for trial. The instruments used at this stage include teacher and student observation sheets, biology and conservation knowledge tests, pro-environment attitude and behaviour questionnaires, and semi-structured interviews (Børresen et al., 2023b; Härtel et al., 2023; Restović & Bulic, 2024). In the fourth stage, disseminate (field trials and implementation), the curriculum is applied in experimental classes of 11th-grade high school students. Observations are conducted to evaluate the learning process, student participation, and teacher involvement.

Quantitative data were collected through knowledge tests and questionnaires, while qualitative data were obtained from observations and interviews. Analysis was conducted descriptively and inferentially to assess the effectiveness of the curriculum in enhancing students' understanding, attitudes, and pro-environmental behaviors (Collado et al., 2020b). After the trial, an evaluation and final revision were conducted based on the analysis results. The results of this evaluation are used to develop a curriculum implementation guide that can be applied more broadly in other schools. The design of this research allows for continuous adjustments and improvements, so that the resulting curriculum can be implemented effectively and support the achievement of the SDGs through contextual and conservation-based biology education.

Data Analysis Techniques

The data collected in this study were analyzed using both quantitative and qualitative methods to provide a comprehensive picture of the curriculum's effectiveness. Quantitative data were obtained from biology and conservation knowledge tests, pro-environmental attitude and behavior questionnaires, and teacher and student observation score sheets. Quantitative analysis was conducted descriptively by calculating the mean, median, standard deviation, and percentage to determine the level of competency achievement, student participation, and the effectiveness of curriculum implementation. Additionally, inferential analysis was conducted using the paired-samples t-test or ANOVA when more than one group was involved to assess significant differences between conditions before and after curriculum implementation. This analysis allows researchers to evaluate improvements in students' understanding of biological concepts, attitudes, and pro-environmental behaviors resulting from the implementation of the curriculum.

Qualitative data were obtained from semi-structured interviews and observation notes during the learning process. Qualitative analysis was conducted using thematic content analysis, which involves grouping data into main themes, such as curriculum effectiveness, participant experiences, constraints and challenges, and improvement suggestions. The results of this analysis are used to provide an in-depth interpretation of the curriculum's impact on students' attitudes and behaviors, and to refine the curriculum through final revisions. With this combination of quantitative and qualitative analysis, the research produces valid, measurable, and comprehensive findings and provides a strong foundation for recommendations on implementing a context-based conservation biology curriculum that supports the achievement of the SDGs.

RESULTS AND DISCUSSION

Define Stage

The Define phase seeks to assess the necessity for a contextual biology curriculum that prioritizes natural resource conservation and incorporates the Sustainable Development Goals (SDGs). This analysis used three primary sources: a literature review, initial teacher interviews, and classroom observation of learning conditions. The findings indicate a significant gap between the existing biology curriculum and the requirements for contextual, conservation-oriented, and SDG-integrated biology education. This observation is consistent with Fajeriadi et al. (2025) research, which found that biology curricula and practices remain predominantly textual and biocentric, lacking contextualization of conservation and sustainability issues.

To achieve genuinely contextual and conservation-oriented biology education, it is necessary to redesign the curriculum to integrate local context, conservation, and socioeconomic dimensions, and to provide teacher training and develop locally based learning resources. Based on the research results of Zebua & Malik (2025) and Lestari et al. (2023b), achieving contextual and conservation-oriented biology education requires a curriculum that integrates local potential and problems, conservation, and socio-economic dimensions; systematic development of local learning resources; and ongoing training for teachers to be able to design and implement learning, practicums, and assessments that foster environmental literacy and conservation character.

Evidence from the literature review, teacher interviews, and classroom observations consistently demonstrates that biology instruction remains largely centered on theoretical mastery, with insufficient emphasis on connecting these concepts to local environmental challenges and practical conservation efforts (Ramdiah et al., 2025). This suggests that the core issue extends beyond the limited inclusion of conservation content to encompass a weak pedagogical connection between biological knowledge, students' lived experiences, and sustainability-oriented actions. These findings support constructivist and contextual learning theories, which posit that students' understanding becomes more meaningful when scientific concepts are linked to tangible experiences and real-world environmental issues. Presenting topics such as ecosystems, biodiversity, or natural resources solely as abstract concepts often leads students to perceive biology as disconnected factual knowledge. In contrast, relating these concepts to urban forests, water quality, local conservation, or environmental management practices enables students to construct meaning, interpret relevant issues, and recognize the significance of biology in ecological decision-making.

Based on Mercan & Varol Selçuk (2024) research findings, presenting topics such as ecosystems, biodiversity, or natural resources solely as abstract concepts often leads students to perceive biology as disjointed, factual knowledge. Conversely, connecting these concepts to urban forests, water quality, local conservation, or environmental management practices allows students to construct meaning, interpret relevant issues, and recognize the importance of biology in ecological decision-making. The results of this Definition phase thus lay an important foundation for curriculum development by advocating the inclusion of conservation content and a shift toward experiential, action-oriented learning. The Define phase results thus establish a critical foundation for curriculum development by advocating for the inclusion of conservation content and a shift toward experiential, action-oriented learning.

Design Stage

The results of the Design phase indicate that the contextual biology curriculum was developed by integrating biological concepts, natural resource conservation, project-based activities, and the Sustainable Development Goals (SDGs). The creation of a conservation-focused syllabus, lesson plans, modules, and teaching materials demonstrates a systematic approach to achieving constructive alignment among learning objectives, instructional activities, and assessments. Based on Baptista et al. (2025) research findings, the development of learning materials focused on contextual cases allows students to directly observe, analyze, discuss, and reflect on environmental issues.

This curriculum design is significant because it integrates three dimensions of learning outcomes: knowledge, attitudes, and skills. In the context of sustainability education, mastery of biological concepts alone is insufficient without ecological awareness and the ability to apply conservation principles in practical contexts. The inclusion of field projects, local case studies, ecosystem observations, and reflective inquiry provides an effective strategy to facilitate students' progression from declarative knowledge to applied understanding. Based on Cutillas et al. (2025) research findings, the inclusion of field projects, local case studies, ecosystem observations, and reflective inquiry provides an effective strategy for facilitating students' progression from declarative knowledge to applied understanding. Therefore, the design phase demonstrated that the developed curriculum has a strong pedagogical foundation by integrating material structure, learning activities, and a focus on sustainability. Therefore, the design phase demonstrates that the developed curriculum possesses a robust pedagogical foundation by integrating material structure, learning activities, and a focus on sustainability.

Develop Stage

The Develop stage aims to validate the contextual biology curriculum that was designed in the Design stage. Validation is conducted by education experts and environmental specialists to assess the feasibility, relevance of the material, effectiveness of the teaching methods, and integration of SDG issues. Additionally, the curriculum is tested in a limited experimental class to evaluate initial implementation and student responses. Here is the table of curriculum validation results by experts (N = 5) based on five assessment aspects:

Table 11.
Expert Content Validity Results of the Contextual Biology Curriculum

Assessment Aspect	Indicator	Score	Category
Content Feasibility	Material is relevant to biology concepts and conservation	4.80	Very Valid
SDGs Integration	Material and activities clearly relate to SDG goals	4.60	Valid
Learning Activities	Practical activities and projects align with student abilities	4.40	Valid
Assessment Guidelines	Competency indicators are clear and measurable	4.60	Valid
Module Readability	Module is easy to understand for teachers and students	4.70	Very Valid
Average		**4.60**	**Valid**

The results of the Design phase indicate that the contextual biology curriculum was developed by integrating biological concepts, natural resource conservation, project-based activities, and the Sustainable Development Goals (SDGs), with a particular focus on incorporating SDG targets related to environmental education into both activities and lesson content. The creation of a conservation-based syllabus, lesson plans, modules, and teaching materials demonstrates a deliberate effort to achieve constructive alignment among learning objectives, instructional activities, and assessments. The curriculum addresses topics such as ecosystems, biodiversity, and conservation, and includes activities that enable students to directly observe, analyze, discuss, and reflect on environmental issues.

Conceptually, this curriculum design is significant because it integrates three dimensions of learning outcomes: knowledge, attitudes, and skills. The Trazona et al. (2025) research findings suggest that a good curriculum integrates the dimensions of knowledge, attitudes, and skills. Within sustainability education, mastery of biological concepts must be complemented by ecological awareness and the practical application of conservation principles. This perspective is supported by Apriana et al. (2025) research findings, which emphasize that biology education should cultivate students' environmental awareness by applying conservation principles. The incorporation of field projects, local case studies, ecosystem observations, and reflective inquiry represents an effective strategy. According to Treibergs et al. (2022), these methods encourage students to progress from factual knowledge to applied understanding. The Design phase demonstrates that the curriculum possesses a robust pedagogical foundation by unifying content, activities, and a sustainability orientation.

Disseminate Stage

The Disseminate stage involved implementing the validated contextual biology curriculum in grade 11 classes at five public senior high schools in Cilegon, with 180 students and biology teachers participating. This stage assessed the curriculum's practicality and effectiveness in enhancing knowledge of biology and conservation, fostering pro-environmental attitudes, and promoting pro-environmental behaviors. Instructional strategies included contextual modules, project-based learning, field observations, and discussions on local conservation and Sustainable Development Goals (SDG) issues. Data collection methods comprised classroom observations, tests, questionnaires, and semi-structured interviews to evaluate teacher performance, student engagement, cognitive outcomes, behavioral changes, and feedback from teachers, students, and experts.

Table 12.
Teacher Observation Results During Curriculum Implementation

Measured Aspect	Score	Interpretation
Quality of Material Delivery	4.20	Teachers delivered content clearly and logically, using real-life examples effectively.
Use of Learning Media	3.90	Visual and digital media were applied effectively, though some teachers underutilized interactive tools.
Student Interaction	4.00	Teachers encouraged participation and peer discussion; collaboration observed in group tasks.
Integration of SDG Issues	3.80	SDG-related content was included, but linkage to real-world sustainability challenges varied.
Provision of Evaluation and Feedback	4.10	Formative assessment and feedback were applied consistently, supporting student learning.
Average	4.00	

Table 12 shows that the observation results indicate that the curriculum could be effectively implemented in classroom instruction. Teachers delivered biology and conservation materials through contextual examples, learning media, and practical activities, while students demonstrated active participation, cooperation, and increased interest in conservation-related topics.

The student observation results further showed that students were actively involved in discussion and practical activities. They asked questions, contributed ideas, and demonstrated enthusiasm when the learning activities were connected to local environmental problems. Teachers also reported that the use of contextual modules and activity-based lesson plans helped them organise the learning process and increased student participation. These findings suggest that the contextual approach helped bridge biological concepts with real environmental issues students experience (Hadi et al., 2022).

Table 13.
Student Observation Results During Curriculum Implementation

Measured Aspect	Average Score	Interpretation
Active Participation	4.10	Students actively responded and contributed during discussions.
Practical Skills	3.90	Practical tasks performed well; minor errors observed in tool usage.
Conceptual Understanding	4.00	Students demonstrated understanding of biological and conservation concepts.
Pro-Environmental Attitudes	4.20	Students showed interest and concern for environmental issues.
Cooperation in Learning Activities	4.00	Group work was effective; responsibilities shared adequately among peers.
Average	**4.00**	

Table 13 shows that students demonstrated positive engagement during the curriculum implementation. Pro-environmental attitudes received the highest scores, suggesting that students exhibited significant interest and concern for conservation issues. According to the Ortega-Lasuen et al. (2023) study, students with pro-environmental attitudes showed particular engagement with conservation when instruction emphasized local context, bio-altruistic values, and species knowledge. Active participation, conceptual understanding, and collaboration received high scores, suggesting that contextual and project-based activities foster greater student engagement in the learning process. Shirinzade & Li (2025) research indicates that contextual and project-based biology learning activities significantly enhance student engagement. These activities not only increase students' physical and mental activity but also improve motivation, creativity, collaboration, and the ability to connect biological concepts to real-world situations.

Practical skills received marginally lower scores, suggesting that certain students require additional guidance in utilizing tools and performing observation-based tasks. The Killpack et al. (2020) study confirmed that practical skills constitute a critical component of biology education. Laboratory activities, fieldwork, inquiry-based exercises, and research projects not only enhance conceptual understanding but also develop students' scientific process skills, professional preparedness, and scientific identity. This aligns with Chang et al. (2024) research, which found that student involvement and participation in context-based problem-solving can encourage deeper understanding of the material.

Table 14.
Students' Knowledge Test Results

Measured Aspect	Average Score	Interpretation
Factual Knowledge	78%	Students recalled key biological concepts accurately.
Conceptual Understanding	75%	Good understanding of ecological principles; some misconceptions noted.
Application Skills	72%	Students applied conservation principles to case studies; solutions varied in creativity.
Connection to SDG Goals	70%	Students could relate lessons to SDG goals, but some connections were superficial.
Average	74%	

Table 14 indicates that students achieved good results in biology and conservation knowledge tests. Factual knowledge obtained the highest score, indicating that students accurately recalled key biological concepts. However, the score for connecting learning materials to SDG goals was relatively lower, suggesting that students still needed more guidance in linking biological and conservation concepts to broader sustainability targets.

These findings align with Vančugovienė et al. (2025) research findings that contextual and experiential learning can strengthen students' conceptual understanding by connecting scientific concepts to concrete situations in their everyday environments. Conservation-based examples, field activities, and case analyses enable students to construct meaning from biological concepts. This approach helps them go beyond simply memorising definitions. However, students scored lower when connecting the material to the SDGs. This aligns with Corres et al. (2020) research findings that show that understanding the sustainability framework requires a higher level of abstraction than simply memorising factual knowledge. Rianti et al. (2024) research findings also indicate that environmental and conservation learning is more effective when students explicitly reflect, engage in problem-solving, and participate in project-based learning.

Table 15.
Pro-Environmental Attitude and Behaviour Results

Measured Aspect	Average Score	Interpretation
Environmental Awareness	4.30	High awareness of environmental issues and biodiversity importance.
Motivation for Environmentally Friendly Actions	4.10	Students showed willingness to participate in eco-friendly activities.
Actual Behaviour (School & Home)	3.80	Environmentally responsible behaviours observed, but consistency varied.
Social Attitudes Related to Conservation	4.00	Students encouraged peers and participated in community initiatives.
Average	4.00	

Table 15 shows that students' pro-environmental attitudes and behaviours were generally positive after the curriculum implementation. Environmental awareness obtained the highest score, while actual behaviour at school and home obtained the lowest score. This finding indicates that students' awareness and motivation improved more than their daily environmental practices, so future curriculum implementation should include more structured habituation activities.

The questionnaire results indicated that students' environmental awareness developed more strongly than their actual pro-environmental behaviour. This finding aligns with Husin et al. (2025) research, which suggests that awareness is an important initial outcome but does not automatically lead to consistent daily practice. For this reason, the curriculum should be supported by recurring environmental activities, school-based conservation projects, and behavioural reinforcement at home and school. These activities can help transform students' awareness into more stable environmental habits.

Table 16.
Summary of Interview Findings

Measured Aspect	Key Findings	Interpretation
Experiences During Curriculum Implementation	Teachers found curriculum feasible but noted time constraints; students enjoyed contextual examples.	Curriculum generally effective; minor adjustments needed for pacing.
Students' Understanding of Conservation Materials	Most students could explain concepts and relate to real-world cases.	Positive comprehension; some gaps in deeper application.
Obstacles and Challenges	Limited resources, varied prior knowledge among students.	Support and scaffolding required for uniform understanding.
Suggestions for Curriculum Improvement	Include more interactive and project-based activities; strengthen SDG integration.	Recommendations inform refinement of curriculum design.

Table 16 summarises the qualitative findings from semi-structured interviews. Teachers considered the curriculum feasible and relevant, but they identified time constraints and limited resources as important challenges. Students reported that contextual examples and field activities helped them understand conservation materials more easily. These findings provide important input for curriculum refinement, particularly by strengthening project-based activities, improving learning media, and deepening SDG integration.

Based on Portuguez Castro & Gómez Zermeño (2020) research, contextual and project-based learning needs enough opportunities for students to observe, investigate, discuss, and reflect on real environmental problems. Limited time and resources can reduce the depth of learning. Scott's et al. (2012) research also emphasises that environmental education is more meaningful when students are directly involved in authentic activities such as fieldwork, local case analysis, and collaborative problem-solving. However, its effectiveness depends highly on teacher facilitation and institutional support.

In addition to observations, knowledge tests in biology and conservation were conducted before (pre-test) and after (post-test) the implementation of the curriculum (Table 17 and 18).

Table 17.
Pre-Test and Post-Test Results

Measured Aspect	n	Mean-Pre-Test	SD-Pre-Test	Mean-Post-Test	SD-Post-Test
Biology Knowledge	180	65.20	7.80	84.60	6.50
Conservation Knowledge	180	60.50	8.20	82.10	7.10
Pro-Environmental Attitude	180	3.20	0.40	4.30	0.30
Pro-Environmental Behavior	180	3.00	0.50	4.10	0.40

Table 18.
Paired-Samples t-Test Results

Measured Aspect	n	t-value	p-value	Interpretation
Biology Knowledge	180	11.24	< 0.001	Significant increase
Conservation Knowledge	180	12.01	< 0.001	Significant increase
Pro-Environmental Attitude	180	10.35	< 0.001	Significant increase
Pro-Environmental Behavior	180	9.87	< 0.001	Significant increase

The significant improvement across all measured aspects indicates that the contextual biology curriculum was effective not only in strengthening students' cognitive understanding but also in promoting affective and behavioral outcomes related to conservation. The increase in knowledge of biology and conservation suggests that linking biological concepts to local environmental issues helped students understand the relevance of biology beyond classroom theory (Nurfatonah & Aminatun, 2025). This finding is important because one of the main weaknesses identified in the Define stage was the limited connection between existing biology materials and real conservation practices. The improvement in pro-environmental attitudes and behaviors also shows that contextual and project-based learning can create a more meaningful learning experience. Students were not only exposed to conservation concepts but were also encouraged to observe, discuss, and reflect on environmental issues in their surroundings (Cardenas Morales et al., 2025). This learning process may explain why students showed greater awareness and a stronger willingness to engage in environmentally responsible actions after the curriculum implementation.

The results of this study also align with the Yuan & Yu (2024) study, which stated the importance of integrating SDG issues into biology learning. By linking topics on ecosystems, biodiversity, and conservation to SDGs 4 and 15, students are encouraged to view biology as part of the broader sustainability challenge (Zhao et al., 2025). However, the relatively low scores in linking learning materials to SDG goals suggest that SDG integration needs to be made more explicit in future curriculum revisions. Therefore, teachers should specifically develop learning scenarios, guiding questions, and assessment rubrics that clearly connect local conservation actions with global sustainability targets. Teachers are advised to incorporate SDG references directly into lesson plans, highlight related SDG targets during instruction, and design assessments that require students to demonstrate how local actions meet SDG goals.

Qualitative findings supported the quantitative results, as teachers found the curriculum feasible and relevant, and students reported that local examples, field observations, and project-based activities enhanced their understanding of conservation material. Consistent with the Niemiller et al. (2021) research findings, these elements facilitated student comprehension. Together, these lines of evidence demonstrate that the curriculum's effectiveness extends beyond measurable improvements to include participants' learning experiences. However, challenges identified in interviews, including time constraints, limited resources, and diverse prior knowledge, highlight the need for teacher training, supporting media, and flexible implementation guidelines to accompany the dissemination of the curriculum.

Moreover, integrating SDG issues adds global and local relevance to the learning. This integration helps students connect theoretical knowledge to real-world sustainability challenges, thereby deepening their understanding of the Sustainable Development Goals and motivating them to see how their actions can contribute to achieving these objectives (Koçulu & Topçu, 2024). Overall, the Disseminate stage demonstrates that the developed curriculum is not only valid, applicable, and effective but also represents a significant advancement in biology education. This approach delivers meaningful progress toward fostering conservation and sustainability, fulfilling the research objectives while serving as a robust model for future educational initiatives.

CONCLUSION

This study developed and evaluated a contextual biology curriculum that integrates natural resource conservation and Sustainable Development Goals (SDG)-oriented learning. The findings demonstrate that the curriculum is feasible, practical, and effective in enhancing students' knowledge of biology and conservation, as well as their pro-environmental attitudes and behaviors. Expert validation confirmed that the curriculum satisfied criteria for content feasibility, SDG integration, learning activities, assessment guidelines, and module readability. Field trials indicated increased student engagement in learning activities, improved understanding of conservation issues, and heightened environmental awareness. Pre-test and post-test analyses revealed significant improvements across all measured domains, suggesting that contextual, project-based, and field-oriented learning approaches can strengthen students' cognitive, affective, and behavioral outcomes. These results suggest that the developed curriculum may serve as an alternative model for integrating sustainability and local conservation issues into biology education. The study also underscores the need for adequate learning materials, comprehensive teacher preparation, structured environmental activities, clearer integration of the SDGs, broader implementation trials, and further investigation into the curriculum's long-term impact on students' sustainable behaviors.

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