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Applying Engineering for One Planet (EOP) Framework to Teach Environmental Risk in Two Institutions

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Abstract

A course module of the environmental risk topic was developed aligning with the Engineering for One Planet (EOP) framework. The module was used in courses from two public institutions: one is a required course named Introduction to Environmental and Ecological Engineering in an Environmental and Ecological Engineering program and open to all engineering students as an elective, while the other is a required course named Solid Waste Management in an Environmental Engineering program. Assessment data were collected to evaluate student understanding of the environmental risks through reflection essays. A qualitative approach was utilized to evaluate the reflection essays, specifically, the Constant Comparative Method was employed to identify emerging themes related to students' comprehension of environmental risks and their alignment with sustainability principles. Essays were coded for key indicators such as depth of critical thinking, integration of EOP concepts, and the students' ability to connect theoretical knowledge with real-world environmental challenges. The qualitative data analysis was supported by rubrics aligned with Bloom's Taxonomy to assess varying cognitive levels demonstrated in student reflections. This approach provided insights into the efficacy of the EOP-aligned module in fostering a deeper understanding of environmental sustainability and risk assessment among engineering students.

Introduction

Engineering education is at a critical juncture where the infusion of sustainability into the curriculum is not just beneficial but essential. As society grapples with the depletion of natural resources, the rise in emissions and waste, and the impact of climate change, engineering curricula must evolve to address these challenges [1-2]. The integration of sustainability concepts into engineering courses is pivotal to cultivating a workforce capable of creating a more sustainable future. Prior research highlights significant gaps in the current engineering education paradigm, particularly in its failure to fully prepare students to work within the constraints of sustainability [3]. Research also suggests that programs with greater emphasis on environmental and social sustainability are more likely to increase the enrollment and retention of students of color [4]. By reimagining engineering curricula through the lens of sustainability, educators can develop innovative teaching approaches that are responsive to the changing needs of the planet and society [5-6].

Engineering for One Planet (EOP) Framework was developed in collaboration with hundreds of individuals from academic, industry, public, and nonprofit sectors to seamlessly integrate into engineering curriculum and uses common sustainability language. It maps the learning outcomes to 2010 Bloom’s Taxonomy, 7 ABET student outcomes, and 17 United Nations Sustainable Development Goals (SDGs). As shown in Figure 1, essential sustainability-focused student learning outcomes in nine topic areas in the categories of “systems thinking”, “knowledge and understanding”, and “skills experiences and behavior” were focused on the construction of EOP framework, making it a practical implementation tool to help educators embed sustainability into engineering education [7].

Figure 1. The EOP Framework [7]

While this curricular and institutional change has been initiated nationally through programs that use the EOP Framework, these efforts have been isolated to individual institutions. This has made sharing of effective approaches to sustainability integration difficult to outline and replicate. There is an ever-increasing need to transform engineering education so that all students encounter environmental and social sustainability principles as an integrated part of their education in professional formation.

This study aims to provide insights into the efficacy of the EOP-aligned module in fostering a deeper understanding of environmental sustainability and risk assessment among engineering students. A course module of the environmental risk topic was developed aligning with the Engineering for One Planet (EOP) framework and implemented in courses from two public institutions. The research question is: how does an EOP-aligned environmental risk module impact engineering students' comprehension of environmental risks, sustainability principles, and their ability to integrate theoretical knowledge into real-world applications across different institutional contexts? Therefore, the primary goal was to evaluate the efficacy of the EOP-aligned module in fostering student understanding of environmental sustainability and risk assessment. The secondary goal was to explore how institutional and course-level differences influenced learning outcomes and engagement levels.

Methodology

Setting

Purdue University, located in West Lafayette, Indiana, is a world-renowned public research institution known for its strong emphasis on STEM (science, technology, engineering, and mathematics) disciplines. With an enrollment exceeding 50,000 students, Purdue boasts a diverse and dynamic student body representing all 50 U.S. states and over 115 countries. The university

is particularly celebrated for its engineering programs, consistently ranked among the top in the nation, which attract high-achieving students with strong academic backgrounds and a keen interest in innovation and problem-solving. Purdue's students benefit from state-of-the-art facilities, robust research opportunities, and a culture that fosters critical thinking, interdisciplinary collaboration, and leadership development. As a Tier 1 research university, Purdue's student population includes a significant proportion of undergraduates and graduates who are highly motivated to address complex global challenges, particularly in areas such as sustainability, environmental protection, and technological advancement.

Kennesaw State University (KSU), located in Kennesaw, Georgia, is a rapidly growing public institution recognized for its commitment to innovation, hands-on learning, and student success. With an enrollment of over 43,000 students, KSU serves a diverse population, including traditional, non-traditional, and international students. As a Carnegie-designated R2 research institution, KSU offers a wide range of undergraduate and graduate programs, with notable strengths in engineering, business, and education. The university emphasizes practical, career-oriented education, providing students with opportunities to engage in real-world problem-solving and applied research. Many KSU students are first-generation college attendees, balancing their studies with work and family commitments, which contributes to a vibrant and resilient campus culture. KSU's focus on accessibility, diversity, and experiential learning makes it an integral part of the Atlanta metro area's academic and professional landscape.

Population

Introduction to Environmental and Ecological Engineering at Purdue University is a core course for the Environmental and Ecological Engineering (EEE) degree major and an elective course for non-EEE students. Sustainability and life cycle thinking were emphasized throughout the course. The course provides introductions to water pollution, air pollution, hazardous and solid wastes, and their control, and environmental impact statements and global pollution issues. The course topics include the overview of sustainable design, chemistry, physical, and biology processes, water quantity and quality, water treatment, wastewater treatment, solid waste management, air quality engineering, and environmental risk. This is a traditional 3-credit face-to-face class with class period recorded. In the fall semester, the majority students in the course are non-EEE students. Particularly in Fall semester of 2024, 96% students (N=105) are in non-EEE majors such as civil engineering (35.71%), chemical engineering (31.25%), computer engineering (11.61%), electrical engineering (8.04%), mechanical engineering (2.68%), environmental and natural resources engineering (1.79%), natural resources and environmental science (1.79%), biochemistry (0.89%), and more. In addition, majority students are juniors (32.1%) and seniors (65.2%). After covering the environmental risk topics, an environmental risk assignment about the military burn pit exposure and TEAM Act (Toxic Exposure Associated Military) was given towards the end of the semester. After analyzing the burn pit exposure issue from the perspective of environmental risk, professional and ethical responsibility, students were asked to write reflection essays to respond to the following questions: (1) How has this course connected your academic preparation to the challenges of managing environmental risk in real-world scenarios? (2) How has this course influenced your personal or professional values concerning sustainability and public health? (3) Provide examples of how you might apply the knowledge and skills gained in this course to sustainability in future professional settings.

Solid Waste Management at KSU is a core course for the Environmental Engineering (EnvE) degree major and an elective course for non-EnvE students. While the course's intent focuses on concepts of generation, storage, collection, transfer, treatment, and disposal of solid waste, students also have the opportunity to address related engineering and management issues like sustainability, life cycle thinking, and environmental risk. Traditionally, this course is taught online or in a hybrid format. During the Fall semester of 2024, the course was taught fully face-to-face and met twice each week for 75 minutes. With only 15 students, the small class size was largely due to the modality shift. When considering the composition of students, most were EnvE majors (60%) and the rest were civil engineering students. Similar to the Purdue University course, students were given an environmental risk assignment related to the TEAM Act and asked to respond to the same reflection questions.

Design and Data Collection

A qualitative approach was utilized to evaluate the student reflection essays submitted as part of an EOP-aligned module in environmental engineering courses. The study involved textual analysis to assess students' comprehension of environmental risks, sustainability principles, and critical thinking skills. A comparative component was incorporated to evaluate differences in engagement and performance between students at two distinct institutions.

Student reflection essays were collected from two institutions: Purdue University, which offered a broad course covering environmental engineering concepts, and KSU, which focused specifically on solid waste management. Essays were anonymized to ensure confidentiality and categorized based on the institution and course context.

Analytical Framework

The analysis employed the Constant Comparative Method [8] to systematically identify and categorize emerging themes. This iterative process involved comparing data segments to refine and develop thematic categories. A coding framework (Table 1) was developed based on predefined categories, including:

- Understanding of Environmental Risks
- Application of Sustainability Principles
- Integration of Course Concepts
- Depth of Critical Thinking
- Ethical Perspectives
- Future Applications

Coding Procedure

The essays were systematically coded using the predefined framework. NVivo software was used to organize and analyze the data, ensuring consistency and transparency in the coding process. Each essay was reviewed for the presence of specific indicators within the six thematic categories:

- **Understanding of Environmental Risks:** Identification of environmental challenges and their real-world impacts.

- **Application of Sustainability Principles:** Demonstration of sustainable practices and ethical decision-making.
- **Integration of Course Concepts:** Application of EOP-aligned principles, such as lifecycle analysis and risk assessment.
- **Depth of Critical Thinking:** Evaluation of trade-offs, complexities, and solutions.
- **Ethical Perspectives:** Awareness of public health, equity, and societal impacts.
- **Future Applications:** Insights into the professional or personal application of learned concepts.

Table 1. Coding Framework

Code Category	Subcategories	Description/Indicators	Example Codes
Understanding of Environmental Risks	- Identification of environmental risks - Causes and impacts of environmental risks - Connection to real-world scenarios	Evidence of understanding specific environmental risks and their real-world implications, including human health and ecological impacts.	"Air pollution as a key risk," "Burn pits and health impacts"
Application of Sustainability Principles	- Ethical decision-making - Sustainable practices - Integration of sustainability in solutions	Demonstrates how students integrate sustainability principles, focusing on long-term environmental and social benefits.	"Recycling and waste reduction," "Balancing economic and environmental goals"
Integration of Course Concepts	- Application of EOP principles - Risk assessment methods - Lifecycle analysis	Evidence of applying EOP concepts to analyze and address challenges, particularly risk assessment and decision-making frameworks.	"Lifecycle analysis for waste management," "EOP principles in action"
Depth of Critical Thinking	- Reflection and evaluation - Balancing trade-offs - Addressing complexity	Analysis of challenges, trade-offs, or complexities involved in environmental decision-making.	"Trade-offs between efficiency and sustainability," "Evaluating stakeholder impacts"
Ethical Perspectives	- Public health considerations - Responsibility to stakeholders - Equity and justice in decisions	Demonstrates awareness of ethical implications and a sense of responsibility toward affected communities and stakeholders.	"Ethics in engineering decisions," "Protecting vulnerable communities"
Future Applications	- Professional practice - Systems thinking - Innovation and technology	Insights into how students plan to apply course concepts and sustainability principles in their future professional or personal roles.	"Air pollution control in designs," "Sustainability in workplace systems"

Rubric Development

A rubric (Table 2) aligned with Bloom's Taxonomy was designed to evaluate cognitive levels demonstrated in the essays. Each category was scored on a four-point scale:

- **Exemplary (4):** In-depth analysis with clear, well-supported examples.
- **Proficient (3):** Adequate analysis with some minor gaps.
- **Developing (2):** Basic understanding with limited application or examples.
- **Beginning (1):** Minimal engagement with the topic and lack of clarity.

Table 2. Bloom-Focused Cognitive Levels Rubric

Criteria	Exemplary (4)	Proficient (3)	Developing (2)	Beginning (1)
Understanding of Environmental Risks	Demonstrates in-depth knowledge and connects risks to real-world scenarios with clarity and precision.	Shows adequate understanding and real-world application with minor gaps in explanation.	Demonstrates some understanding but lacks depth or specificity.	Limited understanding with vague or unclear explanations.
Application of Sustainability Principles	Fully integrates sustainability principles and provides clear examples of ethical and sustainable practices.	Applies sustainability concepts with minor inconsistencies or limited examples.	Mentions sustainability principles but lacks detailed application.	Minimal or no evidence of sustainability principles.
Integration of Course Concepts	Effectively incorporates course concepts (e.g., EOP, risk assessment) with clear and relevant applications.	Adequately integrates course concepts with minor omissions or unclear connections.	Some course concepts are mentioned but lack relevance or clarity.	Minimal or no integration of course concepts.
Depth of Critical Thinking	Analyzes trade-offs, complexity, and ethical considerations with depth and originality.	Provides analysis with some depth, addressing complexity but missing some key trade-offs.	Limited analysis of complexity or trade-offs; lacks originality.	Minimal critical thinking; descriptions are superficial.
Ethical Perspectives	Fully explores ethical implications, public health, and equity issues with examples and justification.	Addresses ethical considerations with some examples but lacks depth or justification.	Mentions ethical issues but lacks clarity or concrete examples.	Minimal or no mention of ethical considerations.
Future Applications	Provides detailed and innovative plans for applying concepts professionally or personally.	Outlines clear plans with some detail but lacks innovation or specificity.	Mentions future applications but lacks clear or actionable plans.	Minimal or no mention of future applications.

Comparative Analysis

To assess differences between the two schools, a quantitative component was introduced. Average scores across the six categories were calculated for each group, and engagement levels (High, Medium, Low) were determined based on total scores. A t-test was conducted to determine the statistical significance of differences between the two groups. This analysis focused on identifying disparities in performance and engagement that could be attributed to differences in course design and institutional context.

Ethical Considerations

All student data was anonymized to protect confidentiality. The study adhered to ethical guidelines for educational research, ensuring that participation in the analysis did not influence academic evaluations or student outcomes.

Results

Purdue University Course

The analysis of the 80 essays submitted by students from Purdue University revealed a balanced distribution of engagement levels and a strong understanding of key concepts. Across the six thematic categories:

- **Understanding of Environmental Risks**: Students scored moderately, with many discussing real-world risks such as landfills, air pollution, and solid waste management. These essays demonstrated a reasonable grasp of the environmental challenges associated with engineering.
- **Application of Sustainability Principles**: This was a strength for Purdue University, with students frequently referencing recycling, ethical decision-making, and sustainable practices. Average scores were high in this category.
- **Integration of Course Concepts**: Students demonstrated moderate integration of lifecycle analysis, risk assessment, and EOP principles, though some essays lacked depth in connecting theoretical knowledge to practical scenarios.
- **Depth of Critical Thinking**: Scores in this category were moderate, with many students evaluating trade-offs and proposing solutions. However, only a minority exhibited advanced critical analysis.
- **Ethical Perspectives**: Ethical considerations, such as public health and societal impacts, were well-addressed by most students, reflecting moderate to high scores.
- **Future Applications**: Students scored high in this category, with many outlining professional and personal plans to apply course concepts to real-world problems.

Engagement Levels: The engagement levels indicate 41.8% of students demonstrated high engagement, 48.1% showed medium engagement, and 10.1% were categorized as low engagement (Figure 2). This highlights a strong connection to the module's content for most students, with room for targeted interventions to support those in the low engagement group.

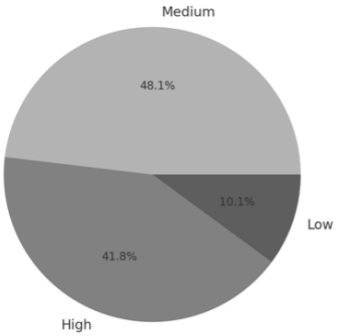

Figure 2. Purdue University Engagement Levels

Kennesaw State University Course

The analysis of the 10 essays from Kennesaw State University revealed a predominance of Medium Engagement levels, with lower overall scores in several categories compared to Purdue University. Across the six thematic categories:

- **Understanding of Environmental Risks**: Scores were lower compared to Purdue University, with fewer essays addressing specific risks in depth.
- **Application of Sustainability Principles**: Performance in this category was comparable to Purdue University, as many students discussed recycling and sustainable practices.
- **Integration of Course Concepts**: This was a weaker area, with limited references to lifecycle analysis, risk assessment, or EOP principles.
- **Depth of Critical Thinking**: Scores in this category were significantly lower, with most essays focusing on surface-level discussions rather than evaluating complexities or trade-offs.
- **Ethical Perspectives**: Scores were like Purdue University, with students addressing public health and societal impacts adequately.
- **Future Applications**: Scores were lower, with fewer students articulating detailed plans for applying course concepts in professional or personal contexts.

Engagement Levels: The engagement levels for this group show a strong skew toward medium engagement, with 82.4% of participants in this category, while 17.6% demonstrated high engagement and none fell into low engagement (Figure 3). This distribution indicates that most students achieved a moderate level of comprehension and application, with a smaller subset showing deeper critical thinking and integration of concepts. The absence of low engagement suggests a baseline effectiveness of the module, though opportunities remain to elevate more students to the high engagement category.

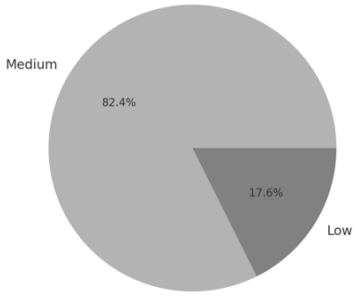

Figure 3. KSU Engagement Levels

Comparative Analysis

Statistical analysis using t-tests revealed significant differences between the two schools in several categories:

- **Understanding of Environmental Risks** ($p = 0.0187$): Purdue University outperformed Kennesaw State University, demonstrating a deeper understanding of environmental challenges.
- **Integration of Course Concepts** ($p = 0.0227$): Purdue University showed stronger connections between theoretical knowledge and practical applications.
- **Depth of Critical Thinking** ($p = 2.33e\text{-}06$): Purdue University significantly outperformed Kennesaw State University in demonstrating critical thinking skills.
- **Future Applications** ($p = 0.0119$): Purdue University students articulated clearer plans for applying course concepts.

Figure 4 provides a visual representation of these results. No significant differences were observed in:

- **Application of Sustainability Principles**: Both schools performed similarly, reflecting a shared understanding of sustainability practices.
- **Ethical Perspectives**: Scores were comparable, with both schools addressing ethical considerations adequately.

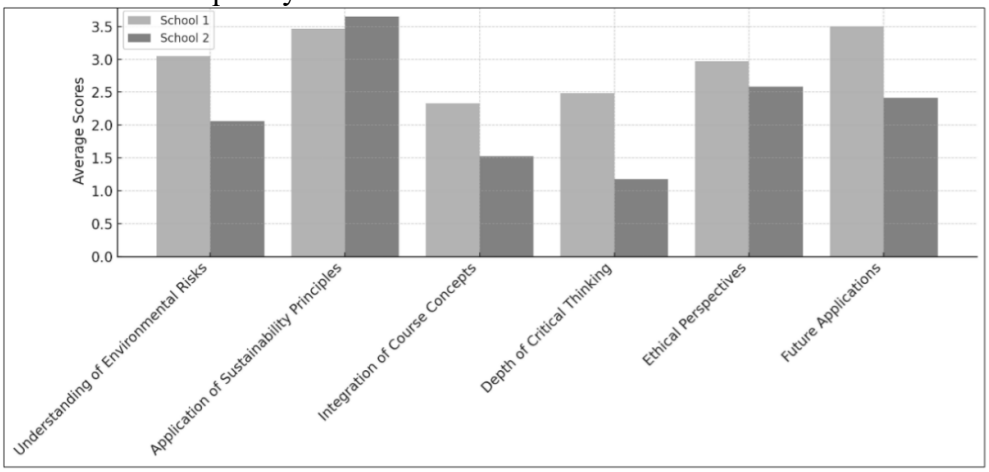

Figure 4. Comparison of Average Scores Across Categories (School 1: Purdue, School 2: KSU)

Discussions

The findings highlight the efficacy of the EOP-aligned module in fostering a deeper understanding of environmental risks and sustainability principles, though differences between the two schools suggest variability in how the module was implemented or received.

Insights into Student Understanding

- **Purdue University Strengths**: Students from Purdue University demonstrated higher levels of engagement, particularly in critical thinking and future applications. This suggests that the module effectively connected theoretical concepts to real-world challenges for this group.
- **Kennesaw State University Gaps**: While Kennesaw State University students exhibited strong Medium Engagement levels, the lack of High Engagement and lower scores in critical thinking and concept integration suggest a need for more support in applying theoretical knowledge.

Comparative Implications

The differences in performance and engagement levels between the two schools can be attributed to several factors, including the type of institution, the student populations, the specific focus of each course, and the timing of the module. Purdue University, offered a course that covered a broad spectrum of environmental engineering concepts, providing students with a more comprehensive framework to understand and engage with topics such as environmental risks, sustainability principles, and critical thinking. This broader context likely enabled students to draw from a wider array of knowledge, resulting in higher levels of engagement and more sophisticated reflections. In addition, the environmental risk EOP module was given at the end of semester, after students learned the basics of all different environmental engineering topics (water, wastewater, waste, air, risk, etc.), so students were more likely to connect the concepts learned throughout the semester as a summary of the course.

In contrast, Kennesaw State University, offered a course specifically focused on solid waste management. While this narrower focus allowed for a deeper dive into a specific area of environmental engineering, it may have limited students' ability to connect with broader sustainability and risk assessment concepts. This specificity is reflected in the predominance of medium engagement levels among Kennesaw State University students, as they were able to grasp the core principles of the course but may not have had the opportunity to explore diverse environmental issues or develop critical thinking to the same extent as their peers at Purdue.

Additionally, the institutional context and student populations likely played a role. Purdue, as a large research-intensive university, may provide more exposure to advanced environmental engineering topics and access to a wider range of academic resources, which can enhance students' ability to critically engage with course material. Almost two-third of students in the Purdue course were seniors and some of them were in their last semester before graduation, so they may have more exposure to the environmental engineering topics and put more thoughts into the practical application and challenges as they are getting ready for their career. In addition,

most students were not in the environmental engineering major, and they may bring different perspectives and connect sustainability into their own diverse professions. For example, many students are from chemical, civil (construction and structure), electrical and computer engineering, most of those fields are the major contributors to some environmental issues (waste, air, and water pollutions). After learning the environmental engineering concepts, students are likely to find many real-world application examples of sustainability in their own fields. In contrast, Kennesaw State, a regional university with a teaching focus, may have designed the course to align with more immediate, practical applications relevant to solid waste management, resulting in a different type of learning outcome.

These findings highlight the importance of aligning course design with institutional strengths and student needs. Broad, comprehensive courses may foster higher engagement and critical thinking by exposing students to a wide range of concepts, while narrowly focused courses can provide in-depth understanding of specific topics but may require additional scaffolding to encourage broader connections and deeper critical engagement.

Implications for Engineering Education

The results underscore the importance of tailoring engineering courses to align with both institutional contexts and specific learning objectives. Broader courses, such as the one offered at Purdue University, can foster higher engagement and critical thinking by providing students with a comprehensive understanding of environmental engineering concepts. These courses prepare students to make interdisciplinary connections and address complex, multifaceted challenges. Conversely, narrowly focused courses, like Kennesaw State University's solid waste management course, can offer in-depth exploration of specialized topics but may require additional instructional support to help students make broader connections and apply critical thinking skills.

These findings suggest that institutions should consider a dual approach to environmental engineering education. Comprehensive courses can be complemented by focused modules that provide detailed exploration of specific topics. Additionally, incorporating interactive learning strategies, such as case studies, role-playing exercises, and collaborative projects, may help students from teaching-focused institutions achieve similar levels of critical engagement and application. In addition, currently most curricular application of EOP framework have been focused on the core courses in environmental engineering major, but our study suggested the meaningful impacts of using EOP framework in elective courses that is open to diverse majors. It worth to explore the benefits on sustainability education using EOP framework in elective courses.

Conclusions and Future Work

This study applied EOP framework to teach environmental risk module in two institutions. The results demonstrate the efficacy of the EOP-aligned module on engineering students' comprehension of environmental risks, sustainability principles, and their ability to integrate theoretical knowledge into real-world applications. The similarities and differences in students' understanding level observed in the two institutions also suggested the importance of tailoring engineering courses to align with both institutional contexts and specific learning objectives. In

addition, the findings showed the positive impact of EOP framework for sustainability education in engineering elective courses. To build on these findings, future research could explore:

1. Longitudinal Studies: Examine how students apply environmental sustainability and risk assessment concepts in their professional careers. This could provide insights into the long-term efficacy of EOP-aligned modules.
2. Instructional Strategies: Investigate the effectiveness of various teaching methods, such as flipped classrooms or project-based learning, in enhancing student engagement and comprehension across different institutional types.
3. Institutional Contexts: Conduct comparative studies across a broader range of institutions, including community colleges and international universities, to better understand how institutional resources and student demographics influence learning outcomes.
4. Focus on Equity: Explore how EOP-aligned modules can be designed to address equity and inclusion, particularly in contexts where access to resources and prior exposure to environmental concepts vary widely.
5. Assessment Tools: Develop and validate more nuanced assessment tools to evaluate student engagement and critical thinking, particularly in narrowly focused courses.

These directions could help refine the implementation of EOP-aligned modules, ensuring they effectively prepare students to address pressing environmental challenges while meeting diverse educational needs.

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