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Integrating Climate Change, Sustainability, Resilience, and Environmental & Social Justice into Civil and Environmental Engineering Education

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Integrating Climate Change, Sustainability, Resilience, and Environmental & Social Justice into Civil and Environmental Engineering Education: Work in Progress

Abstract

Civil and Environmental Engineering (CEE) education has traditionally emphasized the technical and analytical foundations necessary for solving engineering problems. However, the complex challenges of the 21st century ranging from climate change and infrastructure resilience to sustainability and environmental justice, require a broader, more holistic approach to engineering design and decision-making. This Work-in-Progress project aims to infuse the CEE curriculum with interconnected themes of sustainability, climate resilience, and social and environmental justice through a series of modular, course-embedded learning experiences.

The project involves collaborating with faculty across the CEE program to identify existing course content where these critical topics can be meaningfully integrated. New mini-modules are being developed to create a "thread" of related lessons spanning from first-year through senior-level courses. Each module will include a lesson plan, active-learning exercises (e.g., think-pair-share, mini-projects), and reflective assignments that connect technical concepts with societal and environmental implications. For instance, a flood control infrastructure module may be implemented to hydrology and structural analysis courses with different perspectives that asks students to analyze real infrastructure failures through both technical and sociotechnical lenses, connecting engineering decisions to economic, policy, and equity dimensions. By embedding these themes across courses and class levels, the project will help cultivate graduates who can create resilient, equitable, and sustainable solutions that serve both society and the planet.

Motivation

CEE programs have long emphasized technical rigor and analytical problem solving as core components of undergraduate education. While these foundations remain essential, the challenges facing engineers in the 21st century, including climate change, infrastructure resilience, sustainability, and environmental and social justice require engineers to engage with complex, interconnected systems that extend beyond purely technical domains. Reports from professional organizations and accrediting bodies increasingly call for engineering graduates who can account for societal impacts, ethical considerations, and long-term sustainability in their design and decision-making processes [1], [2], [3].

Climate change poses urgent challenges for civil and environmental engineers, influencing water availability, infrastructure performance, and community vulnerability. At the same time, inequitable exposure to environmental risks and unequal access to resilient infrastructure highlight the need to explicitly integrate environmental and social justice considerations into engineering curricula [4], [5]. However, earlier work indicates that sustainability and justice topics are often addressed through standalone electives or isolated modules, limiting students' ability to see these themes as integral to core engineering practice. While active and project-based learning approaches are frequently employed, many implementations emphasize awareness rather than the development of systems-level reasoning, and assessment practices are often limited to single-point, self-reported measures. The literature further highlights that sustainability challenges are inherently complex, requiring pedagogical approaches that engage students in examining assumptions, trade-offs, and stakeholder perspectives, rather than treating sustainability as an add-on to technical analysis [6]. These findings point to the need for scaffolded, curriculum-embedded approaches that integrate sustainability, resilience, and justice across courses while supporting faculty adoption through adaptable instructional materials and more robust assessment strategies.

This work-in-progress project aims to address these gaps by embedding interconnected themes of climate change, sustainability, resilience, and environmental and social justice across the CEE curriculum through modular, course-embedded learning experiences. Rather than adding new courses, the project focuses on identifying opportunities within existing courses where these themes can be meaningfully integrated alongside technical content.

Background

A substantial body of literature documents the importance of integrating sustainability into engineering education and identifies persistent challenges in doing so effectively. Studies have shown that students often struggle to connect technical analysis with broader societal and environmental implications when sustainability is treated as peripheral to core coursework [6]. Systematic reviews emphasize the need for curricular approaches that develop systems thinking, critical reflection, and ethical reasoning alongside technical competence [7], [8], [9]. Several frameworks have been proposed to guide sustainability integration, including competency-based models and Education for Sustainable Development (ESD) learning objectives [10], [11]. Key sustainability competencies such as systems thinking, anticipatory thinking, and normative competence that are directly relevant to CEE practice were identified by earlier work [12]. More recent work highlights the importance of resilience thinking, particularly in the context of climate adaptation and infrastructure planning, where engineers must navigate trade-offs among performance, equity, and long-term risk [13]. Environmental and social justice perspectives further extend this work by raising questions of who benefits from engineering solutions and

who bears the risks [4], [14]. Riley and others argue that justice-oriented engineering education helps students recognize the social dimensions of engineering decisions and challenges dominant narratives that frame engineering as value-neutral [4], [15]. However, faculty often report barriers to integration, including lack of time, limited instructional resources, and uncertainty about how to align justice topics with technical learning outcomes [6], [16].

This work builds on these findings by adopting a modular, scaffolded approach that integrates sustainability, climate resilience, and justice themes directly into selected CEE courses, reducing barriers to adoption while maintaining alignment with technical objectives. The module design is also informed by the Engineering for One Planet (EOP) Framework [17], which provides vetted sustainability and leadership competencies that engineering graduates need regardless of subdiscipline. The EOP Framework's nine topic areas including Systems Thinking, Environmental Literacy, Social Responsibility, and Environmental Impact Assessment map well onto the learning goals of this project and offer a structured vocabulary for aligning modules with both ABET Student Outcomes and broader sustainability competencies. What distinguishes this work from other modular sustainability curricula is its simultaneous integration of three often-siloed frameworks: climate resilience, sustainability, and environmental justice, within a coherent curricular thread. Rather than treating these as separate add-ons or relying on a dedicated standalone course, this approach embeds all three themes across core technical courses at multiple levels of the program. The work also addresses faculty adoption barriers by providing ready-to-use instructional materials designed to align with existing technical learning outcomes, rather than asking faculty to develop new content from scratch.

Project Goals

This project is supported by a curriculum innovation grant (provided by School of Global Environmental Sustainability) and is being developed within the Civil and Environmental Engineering program at Colorado State University. The primary goal is to create a coherent "thread" of sustainability and justice-focused learning experiences that span from the first year through senior-level courses.

Specific project goals include:

1- Identifying existing CEE courses where climate change, sustainability, resilience, and justice topics naturally align with technical content.
2- Developing modular mini-lessons that integrate these themes without displacing core technical material.
3- Supporting faculty adoption through ready-to-use lesson plans, activities, and assessment tools.
4- Gathering formative feedback from faculty and students to iteratively refine the modules.

Module Development

The project uses a collaborative process, with faculty providing input on the modules being developed and points in the curriculum/courses where sustainability and justice considerations can be incorporated due to nature of the core content. Modules are being developed to make the connections between the core concepts and sustainability and justice through active learning and reflection.

Each module will include:

1- A short contextual introduction linking course content to climate, sustainability, or justice challenges.
2- An active-learning component (e.g., think-pair-share, stakeholder perspective/role playing activity, or short scenario-based analysis).
3- A reflective prompt encouraging students to consider societal, environmental, or equity implications of technical decisions.

For example, in hydrology and water resources courses, modules may address changing precipitation patterns, flooding, and drought under climate change scenarios. Students will analyze technical data while also considering stakeholder perspectives, community vulnerability, and equitable adaptation strategies. Similar modules are being developed for other courses. This modular approach aligns with prior research suggesting that curriculum-wide integration, rather than standalone courses, is more effective in helping students perceive sustainability and justice as integral to engineering practice [7], [9].

Example Module: Flood Control Infrastructure (Courses: Transportation Infrastructure, Hydrology, Structural Analysis)

One of the modules being developed by this work is the Flood Control Infrastructure module which is designed to be adaptable. The core framing stays the same but the technical anchor shifts to match the course. In hydrology it connects to stormwater and hydrology content; in transportation it connects to infrastructure policy and city planning; and in structural analysis it connects to structural resilience and failure analysis. Below is a brief outline of the module components as currently designed. This module is intentionally designed to be lightweight in terms of instructor preparation. It uses infrastructure case studies, students encounter the technical details through their existing coursework, and the module redirects that content toward the broader sociotechnical context.

Learning objectives: By the end of this module, students will be able to (1) explain common modes of flood control infrastructure failure and evaluate best practices for improving resilience; (2) analyze the economic, policy, and societal dimensions of flood infrastructure decisions

beyond purely technical performance metrics; and (3) identify and characterize the stakeholders involved in flood control decisions, including communities that bear disproportionate flood risk.

Active-learning activity: Students are assigned a case study of a flood control infrastructure failure or near-failure. They first analyze the technical causes, structural deficiencies, design limitations, maintenance failures and then are asked to look beyond those technical factors to consider economic pressures, political decision-making, and which communities were most affected and why. Working in small groups, they identify the stakeholders involved (residents, city engineers, insurance agencies, downstream communities, environmental advocates) and prepare a short stakeholder analysis. Groups then share out and the class discusses how different stakeholder positions would lead to different engineering and policy recommendations for the same infrastructure problem.

Reflective assessment: Students submit a written reflection responding to two prompts: (1) What factors beyond the technical ones most shaped the outcome of the infrastructure failure you studied, and how should that change how you approach design decisions? (2) Whose perspectives were hardest to incorporate into the engineering decision-making process, and what are the implications of that for how you practice as an engineer? Reflections are assessed with a rubric that looks for evidence of systems thinking, recognizing interconnected technical, social, and economic factors, and engagement with the question of who benefits from and who bears the costs of engineering decisions. There is no single right answer, depth of reasoning is the ultimate goal.

Curricular Thread Overview

Table 1 shows the current plan for how the curricular thread is distributed across the CEE program, including the specific courses targeted and the modules under development for each level. The intent is to build complexity progressively: early modules focus on awareness and framing, mid-level modules introduce analysis of trade-offs and stakeholder dynamics, and senior-level modules push students toward synthesis and design decision-making that integrates technical, social, and ethical considerations.

Table 1. Proposed Curricular Thread: Course Levels, Themes, and Complexity/Focus

Course Level	Target Course Type	Themes Addressed	Complexity / Learning Focus
First Year	Common First Year Engineering Course	Sustainability framing; climate change overview; intro to environmental justice; Bridging the Green Divide Through Value Tension	Awareness and framing; recognizing the "why" of sustainable engineering; opening discussion using Envisioning Cards to surface value tensions
Sophomore	Intro to Environmental Engineering; Materials	Sustainability in materials and waste; How to Steal a River (Sand Mafia ethics); Complementary Field Activities (campus compost tours, Powerhouse)	Connecting technical content to real-world ethics and justice; stakeholder roleplay; immersive field experiences that build environmental awareness
Junior	Transportation; Hydrology; Water and Wastewater Treatment Design; Structural Analysis	Flood Control Infrastructure; Rooftop Rain Collection; Dam ethics; Transportation ethics; New Belgium Brewery Tour (wastewater treatment)	Multi-dimensional analysis of infrastructure resilience; economic, policy, and societal dimensions alongside technical analysis; stakeholder identification and conflict
Senior	Hydraulics; Global Water Challenges; Environmental Engineering Design; Senior Design	Sustainability and Innovation in Engineering; Bridging the Green Divide; Global Approaches in Engineering Design	Synthesis and design across climate, sustainability, and justice themes; science communication; Carleton SERC activities

Module Library Overview

Across the course levels, the project has been developing or adapting a set of distinct modules, structured activities, and field experiences. Several of these are described briefly to illustrate the range of approaches being planned.

Bridging the Green Divide Through Value Tension uses the Envisioning Cards to prompt students to examine how the global transition to sustainable systems creates both opportunities and inequities across communities. It is currently planed to be used as an opening discussion in Global Water Challenges course, in the common first year engineering course, and in the senior level Environmental Engineering Design course for the semester project. The module aims to

reveal value tensions early, before students have been conditioned to treat those tensions as outside the scope of engineering work.

How to Steal a River: In the Evaluation of Civil Engineering Materials course, ethical thinking will be stimulated through discussion of the "Sand Mafia" an organized criminal network that illegally harvests sand and gravel for construction, causing significant ecological damage and suppressing community dissent. Students will engage with the technical background on aggregate science and resource extraction, then roleplay as stakeholders affected by the Sand Mafia's operations. This module will make the connection between materials engineering, a typically technical-only domain, and questions of environmental justice and corporate responsibility.

Rooftop Rain Collection: planned for the Hydrology course will ask students to apply hydrological concepts and modeling to calculate the volume of water that could be harvested from campus rooftops. Students address both the technical calculations and the environmental and water quality concerns associated with rainwater harvesting, and connect their analysis to green building rating systems. This module demonstrates use of campus infrastructure as a teaching case, a system they may find very relevant.

Complementary Field Activities: To enhance student experience and to provide immersive, experiential learning, existing campus and community sustainability resources are planned to be utilized along with the relevant modules. Examples of field trips include on-campus compost and recycling tours in Intro to environmental Engineering course, the New Belgium Brewery engineering tour in Water and Wastewater Treatment Design course, a LEED-certified building tour for Structural Analysis course, a Fort Collins transportation and city planning tour in Infrastructure and Transportation Systems course, and the Historic 1883 Water Works Tour in Hydraulics course. These field trips will be structured to connect to the technical content being taught and include reflective components.

It is also worth noting that complementary sustainability integration work is happening in the same program. A parallel initiative using Writing Across the Curriculum (WAC) principles has redesigned the senior-level Environmental Engineering Design course (40 to 60 students) around a series of scaffolded writing deliverables that build sustainability reasoning across the semester. In that course redesign, individual deliverables are explicitly mapped to ABET Student Outcomes 2, 3, and 4 and to ASEE EOP Framework competencies, including a rubric that assesses ethical reasoning depth, three-pillar sustainability analysis, stakeholder and justice considerations, and evidence-based justification. Preliminary results from that course (n=52 students) found that 78% of students articulated trade-offs across at least two sustainability pillars and 83% identified ethical and justice concerns and proposed mitigation strategies [Omur-

Ozbek ASEE 2026 National Conference paper]. These findings are directly relevant to this project as evidence that structured scaffolding and explicit competency framing can produce meaningful student learning outcomes on sustainability and justice themes, and they support the assessment approach we are adopting here.

Assessment and evaluation plan

As a work-in-progress, assessment focuses on formative evaluation and feedback to guide refinement. Data sources will include:

1- Faculty feedback on module feasibility, alignment, and instructional fit.
2- Student reflections on how modules influenced their understanding of technical content and broader impacts.
3- Selected student work artifacts from module activities.

Qualitative analysis will be used to identify themes related to systems thinking, awareness of climate and justice issues, and perceived relevance to engineering practice. This approach aligns with prior studies demonstrating the value of reflective and artifact-based assessment in sustainability education [8], [11], [12]. More specifically, student reflections and work artifacts will be analyzed using thematic coding [18] to identify patterns in how students engage with sustainability, resilience, and justice themes. Coded responses will be mapped to competency categories drawn from the EOP Framework [17], particularly Systems Thinking, Social Responsibility, and Environmental Literacy, which also align with ABET Student Outcomes 2, 3, and 4. Faculty feedback will be gathered through brief structured interviews or short surveys at the end of each pilot. We will look in particular at whether faculty found the modules feasible to implement, whether they aligned well with existing technical outcomes, and their perceptions of whether the sustainability content was worth the trade-off in terms of any material that had to be reduced or restructured to make room for it. This last question directly responds to faculty concerns about curricular displacement and will help us understand what conditions support sustained adoption. and where adjustments to structure or timing are needed. As modules mature, future iterations of the project will explore more systematic assessment of learning outcomes.

Work-in-progress

Module development and pilot implementation are ongoing. Feedback from faculty will inform revisions to lesson structure and facilitation guidance as the modules are implemented. Student feedback will be collected during pilot offerings starting in Fall 2026 and will be used to refine module content and prompts. Future work will report on the outcomes of the pilot offerings, including faculty feasibility ratings, student reflection themes, and any adjustments made to module structure or timing based on feedback.

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