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Broadening Sustainability Education in Engineering Disciplines

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Work-in-Progress: Broadening Sustainability Education in Engineering Disciplines

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Abstract
This project integrates the Engineering for One Planet (EOP) Framework in 30 courses under 15 faculty members within four engineering departments to positively impact approximately 385 students. The courses range from first-year to graduate-level. Lateral expansion of the framework extends to non-current engineering departments and vertically expands to the university's Sustainability Office. The impact of EOP/sustainability instruction will be measured and freely disseminate all developed materials and findings via multiple mechanisms, particularly a companion website. Researchers have shown that the delivery methods of teaching sustainability varied among their survey respondents and interviewees. The proposed delivery methods are to integrate concepts of sustainability into existing core and elective courses, but also to provide routes for students to focus on sustainability. This is accomplished via project-based learning with and without external advisors, instituting engineering degree emphases and programs in sustainability, and showcasing successes with the Sustainability Office and university faculty for future expansion.

The EOP Initiative and Framework have already provided an excellent foundation to use for assessment. A matrix has been constructed to track the implementation of these outcomes in project courses. This matrix will also aid ABET accreditation efforts and incorporate global considerations via the United Nations Sustainable Development Goals. Making these connections will allow students to see the global significance of their education and decisions. Additional discussion of results and outcomes will be included as they pertain to faculty and administration. The success of early decision-making will be highlighted relative to student learning outcomes and the advancement of program outcomes.

Introduction/Background
Engineering education is undergoing a dynamic shift towards incorporating sustainability principles into its curriculum and pedagogy. Recent advances address various aspects of sustainability, promoting future engineers equipped to tackle global challenges. Key advancements include curriculum integration and interdisciplinary collaboration. Universities are integrating sustainability concepts across disciplines, not just environmental engineering. Courses like "Design for Sustainability" or "Engineering Ethics" encourage holistic thinking and consideration of environmental and social impacts in design projects [1, 2]. Recognizing the interconnected nature of sustainability, engineering programs are fostering collaboration with social sciences, public policy, and business to equip students with diverse perspectives [3].

Continued use and addition of project-based learning and active learning strategies leverage the administrative-level required, including assessment. Experiential learning takes center stage, with students tackling real-world sustainability challenges through projects like designing renewable energy systems for communities or developing sustainable products [4]. Flipped classrooms, simulations, and collaborative learning methods are replacing traditional lectures, engaging students actively and promoting critical thinking about sustainability [5]. Accreditation bodies are incorporating sustainability criteria into their evaluation processes, encouraging universities to strengthen their focus on sustainability [6].

Faludi and Gilbert [7] showed that the delivery methods of the teaching of sustainability varied among their survey respondents and interviewees. The proposed delivery methods are to integrate concepts of sustainability into existing core/required and elective courses, but also to provide routes for students to focus on sustainability. This is accomplished via project-based learning with and without external advisors, instituting engineering degree emphases and programs in sustainability, and broadening participation among instructors campus-wide. All members of the research team agree that concepts of sustainability are not only necessary for engineers to understand, but industry professionals and government agencies see it as an imperative as well [8].

Methods

The team is assessing students' development and understanding of sustainability concepts. This goal is coupled with evaluating efforts to manage and teach students these concepts effectively. Evaluation of the team's efforts relies on feedback from an advisory team of administrative personnel and sustainability professionals outside of academia. Content is being generated and made available to interested stakeholders via multiple avenues. Those interested may be higher education students, K-12 teachers and students, university instructors, and academic administration.

The team is generating a website to share all created content, modules, key findings, and implementation paths of the framework. Recordings of pertinent webinars, workshops, and tutorials are hosted on this site with appropriate links and context. Instructor perceptions of the implementation process will also be documented and combined with lessons learned to provide best practice strategies. An overview of the project path is shown in Figure 1.

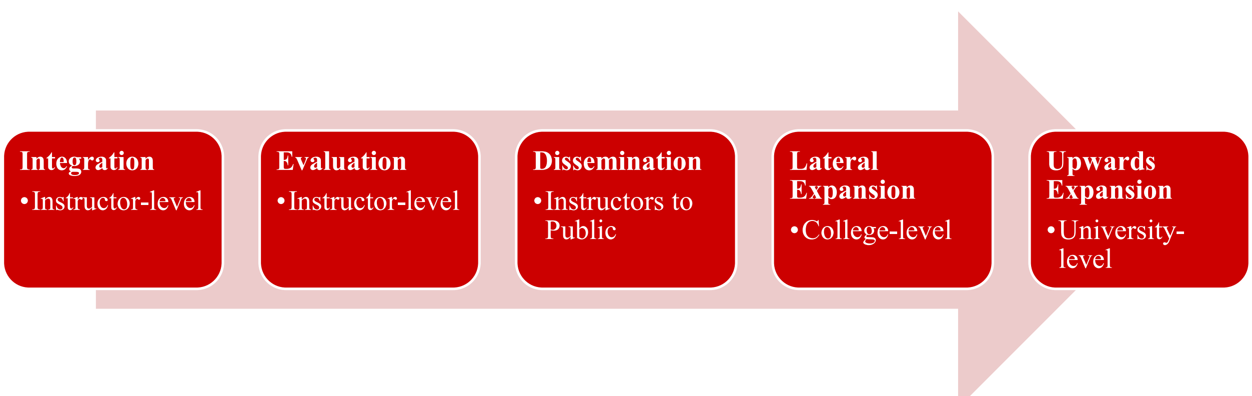

Figure 1: Overview of implementation process

A key change to the team's initial goals is the addition of a number of focus groups for students and teaching faculty. These groups will allow researchers to assess what students retain after the semester, and more importantly, how their thinking has changed with time and other course content. A focus group dedicated to faculty will reveal barriers to teaching concepts of sustainability in the classroom and show potentially apprehensive instructors that existing content can be modified to incorporate sustainability, while decreasing lecture preparation time.

Integration – Integrate the EOP Framework in multiple courses across the College of Engineering. These span first-year to graduate-level students based on enrollment data. This is being accomplished via two subtasks.

a. Create and implement adaptable learning modules with assessment guidelines and rubrics. Non-technical topics may include circular economy, social and environmental justice, and sustainability. Technical topics are course specific.
b. Implement problem-based learning (PBL) projects. Diversity, equity, and inclusion, (DEI) and environmental justice themes coincide with the EOP Framework learning outcomes and instructor knowledge.

Each instructor assesses their EOP learning outcomes to conclude if students (1) met the criteria, (2) nearly met the criteria, or (3) did not meet the criteria. Each criterion will be decided by the instructor and tied to the assessment's rubric or other accreditation outcome. An example is that each senior chemical engineering student must give an oral presentation per ABET student outcome criterion 3 [9]. An instructor may set the 'met the criteria' score at 80% based on an existing rubric. Any student that earns a 70-80% may be the category of 'nearly met the criteria,' and any student that achieves less than 70% 'did not meet the criteria.'

Evaluation – Evaluate the impact of EOP instruction via assessments, surveys, and interviews. The latter two include all stakeholders, e.g., industry, students, and faculty, associated with the course or assessment. These data include EOP learning outcomes and criteria met/not met, assessment type, level of Bloom's taxonomy, and, as applicable, the corresponding United Nations Sustainable Development Goal and ABET criterion. Course information and demographics are recorded with encountered challenges and recommendations of framework implementation. To complement the quantitative evaluation, the Sustainability Office is *qualitatively* assessing the impact of EOP instruction on students in representative EOP-infused courses; resources already exist for these assessments. [Author] will aid in these assessments that include focus groups of students and an optional group of instructors pending interest.

Dissemination –Disseminate educational products and resources. Assessment results, challenges, and recommendations will be made available. Much of the dissemination will occur through the dedicated website (to be documented in final paper).

Lateral Expansion – Provide seminars and workshops on EOP integration to other College of Engineering instructors and university administration to gain additional support. Assessment criteria and processes in the fields of engineering are anticipated to inform the teaching of sustainable concepts in non-engineering fields on campus.

Upwards Expansion – Work with the university's Sustainability Office to evaluate integration of the EOP Framework and assessment strategies into existing campus-wide activities and programs. This objective directly aligns with the university's Strategic Plan [10].

The EOP Initiative and Framework have already provided an excellent foundation to use for assessment. A matrix has been constructed to track the implementation of these outcomes in project courses. This matrix will also aid ABET accreditation efforts and incorporate global considerations via the United Nations Sustainable Development Goals. Making these connections will allow students to see the global significance of their education and decisions. Additional discussion of results and outcomes will be included as they pertain to faculty and administration. The success of early decision-making will be highlighted relative to student learning outcomes and the advancement of program outcomes.

Preliminary Findings

Courses that participate in this study are summarized in Table 1. These data show 30 courses being taught by 15 faculty members in four engineering departments; most of the courses are in the department of chemical engineering.

Table 1: Courses participating in this study – adding concepts of sustainability based on the Engineering for One Planet Framework

Semester	Course	Course Title	Enroll.	Req/Elec
F23	CH EN 1703	Introduction to Chemical Engineering	66	R
F23	CH EN 3353	Fluid Mechanics	61	R
F23	CH EN 3453	Heat Transfer	59	R
F23	CH EN 3701	Projects Lab I	62	R
F23	CH EN 4203	Process Control	64	R
F23	CH EN 4253	Process Design I	64	R
F23	CH EN 4701	Projects Lab III	64	R
F23	CH EN 4706	Capstone Project I	64	R
F23	CH EN 5555	Catalysis Science and Engineering	1	E
F23	CH EN 5960	Practical Industrial Process Engineering	10	E
F23	CH EN 6555	Catalysis Science and Engineering, Grad.	18	E
F23	ENGIN 1022	Survey of Engineering	73	E
F23	MET E 5330	Renewable Energy	4	E
F23	MET E 6330	Renewable Energy, Graduate	8	E
F23/S24	CH EN 3253	Chemical Process Safety	76	R
F23/S24	CH EN 4870	Industrial Energy Analysis	30	E
F23/S24	CVEEN 4900	Professional Practice and Design I	59	R
F23/S24	CVEEN 4910	Professional Practice and Design II	51	R
S24	CH EN 1705	Chemical Eng. Design and Innovation	52	R
S24	CH EN 2800	Fundamentals of Process Engineering	55	R
S24	CH EN 3553	Chemical Reaction Engineering	64	R
S24	CH EN 3702	Projects Lab II	61	R
S24	CH EN 4707	Capstone Project II	63	R
S24	CH EN 5103	Biochemical Engineering	61	R
S24	CH EN 5205	Smart Systems	12	E
S24	CH EN 5253	Process Design II	48	R
S24	CH EN 5305	Air Pollution Control	8	E
S24	CH EN 5960	Product Design	16	R
S24	CH EN 6205	Smart Systems, Graduate	7	E
S24	CH EN 6305	Air Pollution Control, Graduate	4	E

An example of one assignment and assessment pair is from the 4000-level course, Professional Practice and Design I. Students are required to produce a project 'Needs Statement' for the course; this occurs at the quarter point of the two-semester sequence. Aligning with ABET criteria number two, the assignment described below satisfies the advanced EOP design learning outcome, "Implement stakeholder user experience/participatory studies (e.g., design thinking, human-centered design) and social impact assessments to meet user needs in responsible, novel, improved, ethical, and sustainable ways."

Assignment: Each student prepares a Project Program (or Brief) that reflects seven weeks of study. The first three weeks' research various stakeholders and their needs. The second three weeks research the technical needs and definition of the project. The seventh week synthesizes this work to produce a single project statement that identifies constraints, needs, and requirements of the project. This document occurs at the mid-point of the first course in the capstone sequence. The Program assignment is specifically designed to set the stage for the subsequent Feasibility Study and Conceptual Design. It is also specifically designed to have each and every study write an explicit Problem Statement, etc. In other words, the assignment provides direct data for the performance indicator.

> *Problem statement given to students*: The Program captures the essence of the project. Your goal here is convert the original Project Statement that you were provided into a technical document that ties together functional relationships and major elements of the design. The document should provide a strong basis by which to later develop and measure the feasibility of concepts and alternative designs. It should translate preferences and opinions into project requirements that are supported by hard data. It should refine the big picture goals into an organized and functional set of detailed goals that balance innovation with established use, balance user needs with constructor and facility needs.

Success Criteria: The reviewer(s) of the report asked the question(s): How well does the document prepare the way for an engineering feasibility study? How well does it meet the expectations noted in the assignment statement? Of the expectations of a professional report?

> The work of each student is rated on a rubric where 70% means minimum competency. Minimum competency here means that the response identifies or addresses: (1) Needs of stakeholders (owner, users, etc.), (2) Needs of facility, (3) Statement of existing facility and conditions, (4) Consequences of doing nothing, and (5) Goals and Vision. We want each student to demonstrate the desired behaviors at least some of the time. The metric is the percent of students who achieve the minimum desired performance level. The decision and action process are (1) at least 80% of the students have a score of 70% or higher, (2) if 70% to 80% of the students have a score of 70% or higher, then the situation is flagged for further monitoring but no other action is required, and (3) if less than 70% of the students have a score of 70% or higher, then detailed review is initiated. A scoring rubric is below.

Score	**Description of Content**	**Description of Format**
$90 \leq$ Score ≤ 100	Report summarizes most or all of the needs, opportunities, and challenges.	Report follows a professional format with only a few minor aspects that could lead to confusion, lack of clarity, etc.

Score	Description of Content	Description of Format
80 ≤ Score < 90	Report largely presents a professional tone. But there are missing details. It needs revisions before sharing with a "real-world" client.	Report follows a professional format but has aspects that directly lead to confusion, lack of clarity, etc.
70 ≤ Score < 80	Report missing a major element but meets a minimum. Elements are addressed but at a superficial level.	Report has a format that is minimal at best. Examples include lack of organized structure, no coherency to the structure, graphics and tables without proper reference or clarity. Content is there but difficult to follow simply due to its format and presentation.
Score < 70	Many missing elements, addressed at superficial level at best, in essence not responsive to the charge of the document.	Lacks coherency, appearance, organization, and clarity of a minimally competent document.

Assessment data of this assignment is detailed in Table 2.

Table 2: Assessment data for the 4000-level course, Professional Practice and Design I assignment.

Score	Frequency	Relative Frequency	Cum Percent ≥ Floor
90 ≤ Score ≤ 100	6	6 of 14 = 42.8%	6 of 14 = 42.8 %
80 ≤ Score < 90	3	3 of 14 = 21.4%	**9 of 14 = 64.3%**
70 ≤ Score < 80	4	4 of 14 = 28.6%	**13 of 14 = 92.8 %**
Score < 70	1	1 of 14 = 7.1%	

Students successfully formatted the report and followed convention, followed the provided structure, and understood the content that had been provided. More than 80% of the students met the minimum of a 70% score. ■

It is clear that students welcome concepts of sustainability in their coursework based on a Spring 2023 survey asking students, "In what area(s) of chemical engineering are you most interested in working?" Students could choose one or more of 26 topics that ranged from traditional careers, e.g., oil and gas, to cutting-edge product manufacturing and research. The top three choices, in order, were alternative energy, nuclear, and environmental. This survey revealed that more than half of the students are thinking about concepts of sustainability, whether they realize it or not. Coupling these topics with concepts like circular economy and social/environmental justice provides a much-desired view of the engineering landscape.

Path Forward

The implementation of the EOP Framework directly aligns with the university's strategic plan by (1) preparing students for a dynamic and global workforce, (2) provide an exceptional educational experience, and (3) to identify and implement best practices in diversity, equity, and inclusion. Overall, the framework serves as a valuable guide for engineering educators seeking to prepare their students for a more sustainable future. By integrating sustainability principles into their programs, educators can empower future engineers to be proactive problem-solvers and responsible global citizens.

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