Work in Progress: Sustainability in First-Year Engineering Design: A Collaborative Approach

Overview: A team of faculty members at the University of Colorado Boulder (CU) received a grant from the American Society for Engineering Education (ASEE) Engineering for One Planet (EOP) program to enhance the integration of sustainability topics into the first-year engineering design course. This course serves students from across the college. The team developed materials which they made available to the larger group (11 instructors across 12 sections in Fall 2023). This paper briefly presents the materials that were developed, mapping the concepts to the EOP framework. Simple survey data from students provide insights into student interests and the impact of this material in the course.

Background

All engineers should be trained to consider sustainability in their work [1]. This should begin when students are first introduced to engineering, setting an expectation that sustainability considerations are a normal part of engineering [2]. At CU, the first-year engineering design course (FYED) was selected for sustainability integration. FYED is taken by the majority of students across all engineering majors. The course has multiple instructors who span all disciplines from the college, which can lead to variability in course content. This research leveraged insights from a diffusion of innovation study [3] to make integrating sustainability easy for instructors while also providing them with choices.

Sustainable engineering is a complex topic which could span a number of areas. In this work we use the framework developed by EOP [4]. The EOP framework includes nine topics, and all could be appropriate for a FYED course; Table 1 shows the topics of focus in this work. Two of the nine EOP topics (design and communication & teamwork) were already core learning goals of the FYED course. Critical thinking and social responsibility (ethics) were closely related to goals in the course. Responsible business and economy naturally tie to costs which is already a constraint in the design process. The instructional design team explored ways to create new links to specific EOP topics that were not normally integrated: materials selection, environmental literacy, environmental impact assessment, and systems thinking.

Course Materials

The materials generated and shared related to sustainability are summarized in Table 1, mapped to the EOP topics. Some of these are further described below.

Table 1. FYED course materials integrating sustainability

Sustainability materials	EOP topics
Introductory lecture	Environmental impact assessment, environmental literacy, materials selection, social responsibility
Checklist / Scorecard	Environmental impact assessment, materials selection, social responsibility
Project prompts	Environmental literacy, materials selection, social responsibility, design
Ethics assignment	Social responsibility
Poster rubric	Environmental impact assessment, environmental literacy, materials selection, social responsibility, responsible economics

Sustainability Checklist

To help students think through lifecycle assessment associated with their projects a checklist was created, inspired by Leydens and Lucena [5] and ISE [6]; see Table 2. Upon the advice of the EOP-assigned mentors, this was broken into two phases: production plus end-of-life or product use. The intent was for student groups to select which portion of the project was likely to have greater sustainability concerns for their particular project (which was generally making a product). Categories were selected to reflect the environmental, social, and economic pillars of sustainability. The intent was for students to use the checklist and write a narrative associated with each element to reflect how they considered (or did not consider) the element. For first-year students, it proved to be challenging to balance accuracy (with many categories) versus ease of use. Students in one section of the FYED course applied the produce/dispose phase of the checklist to their introductory projects (a light sculpture for a cause with few long term energy use or safety issues). This assignment seemed moderately successful, as student teams described how many of the checklist categories were considered. However, it was hoped that the student teams would also apply the use phase of the sustainability scorecard to their main projects (which in many cases were intended for long-term use with on-going energy and/or water use). The requirement to use the scorecard in the main projects was not clearly communicated, so only one of the six student teams integrated the scorecard into their final report.

Table 2. Sustainability Checklist Categories

Produce / Dispose Phase	Use Phase
Materials Selection (environmental impacts) Use all opportunities to avoid using new materials Sourcing local materials (regional preferred over broader US over international) Use renewable materials Use non-toxic materials (inc. toxicity during production) Consider end-of-life issues = reuse > recycle > disposal (cradle to cradle optimal) Use materials with lower carbon footprint Use materials that avoid other negative environmental effects (production that consumes less water, emits fewer pollutants to air / water / soil)	**Environmental Criteria** Your product requires no external power Your product minimizes energy consumption Your product uses renewable energy Your product uses energy with lower burden (e.g., rechargeable batteries, biodiesel) Your product uses minimal water Your product creates minimal waste during use
Social Responsibility Criteria What direct and indirect positive social / cultural impacts does your product have during its production (e.g., workers producing the products, labor practices, health, livelihood) What direct and indirect negative social / cultural impacts did your product avoid during its production (e.g., workers producing the products, labor practices, health, livelihood) Your product avoided differential negative impacts on low-income, minoritized, and marginalized groups during production or disposal	**Social Responsibility Criteria** What steps have you taken to minimize any negative human safety, health, and welfare impacts during the use of your product? What direct and indirect positive social / cultural impacts does your product have during its use What direct and indirect negative social / cultural impacts did your product avoid during its use Your product avoided differential negative impacts on low-income, minoritized, and marginalized groups during its use
Economics Total cost of materials purchased (if you are borrowing and will return something like Arduino uno board, log in separate category)	**Economics** Cost of monthly operation (such as energy, battery replacement, etc.) Cost of yearly maintenance (replace parts, labor)
SDGs: Your design contributes to any of the 17 United Nations Sustainable Development Goals [7]	**SDGs**: Your design contributes to any of the 17 United Nations Sustainable Development Goals

Final Project Prompts

Students in the FYED course spend the majority of the semester (10-12 weeks) working in teams on a main project. Each instructor has the option of selecting a theme for all student projects or leaving project options more open. Three example prompts that focus students on important global sustainability challenges are provided below in Table 3. Author2 had all teams in her two sections work on projects to address climate change. Author3 offered the water and SDG prompts as options for her students.

Table 3. Final project prompts that focus on sustainability issues

Climate Change Final Project Prompt
Climate change is the greatest crisis of our time. We are encouraging you to actively pursue carbon reduction solutions. This involves leveraging scientific, technological, and engineering advancements to address carbon pollution issues and effectively communicate these solutions to inspire behavioral change. Your team will have the opportunity to choose from the following prompts provided by Mission Zero Project to guide your final project. Mission Zero is an organization that supports student-driven sustainability innovation at CU Boulder. Mission Zero empowers student-led ingenuity to change the choices people have and the choices they make about their carbon footprint.
Water Final Project Prompt
Water is essential for life. However, we are losing our connection to this precious resource. You are encouraged to explore water controversies, water scarcity, and availability of clean water. Your team has the opportunity to design helpful solutions to water needs.
Sustainable Development Goals Final Project Prompt
The United Nations has declared 17 Sustainable Development Goals (SDGs) [7]. The SDGs are expansive and have many opportunities for you and your group to find an area of interest to which you'd like to contribute. Your team is tasked with selecting an SDG of interest and designing a product that could contribute to achieving that goal.

Ethics assignment

Sustainability is a natural fit with engineering ethics. Instructors can choose to integrate ethics into the FYED course in a variety of ways. In the context of the EOP project, an ethics assignment was created to help the students to critically reflect on their main project through sustainability lenses. The words of Karwat [8] resonated as inspiration for the assignment:

> "the goal…[is to] *make explicit* the values and key drivers of *why* engineering is done, and having that knowledge shape *how* engineering is done. …engineering is… not solely about the design of technical systems, but the design of systems that include tools, systems of meaning, and instructions, of which technical solutions are a part. …. personal values in fact do matter in … engineering…"

The individual assignment prompt is shown in Table 4 and provided students with a choice of discussion topics from Karwat's Table 1 [8, p. 1337]. Across the three assignment categories, the most popular questions among students were: "Who has the most to directly gain and lose from your work? How and why?", "How are local, regional, and larger environments and ecological systems affected by your work?", and "Do particular groups of people have to pay more or less than others…?". The writing requirement may have been too short to push students, and we suggest increasing it to 150 to 250 words. The assignment could also be appropriate for other design courses, and was used by another instructor in a sophomore-level service-learning course.

Table 4. Prompt for ethics assignment; referred to Table 1 from [8]

Ethics Assignment
Select and answer three of the questions below (from the questions column of the table): one from the social/political considerations OR praxis sphere; one from environmental considerations sphere; one from economic considerations sphere. Your answer to each question should relate specifically to your project this semester. Your answer to each question should be 100 to 200 words in length.

Poster rubric

The FYED course culminates with an exposition where student teams create posters and show their projects to external judges and the public. A poster rubric (Table 5) used to evaluate team projects includes five EOP categories. The EOP team scored digital files for the posters that were submitted by the instructors on behalf of their students. There were 3 to 4 raters for each poster. None of the faculty teaching the sections shared this rubric with students in advance. Across sections, it was clear that students were mentored differently on different elements (e.g., more complete economics description or not, however all mentioned safety). The three student teams recognized as winners in Fall 2023 were each selected from different sections (and not sections of the three authors who were also judged). It was great to see students map sustainability ideas to all projects - not just those with obvious environmental applications. Future changes in the rubric are planned and discussions are underway to decide whether or not to share the rubric with all sections / students in advance.

Table 5. Poster Rubric

Category	Not evident (0 points)	Some evidence (1 point)	Strong Evidence (2 points)
Environmental impact assessment	Not evident	considered lifecycle environmental elements for 1 aspect (e.g., CO_2e)	considered lifecycle environmental elements for multiple elements (e.g., GHG, water, toxicity, air pollutants)
Materials selection	Not evident	Discussed choices of 1 material that considered 1 or more sustainability elements (reuse, recycled, non-toxic, local sourced)	Discussed choices of multiple materials that considered 1 or more sustainability elements (reuse, recycled, non-toxic, local sourced)
Social responsibility / ethics	Not evident	Evidence some consideration of safety, human health, or welfare	Considered safety, human health, and welfare in multiple stages of the product lifecycle
Responsible economics (costs)	Cost info lacking	Clear communication of costs (spent by team and value if did not borrow items)	Clear communication of costs, considered in build and operation / maintenance
Environmental literacy	No evidence	Could link to 1 or more SDGs	Linked to one or more SDGs on poster
Regulatory & standards compliance	No evidence	Evidence considered 1 standard or regulation	More than 1 considered

Measuring student interest and outcomes

The FYED course includes a pre and post survey for students that asks questions about interests, skills, identity, belonging, and outcomes (IRB Protocol 11-0651). The survey has been previously described [9] and concludes with demographic items. The survey already included a couple of items on sustainability and a few more were added. About 360 students were enrolled in the course across 12 sections in Fall 2023; the majority of the students consented to participate in the research on the pre-survey (94%) and fewer on the post survey (75%).

The pre survey asked students to rate their interest in learning about sustainability topics using a scale of 1 (none) to 5 (extremely interested); results are summarized in Table 6. On average, students were moderately (3) to very (4) interested in learning about these topics. There was significantly higher interest among female as compared to male students in learning about sustainable practices, climate change solutions, and net zero solutions (t-test p values <0.001, <0.001, and 0.002; Cohen's d values 0.66, 0.66, and 0.37, respectively). There was also significantly higher interest among students majoring in / interested in majoring in environmental engineering compared to aerospace and mechanical engineering. Interest is an important motivator for learning. Overall there were 61 students with none (1) or slight (2) interest in net zero, which speaks to the potential benefits of allowing students choice in selecting the focus for their project versus instructors constraining all projects tightly to a single theme.

Table 6. Pre Survey: Student interest in learning about the following (1 to 5 scale), average and standard deviation shown

Student Group (n)	Sustainable practices	Climate change solutions	Net Zero (Carbon Zero) solutions
All (340)	3.52 ± 0.99	3.56 ± 1.10	3.54 ± 1.10
Male (225)	3.31 ± 0.94	3.32 ± 1.06	3.41 ± 1.08
Female (115)	3.93 ± 0.96	3.58 ± 1.12	3.60 ± 1.11
Environmental Eng (34)	4.50 ± 0.57	4.47 ± 0.72	4.38 ± 1.11
Mechanical Eng (252)	$3.43 \pm 0.87^{**D}$	$3.46 \pm 0.98^{**D}$	$3.52 \pm 1.01^{**D}$
Aerospace Eng (90)	$3.36 \pm 1.07^{**D}$	$3.47 \pm 1.18^{**D}$	$3.42 \pm 1.12^{**D}$

Compared to Environmental; 2-tailed t-test: ** $p < 0.01$; ^{D} Large effect size Cohen's D >0.8

Students were asked about their degree of confidence to perform tasks related to sustainability, on a scale of 0 (not at all confident) to 100 (fully confident); pre and post survey results are summarized in Table 7. On average students entered the semester with moderate confidence to perform various tasks related to sustainability. Students' initial degree of confidence was similar among female and male students, with the exception of lower confidence among female students on economic elements (average female 55, male 66, $p < 0.001$, Cohen's d 0.49). Environmental engineering students had lower confidence in economic elements and stronger confidence in environmental and sustainability compared to mechanical engineering majors (data not shown).

The types of materials for sustainability integration into the 12 sections of the FYED course across 11 instructors varied substantially. Among those who responded to a survey after the end of the semester, some instructors incorporated all of the EOP elements provided, some just a few, others did not use any of the EOP resources but incorporated sustainability in their own way; those who did not respond to the survey may not have included sustainability at all. Sections of the course were roughly classified into six 'standard' and six sustainability focused (recognizing the limitations of this rough binary grouping). Student responses on the post survey among the sections of each type are summarized in Table 7. Student confidence increased in all areas, with higher average post ratings in the sustainability-focused sections for understanding environmental risks, interdependency, and sustainable engineering.

Table 7. Confidence to perform tasks (0 to 100 scale); average and standard deviation

Survey Statement	Pre (n=340)	Post general sections (n=143)	Post sustainability focused sections (n=126)
Understand environmental risks associated with engineering projects	62 ± 24	69 ± 19	$76 \pm 15^{**D}$
Identify economic elements of an engineering project	62 ± 23	73 ± 16	74 ± 17
Identify the social elements of an engineering project	64 ± 21	74 ± 18	75 ± 17
Understand the interdependency among environmental, social, and economic aspects of engineering	62 ± 23	70 ± 19	$75 \pm 18^{*d}$
Understand the meaning and application of sustainable engineering	65 ± 23	73 ± 19	$81 \pm 16^{**D}$

Compared to post general sections; 2-tailed t-test: ** $p < 0.01$, * $p < 0.05$; Cohen's d: ^{D} $d > 0.4$; ^{d} $d > 0.2$

Future Work

The sustainability materials are being offered and used again in Spring 2024. The research team has received IRB approval (Protocol 23-0645) and plans to be able to collect and evaluate direct evidence of student learning via assignments such as the team final reports and individual ethics assignments. This will provide more details on the extent to which different implementation strategies were effective. This research could also continue as individual instructors customize the sustainability materials to their own teaching styles.

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