Sustainability in Engineering Graphics and Bicycle-Powered Blenders

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(Work in Progress) Sustainability in Engineering Graphics and Bicycle-Powered Blenders

Background

The purpose of this work-in-progress paper is to share developments related to an ASEE Engineering for One Planet (EOP) Mini-Grant Program Cohort 2 Award to the autho that began in the summer of 2023 and ran through January 2024. The project has two objectives: 1) Use the EOP Framework (Figure 1) to modify learning outcomes in MEAM 1010 Introduction to Mechanical Design, a course that is already taught every semester to classes of ~80 students, and 2) Leverage the EOP Framework to create MEAM 2300, a new course on bicycle engineering and culture. The students have identified that outside MEAM 1010, there are no other mechanical engineering courses they can take in their first year. Course offerings in engineering that involve sustainability are also lacking, even for students in their second through fourth years. By pursuing these course modifications and design efforts in parallel, both of these issues can be addressed. The author is the instructor for both of these courses at the University of Pennsylvania in the Department of Mechanical Engineering & Applied Mechanics (MEAM).

Figure 1: Engineering for One Planet (EOP) framework image[1]

Engineering for One Planet (EOP) Framework

From the EOP Website [2]: "The EOP Framework is a cornerstone of the EOP initiative, the first of its kind to guide coursework, teaching tools, and student experiences that define what it means to be an engineer who is equipped to protect our planet and the life it sustains. It provides faculty with a vetted menu of competencies that every graduating engineer, regardless of subdiscipline,

needs to acquire to design, code, build, and implement solutions that are socially and environmentally sustainable."

Practically, the EOP Framework is a list of learning objectives organized into nine topic areas (Figure 1). There are also activity and teaching guides published on the website that help faculty integrate the learning objectives into their courses.

MEAM 1010 Introduction to Mechanical Design

MEAM 1010 focuses primarily on engineering graphics (using SOLIDWORKS software) and digital fabrication using laser cutters and 3D printers in the Rapid Prototyping Lab (RPL). Only about one-third of students in MEAM 1010 in any given semester are MEAM majors. The other majors range from other engineers (electrical, bio, etc.) to physics and even history majors. Although the course is not technically required even for MEAM students, over 95% of them take the course in their first year. Consequently, by teaching sustainability concepts in this class, it not only reach almost all the mechanical engineers, but a broad cross-section of the undergraduate community. The class is taught each fall and spring semester, and this paper focuses on the addition of sustainability topics in the Fall 2023 semester.

Attitudes towards sustainability

An initial survey was given to all students to assess their baseline attitudes towards sustainability. The students were asked to "Please rate your agreement with the following statements" below. They rated the statements using a 5-point Likert-type scale where the five response options were Strongly Disagree, Disagree, Neither Agree nor Disagree, Agree, and Strongly Agree. In an effort to leverage validated survey instruments, the first 15 questions were taken from the revised New Ecological Paradigm (NEP) scale [3]. The NEP is designed to measure the environmental concern of groups of people and is considered a measure of environmental worldview. Responses to these fifteen statements are then used to construct various statistical measures of environmental concern. Questions 16 through 22 were adapted from a similar questionnaire for interior design students [4].

1) We are approaching the limit of the number of people the earth can support
2) Humans have the right to modify the natural environment to suit their needs
3) When humans interfere with nature it often produces disastrous consequences
4) Human ingenuity will ensure that we do NOT make the earth unlivable
5) Humans are severely abusing the environment
6) The earth has plenty of natural resources if we just learn how to develop them
7) Plants and animals have as much right as humans to exist
8) The balance of nature is strong enough to cope with the impacts of modern industrial nations
9) Despite our special abilities humans are still subject to the laws of nature

10) The so-called “ecological crisis” facing humankind has been greatly exaggerated
11) The earth is like a spaceship with very limited room and resources
12) Humans were meant to rule over the rest of nature
13) The balance of nature is very delicate and easily upset
14) Humans will eventually learn enough about how nature works to be able to control it
15) If things continue on their present course, we will soon experience a major ecological catastrophe
16) I feel I could do a mechanical engineering project using sustainable methods
17) I feel I could do a mechanical engineering project using sustainable materials
18) I feel green organizations/certification will solve environmental issues in design
19) I think that using sustainable practices in design should be required
20) If I had the opportunity I would build my home using sustainable methods
21) I could direct someone to an example of a sustainable product
22) I think that training on sustainable methods and materials should be required within a mechanical engineering program

Although students completed the assignment as part of their weekly participation grade, informed consent was not obtained, so the results of this survey will not be reported in this paper. Future work will focus on obtaining informed consent as part of the Institutional Review Board protocol for review under the exempt category and enabling voluntary participation.

Puzzle cube life cycle assessment (LCA)

To address several EOP framework learning outcomes, a new assignment was created based on an existing class project on making wooden puzzle cubes.

The main EOP topic areas and corresponding core learning outcomes addressed were:

- Design
    - Is able to set design goals and use technical analyses to choose strategies that minimize environmental impact
- Materials Choice
    - Is able to select materials and consider design alternatives that enable a long functional lifetime, have reduced, minimal, no harm, or are restorative to people and environmental ecosystems
    - Is aware of the potential impacts of the materials through the supply chain —from raw material extraction through manufacturing, use, reuse/recycling and end of life— with a focus on minimizing negative impacts to the planet and all people (i.e., considering impacts to minoritized groups)
- Environmental Impact Measurement

- Is familiar with high-level environmental impact measurements (e.g., basic lifecycle assessments and life-cycle hazards; i.e., how they work, what information they require, how to incorporate their findings into their work)

In the original project, students make a 3x3x3 block wooden cube puzzle by configuring ¾" wooden blocks into five separate pieces of 3-6 blocks each (Figure 2).

Figure 2: Puzzle cube made of wooden blocks

Students were then asked to use the Sustainability application in SolidWorks (Figure 3) which essentially performs a Life Cycle Assessment (LCA) on a part or assembly of parts (Figure 4).

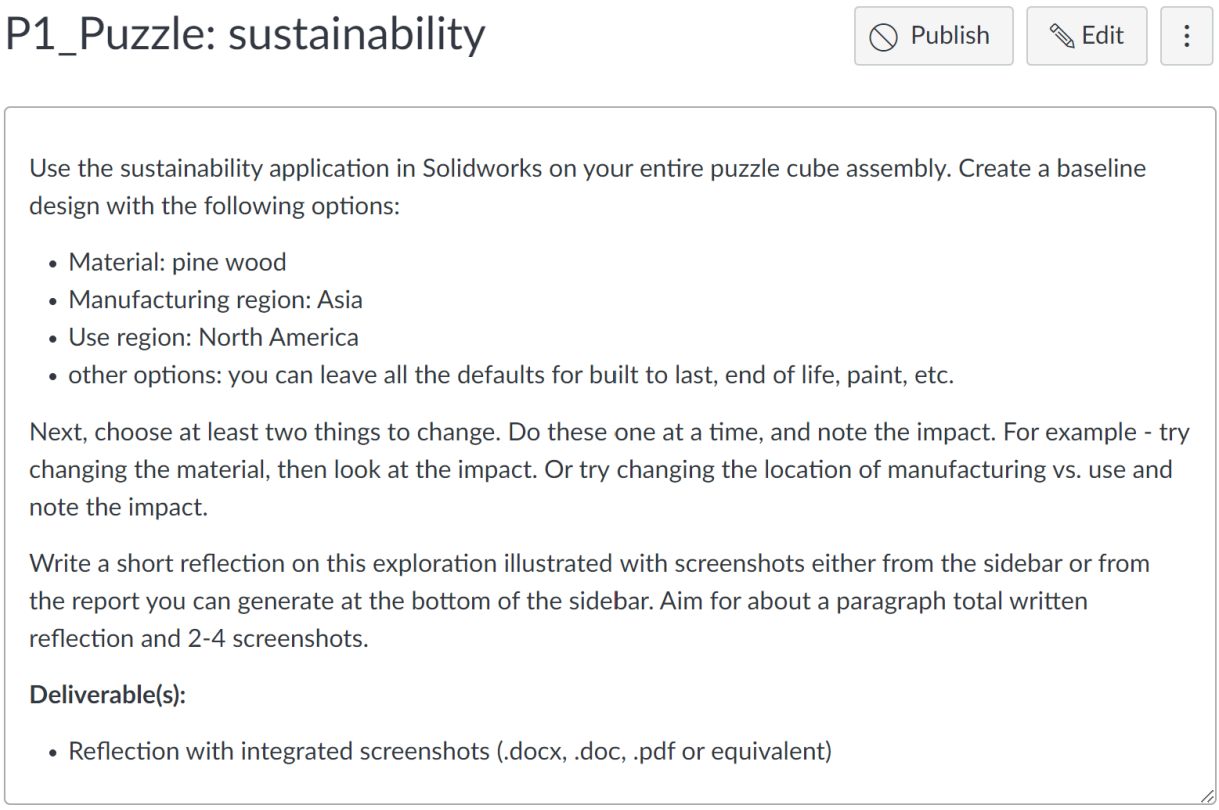

Figure 3: SOLIDWORKS Sustainability application assignment

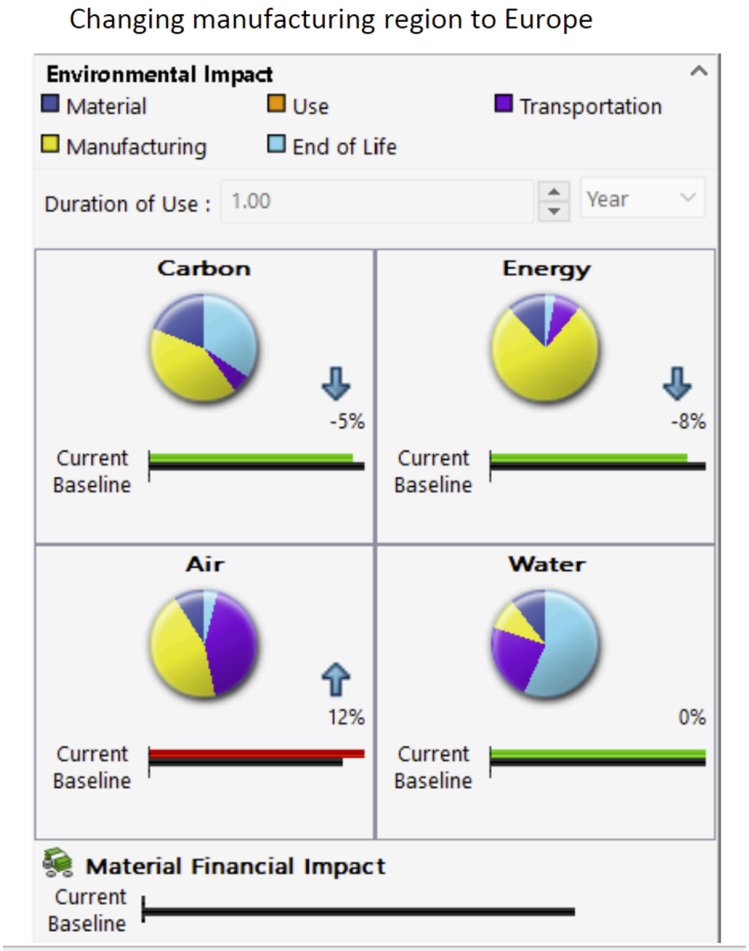

Figure 4: Impact of changing the manufacturing region from Asia to Europe [5]

In this example from a student, changing the manufacturing region from Asia to Europe led to a lower impact on carbon footprint and energy consumption, had no impact on water eutrophication, and increased the impact on air acidification.

Design for Disassembly

To address another EOP framework outcome in the Design topic area, a new assignment was created in reference to an existing class project called Dissect. The main EOP topic area and corresponding core learning outcome addressed was:

- Design
    - Is able to design for the environment based on discipline-specific technical skills (e.g., light-weighting, design for repairability and durability, design for upgradeability, design for **disassembly**, flexibility, and reuse, design for part or whole recovery, etc.)

In the original project, students disassembled a small plastic wind-up toy, measured and modeled all the parts, and then created an assembly of those parts in SOLIDWORKS. A portion of class time during this project was devoted to discussing design for disassembly using resources through VentureWell [6] and other resources on design for active disassembly [7].

Students were then asked to "describe at least one thing you would change about your Dissect toy to make it easier to disassemble". Their answers described how they would remove press fits, minimize the different types of fasteners, and avoid adhesives where possible - all in alignment with principles of design for disassembly.

MEAM 2300 Bicycles: The Mechanical Advantage

This class was taught for the first time in the Spring 2024 semester. The interdisciplinary course combines bicycle design, engineering, and service learning to provide students with a comprehensive understanding of the history, function, and impact of bicycles on society and the environment. Through hands-on projects, volunteering at a local bike shop, and discussions, students will develop advanced bicycle design and engineering skills, gain practical experience and exposure to real-world bicycle design and engineering, and explore the critical impact of the bicycle industry on sustainability.

Sustainability and bicycles

The week of the class set aside for sustainability focused on enabling the students to explain the links between bicycles and sustainability in terms of materials, manufacturing, and energy usage. Since this followed a week on biomechanics, we talked about both embodied energy usage in manufacturing and distribution and the human energy used to power the bicycle.

The main EOP topic areas and corresponding core learning outcomes addressed were:

- Critical Thinking
    - Is able to define problems comprehensively with consideration of consequences, unintended and intended
- Systems Thinking
    - Demonstrates whole system awareness with the ability to identify and understand interconnectedness (intersecting, related and/or connected systems; synergies and rebound effects) and how all human-made designs rely upon and are embedded within ecological systems

The instructor did a whole systems mapping exercise with the students in class to address the systems thinking learning objective. Then the class moved into a discussion of the relative sustainability of naturally sourced rubber vs synthetic rubber for bicycle tires to address the critical thinking learning objective.

Service Learning

The course is designated as an Academically Based Community Service (ABCS) course through Penn's Netter Center [8]. ABCS courses bring together academic expertise and the expertise of the community via mutually beneficial, mutually-transformational democratic partnerships. Students in the class are each expected to devote about 25 hours over the course of the semester to service learning work. The two main partners for this class are Neighborhood Bike Works and Rebel Ventures. Neighborhood Bike Works is a community bike shop that accepts donated and used bikes then fixes them up and sells them back to the community. They also run several youth and adult programs that bike sales help fund. At Neighborhood Bike Works, students were trained as volunteer mechanics, then volunteered to help during shop and open bike repair hours. With Rebel Ventures, MEAM 2300 students worked together with teens at three different West Philadelphia high schools with assistance from the Netter Center staff to establish Smoothie Bike Labs at each school. There was a pilot program last year with one high school, and an internal grant enabled us to expand the program this year. Bikes were modified to support blenders mounted to their rear racks, and nursing students who are also part of the program will work with engineering students and project staff to implement nutrition-based education that includes using the bikes to make smoothies.

The main EOP topic areas and corresponding core learning outcomes addressed were:

- Social Responsibility
    - Is familiar with ways to create robust, dynamic and resilient systems and ways to develop transdisciplinary stakeholder networks
- Communication and Teamwork
    - Communicates through audience-specific written, graphic/visual, oral and interpersonal communication skills, in order to
        - sell, pitch and explain ideas and advance learning
        - work well with others, across disciplines and cultures
    - Interacts with, collaborates on and leads multidisciplinary teams, effectively representing an engineering perspective in a comprehensible manner through project based work

Some members of the team recently worked with Penn Police to repurpose abandoned bikes (Figure 5) that had been in holding for years. Many of the bikes already had rear racks and were refurbished along with students at the three high schools and used for making bike-powered blenders (smoothie bikes).

Figure 5: (L) Tex Kang, a member of the Smoothie Bike Team, with a member of the Penn Police department in the background (R) Some of the many abandoned bikes that Penn Police collect every year off of racks on campus.

Progress and Impact to Date

Between the two classes described above, 184 students across 23 unique majors were exposed to sustainability topics through EOP framework learning objectives (Table 1). Additionally, the 22 students in MEAM 2300 completed 25 hours of community service each, for a total of 550 hours of service.

Table 1: Students exposed to sustainability topics over the course of the ASEE EOP MGP

Class	**Semester**	**# students**	**# majors**
MEAM 1010	Fall 2023	72	14
MEAM 1010	Spring 2024	90	20
MEAM 2300	Spring 2024	22	6

Furthermore, MEAM 2300 has received follow-on funding and support through two different internal programs: Penn4C and Penn Global Seminars. The Community Collaboratory for Co-Creation (Penn4C) [9] is an initiative led by the University of Pennsylvania School of Nursing and the School of Engineering and Applied Sciences, based on the recognition that technological solutions should be designed with active engagement of marginalized communities with the explicit goal to challenge rather than reproduce or exacerbate structural inequalities as technology often does. The priorities of the Collaboratory focus on three areas: Research, Education and Community Engagement, and Outreach. The smoothie bike team has received a $60,000 grant from Penn4C that is divided evenly between engineering, nursing, and Rebel Ventures - the community partner through which the work with three different high schools is coordinated.

Additionally, the class was recently accepted into Penn Global Seminars [10]. This program combines intensive semester-long study with a short-term travel component that deepens student understanding of concepts discussed in the classroom. Through this program, the class will travel to the Netherlands during the Spring 2025 semester over spring break. The students will be immersed in the bike-friendly city of Amsterdam, and visit several faculty and labs at TU Delft, including one of the only bicycle engineering labs in the world.

Conclusion & Next Steps

The next steps for MEAM 1010 are to reconsider the content and implementation of the attitudes towards sustainability assessment and get IRB approval for administration so that results can be published in future work. The instructor will also work on better methods to evaluate the impact of including sustainability content in the course, potentially including the same attitudes towards sustainability assessment at the end of the course. For MEAM 2300, the instructor will continue to execute the plan to integrate EOP framework learning outcomes into the course and work with the service learning partners. Finally, the instructor will continue to plan for the Spring 2025 trip to the Netherlands and how to fully leverage that experience before and after through a modified course structure.

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