Board 142: A New Paradigm for Sustainability Engineering: A Transdisciplinary, Learner-Centered, and DEI-Focused Approach

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Abstract

Sustainability is an overarching challenge for the 21st century at local, national, and international levels. A new generation of engineers trained in sustainability is crucial to ensure the quality of life for current and future generations. To meet this challenge, the University of Puerto Rico, Mayagüez Campus (UPRM), with support from the National Science Foundation (NSF), Improving Undergraduate STEM Education (IUSE): Hispanic-Serving Institutions (HSI) Program, aims to create a new Minor in Sustainability Engineering, as a precursor to a bachelor's degree in the same area. This paper describes a recently awarded project comprising the design and implementation of a Sustainability Engineering (SE) Minor at UPRM. We propose a poster presentation to discuss our SE Minor plan and collect data about people's perceptions of sustainability in engineering.

1. Introduction

Addressing "Sustainability" is an overarching challenge for the 21st century, requiring engineers to play a critical role. In the US, undergraduate degree programs that directly attend to sustainability are of two types: (1) interdisciplinary programs that do not grant engineering degrees and (2) environmental engineering programs that are vital but do not entirely address the holistic notion of sustainability. However, based on our reading of "Strengthening Sustainability Programs and Curricula at the Undergraduate and Graduate Levels" [1] and our independent literature review, *in the US, there appear to be no undergraduate engineering degree programs that are broadly oriented around sustainability* in the sense of the three pillars commonly referred to as the 3P's (People, Planet, Prosperity) or the 3E's (Equity, Environment, and Economics).[2][3]

Further, the local conditions in Puerto Rico - a multi-hazard risk region with vulnerable populations and infrastructure embedded in a struggling economy - have inspired new urgency and resolve to respond to our common challenges that are at once local and global. The available natural resources, combined with the tangible entrepreneurial spirit of our current generation of students, demand that we don't simply follow but become a leader for innovative approaches and models for an equitable, post-carbon, circular economy that supports a human flourishing and ecological integrity. There is a need and opportunity to create a coherent program to form new engineering graduates capable of meeting technical engineering requirements woven with the social, economic, political, environmental, and other facets central to sustainability and resilience.

In response, an interdisciplinary team of researchers proposed the creation of a new Sustainable Engineering (SE) Minor at UPRM as part of a larger plan to develop a new Bachelor's degree program in this area. This plan will allow concrete developmental progress while acknowledging that engineering students will continue to enroll in a traditional engineering program. The Minor will thus be designed to complement and strengthen the existing engineering programs while building the essential recruitment, coursework, pedagogical framework, and stakeholder support for the Bachelor's program. Likewise, the corresponding study plan will allow students to simultaneously fulfill the requirements of their major programs alongside those of the Minor.

The Minor will seek to attract more female students by advancing the notion that all engineering disciplines are vital to the cause of sustainability. Indeed, "when ... engineering programs are aligned with pressing social issues, the number of underrepresented groups - particularly women - in those programs is likely to increase".[4] More broadly, the Minor will infuse a culture of Justice, Equity, Diversity, and Inclusion (JEDI) that directly coheres with the theme of sustainability and will also promote local workforce development.

Finally, along with the program development, a STEM research plan will investigate how students choose engineering programs and how their preconceptions and mindsets about sustainability will evolve. In addition, we will provide research and practice opportunities to participants through collaborations with local partners. Overall, this project will enhance undergraduate STEM education by filling a clear gap in the priority area of sustainability, directly serving UPRM, and providing a model for other institutions. Developing the associated courses and materials in English and Spanish will make them particularly accessible to other HSIs.

2. Institutional Profile

General Information

The UPRM was established as a public land-grant institution and today also has sea-grant and space-grant academic affiliations. According to the Carnegie Classification, it is classified as a very high undergraduate, master's college, and universities-larger program, doctoral research STEM dominant. UPRM has an enrollment of approximately 11,000 students at all levels, including nearly 5,000 in engineering programs.

UPRM offers nine undergraduate programs in Engineering: Chemical Engineering, Civil Engineering, Computer Engineering, Computer Science & Engineering, Electrical Engineering, Industrial Engineering, Mechanical Engineering, Software Engineering, and Surveying. While these programs are all ABET accredited and of high quality, none cite sustainability explicitly in their mission statements. Only Civil Engineering offers courses that identify "sustainability" in the catalog description; outside of these two technical electives, which deal with sustainable infrastructure and construction, other essential sustainability topics such as life cycle analysis, sustainable decision analysis, and low carbon materials are scarcely present in the engineering curricula.

Underrepresentation of Women in Engineering Programs

Ostensibly the portion of women who graduate from engineering programs at UPRM, meets or exceeds national averages, as shown in Table 1.[5]

Table 1. Comparison of Percent Female Graduates at UPRM and Nationally (2019)

	Civil	Electrical	Industrial	Mechanical	Chemical	Computer	CS & Eng
UPRM	28%	13%	43%	17%	55%	18%	8%
ASEE	25%	14%	31%	16%	36%	13%	19%

Nevertheless, except for Chemical Engineering and Industrial Engineering, women are under-represented in the various engineering programs. This pattern is apparent at the graduation, admissions, and application levels. As a result, the focus of this project is on the recruitment of female students. Results from recent studies by members of this team provide a baseline to understand the factors that impact female recruitment [6], along with the differences in autonomy, relatedness, and competence by gender and culture.[7] Also, they have demonstrated that the number of role models and mentors is crucial in motivating female recruitment at UPRM. This proposal involves a strong team of female role models from different engineering fields with outreach and engineering education expertise.

Institutional Approaches to Justice, Equity, Diversity, and Inclusion (JEDI)

UPRM has a policy of non-discrimination that states that a student or employee cannot be discriminated against based on race, color, sex or gender, birth, age, origin, social status, civil status, ideas, religion, political views, nation, origin, or handicap. However, UPRM is only beginning to incorporate JEDI into Strategic Planning. This project will accelerate those efforts. We intend to work with administrators to develop a climate survey and to improve the counting of non-binary students.

3. Mindsets

Before discussing the program design, we deliberate a set of mindsets essential to develop in students. This is a precursor to developing a competency-based profile that is under development.

Student Self-efficacy

Aside from the theme of Sustainability, students in the new programs must be prepared to be self-motivated and willing to take a high level of responsibility for their learning. We plan to use the Pittsburgh Freshman Engineering Attitudes Survey (PFEAS) to assess student self-efficacy upon entry and use this data for mentoring and student evolution assessment.[8] We note that a multi-institution study of over 6,000 students to whom the PFEAS was administered indicates that, in general, female students are less confident about their engineering abilities. Exposing students, particularly women, to growth mindset theory, close faculty interaction, and other support networks will help build confidence.[9] The importance of self-efficacy for sustainable engineering studies emphasizes the role of intrinsic motivation and the need for students to be engaged in building a sustainability mindset from the outset of their education.[10]

Mindsets and Attitudes about Engineering and Technology

The attitudes carried by engineers in their field and of technology are essential for anticipating how they will grow in a program focused on sustainability. Cech has identified three "ideological pillars: the ideology of depoliticization, which frames any "non-technical" concerns such as public welfare as irrelevant to "real" engineering work; the technical/social dualism, which devalues "social" competencies such as those related to the public welfare; and the meritocratic ideology, which frames existing social structures as fair and just" and has argued that these attitudes militate against engineers' commitment to public welfare.[11] These and other mindsets are important to address, as even though our program is for engineers, non-technical approaches to sustainability, such as behavioral change, must be equally valued.[12]

Mindsets on Sustainability

Indeed, many people recognize the definition of "sustainable development" from the Brundtland Report, "[to meet] the needs of the present without compromising the ability of future generations to meet their own needs".[13] Many notions and definitions abound. The Minor will provide a comprehensive critique of various definitions of sustainability.

Mindsets on Justice, Equity, Diversity, and Inclusion (JEDI)

Just as intersectional identity and status factors influence students' inclusion and progress in educational settings, similar factors indicate vulnerability to stresses caused by unsustainable practices. Sustainable Engineering seeks to invert this to use positive attitudes toward JEDI as a driver to both reduce vulnerabilities in the short term and establish better practices in the long term. The Intergovernmental Panel on Climate Change (IPCC) recently called attention to the need for "non-selfish values that promote the welfare of others (including nature), noting that some but not all indigenous societies are known to focus on 'collective' as opposed to 'individual' interests and values, which often result in positive resource conservation strategies and wellbeing".[12] Related to the collective/individual mindset suggested here is a paternalistic mindset of those in power to assume to 'know' how to 'solve' the 'problems' of others in 'need'.[14] A positive Diversity, Equity, and Inclusion (DEI) mindset will expand the engineers' diversity and open the door to seeing members of vulnerable communities as 'partners' and 'co-designers' who have 'objectives'.[15][16]

4. Research Methodology

STEM Education Research Plan: Development and Propagation of Mindsets

This project will undertake basic STEM education research to inform our program design and the broad literature on best educational practices for fostering education for sustainability within the engineering context.

Research on Sustainability Education. Despite the myriad efforts for sustainability in research and education, the National Academies recommends that "[r]esearch is also needed on how core competencies and content areas across sustainability programs are converging, diverging, or evolving; on the effectiveness of the different student-centered, interactive pedagogies used across programs; and on how institutional policies, structures, and curricula affect the development and flourishing of these programs" (National Academies, 2020). With this in mind, we pose Research Question (RQ) 1: **What are the emerging competencies and mindsets established by other stakeholders?** Polling stakeholders – students, faculty, industry, government agencies, nongovernmental organizations, and community leaders – will answer this question following a Delphi framework.[17] We will deploy a seven-point Likert scale questionnaire to gather the stakeholders' opinions until we conclude.

Research on Sustainability Mindsets. In parallel to the Delphi study to capture the wide breadth of thought, equally important is to study how a mindset regarding sustainability evolves within a student. Little direct research appears to have been done on this issue, although we hypothesize that the four domains of mindsets described previously will be influential. What is less clear is if or how the domains will conspire to form a coherent whole. Therefore, we pose RQ2: **How do (pre)Conceptions and Mindsets of Sustainable Engineering Evolve?** Because the anticipated

cohort size is small and this question seeks to identify a phenomenon that has not yet been characterized, a qualitative study is proposed that will examine student responses to reflective exercises embedded in their coursework, interviews, and discussions.

We will follow a backward design approach to develop learning experiences and instructional activities with acceptable evidence.[18] To ensure a longitudinal study, we will include at least one reflective exercise in each major program element, including recruitment meetings, summer camps, courses, JEDI seminars, and research/practice experience. Finally, the researchers will observe student, faculty, and stakeholders' interactions during these activities. We will use grounded theory to identify emerging patterns and themes for the analysis. We will use instruments from the works cited in the previous section to provide a coding scheme of expected categories.[19]

5. Design of the Sustainable Engineering Minor

The new Minor will establish and enculturate a Sustainability Engineering Mindset – to be developed through research and educational activities – reflecting the values, beliefs, and ways of thinking that lead toward sustainable development in the context of engineering and engineering education. The Minor will be highly informed by best practices for user-centered design, introducing opportunities for self-reflection, trial and error, and action-taking through a student-centered project-based learning approach that recognizes that students are in transition to adulthood. A robust stakeholder engagement process will be undertaken to align activities with goals, involving three undergraduate mentors per year as co-designers and co-facilitators. Although the Minor will be open to all students with basic qualifications, unlike traditional minors that require substantial coursework, this Minor is designed for new freshmen so that they can develop Sustainability Knowledge, Skills, and Attitudes (KSA's) from the outset and use these as a map in the overall programs of study.

First Experience: Pre-freshman Summer Camp

Upon admission to the Minor, students will attend a one-week Summer Camp immediately preceding their first semester at UPRM. The activities will orient the students to the learner-centered nature of the Minor and begin building the Community of Practice built on themes of sustainable engineering. Hands-on activities and games will be designed as active learning experiences in sustainable engineering while impacting the student's mindsets defined in this proposal. JEDI will be introduced to students as embedded within the development of sustainability and related mindsets. Current undergraduate students will develop leadership and teamwork skills by working as mentors for the summer camp participants. The Summer Camp will be modeled on the Pre-Engineering Camp at UPRM,[20] which has developed undergraduate students as leaders and attracted high school students for nearly a decade.

Learning Outcomes

The sustainability minor was created with the following student learning outcomes:

- Be able to explain the key principles and concepts of sustainability, including environmental, social, and economic sustainability.

- Be able to identify and analyze sustainability challenges facing communities and

organizations and develop and implement sustainable solutions.

- Be able to apply principles of justice, equity, diversity, and inclusion to sustainability initiatives and evaluate their effectiveness in promoting social and environmental justice.

- Be able to describe the connections between sustainability and individual and community well-being.

Curricular Structure of Minor

As part of the Minor, the following new courses will be developed:

a) *Creating a Sustainable World*, taken in the first semester, is a general education level course that will be open to all students in all disciplines, intending to develop literacy in topics ranging from definitions and histories of sustainability frameworks, bio-physical and social planetary boundaries, energy, water, agriculture, materials, career planning, and other topics.

b) *This is Engineering*, taken in the second semester, will be a freshmen design style class, with hands-on problem-based learning, with sustainability embedded in all projects.

c) A seminar on *Justice, Equity, Diversity, and Inclusion* will be developed for students to explore issues such as implicit bias and paternalism and reinforce the idea that co-design with communities will reduce discrimination and lead to better solutions.

d) New courses, *Wellbeing and Sustainability Economics* will be developed to introduce students to essential ideas of natural capital, circular economies, and measures of well-being and prosperity.

e) Other new courses include *Products, Services, and Sustainability*, which provides an introduction to Life Cycle Analysis, embedded energy, and extended consumer responsibility; *Smart Cities*: will combine Information and Communication Technologies (ICT) and ecological frameworks to conceive cities with high citizen participation, communication, and equity, state of the art technologies, resiliency, and governance; *Energy and Sustainability*, which will combine a history of energy development with overviews of the energy value chain; and *Design and Practice for Community Resilience*: This course, piloted in 2019 [16] provides students with opportunities for service learning that relate to local sustainability and resilience challenges, combining "Do-it-yourself" solutions with the installation of small-scale commercial products and systems.

f) Students will also take a Co-op course to gain practical training or research experience with a sustainability-focused organization.

g) The Minor will establish a Community of Practice for students and faculty to share experiences, ideate, and play.

h) To support new freshmen in the Minor, the NSF HSI grant provides partial tuition and stipends, with a total value of approximately $3,000, for up to ten students per year, for three years.

Our program will adopt a problem-based learning framework to cultivate students' understanding of sustainability throughout the curriculum. Moreover, our courses have been meticulously designed following the PPP framework. Unlike traditional engineering programs that primarily focus on technical content, briefly touching on sustainability as a solution, our program aims to educate students on sustainability concepts and employ engineering principles to design and develop sustainable solutions to problems.

6. Preliminary Outcomes

To date, the primary outcomes are developmental. The team has participated in several important and formative events, such as the Olin College Summer Institute in 2021, the 2022 STEM for All Video Showcase, and the inaugural cohort of the ASEE Engineering One Planet (EOP) Mini-grant Program (2022-23). These opportunities helped us develop our internal team, learn appropriate methods of curricular development, understand relevant frameworks to define sustainability outcomes, and disseminate our progress to stakeholders.

To date, three of the new courses are being piloted: Energy and Sustainability (Summer 2021), Creating a Sustainable World (Fall 2022, Spring 2023), and Products, Services, and Sustainability (Spring 2023). Wellbeing and Sustainability Economics is well underway, and the next course to be developed is This is Engineering. Course evaluations will be conducted at the end of the current semester and analyzed during the summer.

Finally, the team is developing several stakeholder surveys and interviews to better understand the market interest and baseline mindsets among the stakeholders. The survey is under preparation and expected to launch during the summer at the ASEE Annual Conference.

7. Conclusions

A need exists for new programming in engineering that attends to sustainability in the broad sense. A plan is underway at UPRM to develop a Minor, followed by a bachelor's program, in Sustainability Engineering. In progress is the development of new courses and stakeholder inquiry. This poster presentation allowed data collection for the Delphi process at the conference.

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