Infusing Sustainability into Diverse Courses and Programs Using Open Source Engineering for One Planet (EOP) Teaching Resources

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Introduction

Climate change, pollution, environmental toxicity, and biodiversity loss are among our most pressing challenges today [1], [2]. These challenges can be addressed or exacerbated through engineering activities, leading industry and agencies to increasingly seek engineers who are as well-versed in technological expertise as they are in social and environmental sustainability and climate action [3], [4], [5]. However, engineering students are not typically graduating with the skills, knowledge, and experiences needed to protect and improve our planet and our lives, despite student and industry demand for it [6], [7], [8].

The Engineering for One Planet (EOP) [9] initiative seeks to change the course of engineering education to reflect the growing urgency to incorporate fundamental climate and sustainability topics into all engineering disciplines. Catalyzed by The Lemelson Foundation [10] and VentureWell [11] in 2020 —in collaboration with hundreds of contributors from across geographies, lived experience, and sectors — EOP seeks to ensure that all engineers are equipped with core skills in social and environmental sustainability, such as sustainable design and lifecycle impacts, and related professional skills, such as teamwork and critical thinking.

Fueled by the input and collaboration of a growing global community of hundreds of stakeholders, the EOP initiative fosters curricular transformation through three interrelated approaches: 1) developing and sharing teaching resources through community feedback and vetting in diverse courses and programs, 2) funding faculty change efforts and supporting faculty capacity-building, and 3) activating and supporting collaboration among diverse stakeholders across sectors.

In this paper, we will focus on the first approach and discuss how these open source teaching resources have been and are being informed, developed, and refined over the past several years, their impact to date, and areas for future work. The paper will share the unique ways EOP resources have been co-created by hundreds of cross-sector stakeholders and used in curricular change efforts across diverse institutions —including Minority Serving Institutions (MSIs), R1 and R2 universities, and community colleges—, what lessons are being learned that can help faculty with their efforts to infuse sustainability into their courses, and what else is needed to go beyond changing discrete courses to changing the course of engineering.

Background & Preliminary Research

All sectors, from industry to academia to government, are investing in environmental and social sustainability as critical priorities [3], [4]. Sustainability goals and actions, by necessity, require input from many fields, but engineers have a particularly influential role due to the structures and products they build, and the associated choices they make [5]. Yet, engineers are typically not prepared with knowledge and skills in sustainability [6], [7], [8]. The Engineering for One Planet (EOP) initiative aims to address this challenge by ensuring all future engineers, no matter their discipline, are equipped with the skills, knowledge, understanding, and mindsets to design, build, and create in sustainable ways.

Since launching in 2020 and with continuous collaborative engagement with stakeholders, the EOP initiative has generated valuable knowledge and open source practices and resources that are accelerating the infusion of sustainability principles across engineering curricula. Between 2017 and 2020, before the EOP initiative was launched, a great deal of research, interviews, convening of stakeholders from across sectors and disciplines, development of content through open source activities, etc., took place as is depicted in Figure 1. These collaborative actions led to learnings, insights, refinement of ideas, and the development of processes and strategies that underlie the EOP initiative and are leading to successful results. This historical timeline is detailed below.

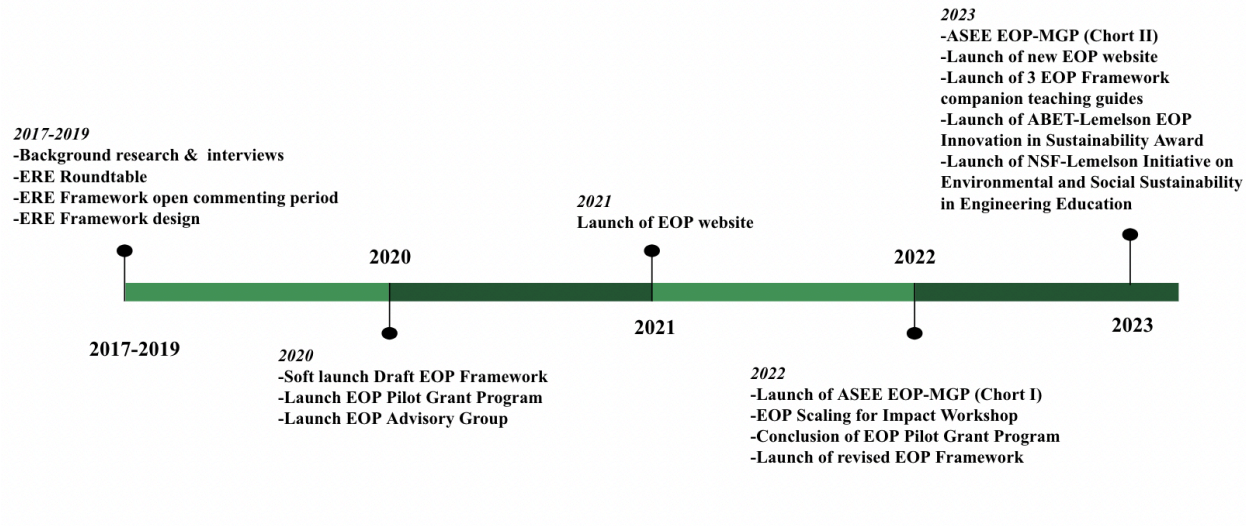

Figure 1: *Timeline of EOP resources development and launch including research, teaching resources, website, award, and curriculum change grants.*

2017: Teaching Environmentally Responsible Inventing: Higher Education Environmental Landscape Research and Analysis Phase 1 Report

Research to develop the EOP initiative began with a qualitative study to understand the barriers and opportunities for integrating environmental responsibility (ER) in higher education. At that time, The Lemelson Foundation was strategically focused on ER and "inventing green" vs. EOP's now broader scope of sustainability and related professional skills across all engineering education. In 2017, The Lemelson Foundation commissioned a study through a sustainability-focused consultancy, Alula Consulting [12], where two experts in sustainability, sustainable design, and engineering education were hired to conduct, analyze, and report the following specific objectives:

- Identify best practices.
- Determine best ways to introduce and maximize ER integration in invention education.
- Identify experts, what is being taught, what has been successful, what conditions are conducive to success, where are the gaps, and what are the challenges and friction points.
- Identify curricula and pedagogy in higher education that can be translated upstream to younger students.
- Create a collection of current ER innovation and entrepreneurship-focused programs being implemented around the globe in higher education.
- Develop 5-10 high-priority recommendations for next steps.

The study included an extensive literature review and in-depth interviews with 25 individuals representing several demographics. Researchers reviewed publications across engineering, business, and design disciplines. Interviewees included educators and subject matter experts (n=19) in academia and recent graduates and young inventors (n=6) in industry. Academic institutions included universities at undergraduate and graduate levels, as well as a community college; engineering, design, and business programs, both public and private. Locations included 5 continents and 10 countries, and the gender balance of interviewees was 40% male and 60% female.

This study revealed that while there was evidence of effective curricula and instructional methods in some higher education design and engineering programs, ER coursework was not commonly required or ubiquitous in the invention education-related landscape. At the time, nearly a decade had passed since the largest comprehensive study of U.S. engineering education had been conducted [13]. This study, funded by the Environmental Protection Agency (EPA), surveyed 1,368 administrative heads at 364 higher educational institutions teaching engineering. Such previous research, while valuable for making recommendations for best practices in teaching ER to inventors and innovators, demonstrated that sustainability education in engineering was minimal and had not changed much over 10 years.

The commissioned research led to two high-priority recommendations: 1) *Invest in Faculty* to support their development and education. The study showed that most faculty had not been exposed to ER in their own education and were not prepared to teach these topics. Some proposed approaches included faculty workshops and training, curriculum development and sharing, and academic recognition. 2) *Foster external partnerships* among schools and companies, NGOs, and/or government, especially partnerships to provide students with real-world ER project experiences. This could overcome the barriers of perceived lack of demand for ER in industry, academic hoops, and potentially lack of funding. Some possibilities included an online platform for interested parties to meet each to form partnerships, programs to foster mentorship, and exploring feasibility of increasing government or accreditation requirements for sustainability in curriculum. A summary of research results and recommendations were published as a report in 2018 [14] and subsequently as a peer-reviewed publication [15].

2018: EPA Study Follow On Study

Following the completion of the 2018 Report [14], The Lemelson Foundation was left with several unanswered questions about what had transpired since the publication of the EPA study [13] highlighted in the 2018 report and commissioned Alula Consulting to contact the authors for more information. In this follow-on study, the researcher attempted to connect with all of the EPA study authors. Through informal interviews, the researcher sought to better understand how the EPA research came about, what authors learned, what progress had been made (or not made) as a result of what was learned, and why. The researcher corresponded with seven of the nine authors and conducted extensive, one-on-one phone interviews with three of the authors. All authors interviewed recommended that The Lemelson Foundation start with the *Invest in Faculty* high-priority recommendation described in the 2018 report. EPA authors suggested that lack of funding, accreditation standards, incentives and accolades, and easy to access, quality resources

were key barriers for adoption and integration of ER education in engineering. A key finding cited was that the biggest challenge with integration of ER into engineering curriculum today is that it is a systemic problem that involves all levels of academia; a systemic problem therefore requires a systemic solution.

A key recommendation to foster the development of environmentally responsible engineering (ERE) was to use a multipronged approach that would support and invest in faculty in order to overcome academic barriers and to work in partnership with professional societies and accrediting bodies, including specific references to ABET. ABET is a nonprofit that accredits engineering programs by ensuring that engineering programs meet the quality standards that prepare graduates to enter the professional practice of engineering. All ABET-accredited engineering programs must comply with and receive accreditation from the Engineering Accreditation Commission (EAC) and demonstrate that their programs satisfy all of the General Criteria for Baccalaureate Level Programs [16].

The follow-on study resulted in four key recommendations for generating systemic change: support faculty development and resources, develop faculty incentives, rally academic allies, and seek to work with influential organizations, such as ABET [17].

2019: ERE Roundtable

Prior to VentureWell's annual OPEN conference in 2019, The Lemelson Foundation and VentureWell designed and co-hosted a two-day roundtable event called *Principles of Environmentally Responsible Engineering: Creating a Roadmap for Change* which convened 20 leaders from across higher education, nonprofit, business, and government. These 20 experts, who were already deeply engaged in incorporating sustainable engineering, green chemistry or sustainable design into their work, came together with the aim of creating a roadmap for defining and developing a framework for ERE. Throughout the two days, participants shared their personal experiences and challenges, reflected on the urgent need to identify scalable levers for impact, and grappled with the inherent value of creating a framework for teaching ERE. In the end, shared enthusiasm for making progress led to general agreement that collective action was needed in addition to a framework. Together, roundtable participants generated a high-level list of questions that need to be answered and stakeholders that needed to be engaged to develop and drive forward a framework for the concepts, values, and skills all engineering students need to learn in order to engineer with the health and sustainability of the planet in mind.

At the conclusion of the event, participants provided recommendations for action, including to write a white paper that would serve as a strategic document to clarify the rationale and urgency of this work and refine parameters for an ERE framework. They proposed establishing a timeline of critical milestones and deliverables for the future of this effort and expressed their enthusiasm about taking part in future activities. A summary report of the event was published by VentureWell in 2019 [18]. The roundtable also led to the initiative's new name, Engineering for One Planet (EOP), reflecting a more inclusive and flexible scope than ERE.

2019 - ERE White Paper

As stated above, a key recommendation of the ERE Roundtable was to generate a strategic document that clearly identified the challenges that we collectively face in developing ERE

programs, and to outline a rationale and a theory of change for this initiative, including a timeline of past work, present state, and future opportunities. Working with The Lemelson Foundation, Alula Consulting and VentureWell developed a white paper entitled, *Engineering for One Planet: Launching a Collaborative Effort to Proliferate Principles of Environmentally Responsible Engineering in Higher Education Institutions* [19]. Two key takeaways from the white paper were a theory of change (ToC) for the effort and key milestones for the future of the work.

The ToC presented in the paper outlined a basic systemic change strategy to move forward in ERE education in US-based institutions of higher education (see Figure 2). The ToC's purpose was to enable a collective dialog to define how strategies and actions would achieve change, communicate a vision for change, identify expected results for change and to serve as a tool to guide and inform current and future collaborative actions [19]. Stakeholders noted that engineering education is a complex system where no single organization or sector could successfully create transformative, sustained curricular change by working independently. Therefore, transforming engineering education to more broadly and deeply integrate sustainability would require bottom-up and top-down change efforts. It would require intentional contributions and collaboration among various actors in the engineering education system (e.g., faculty members, students, academic leaders, engineering employers, industry professionals, government professionals, etc.).

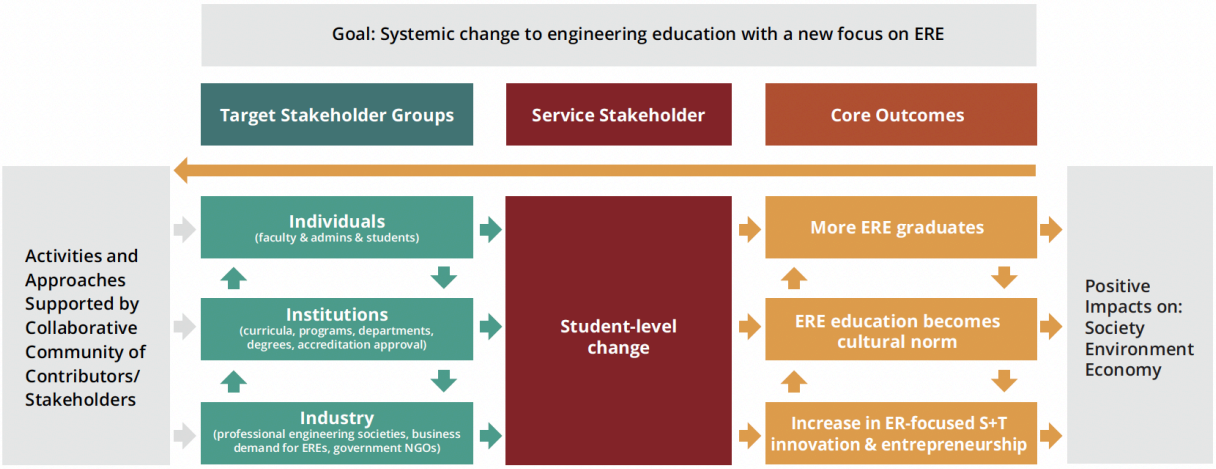

Figure 2: *Systemic-level theory of change for environmentally responsible engineering in higher education for US-based institutions with delineated target and service populations and core outcomes as outlined in the white paper entitled, "Engineering for One Planet: Launching a Collaborative Effort to Proliferate Principles of Environmentally Responsible Engineering in Higher Education Institutions" [19]. Adapted with the author's permission.*

Additionally, the white paper listed seven critical milestones and deliverables to accomplish over the next five years to achieve with the collaborative support and input of the growing community of ERE stakeholders (see Figure 3) [19].

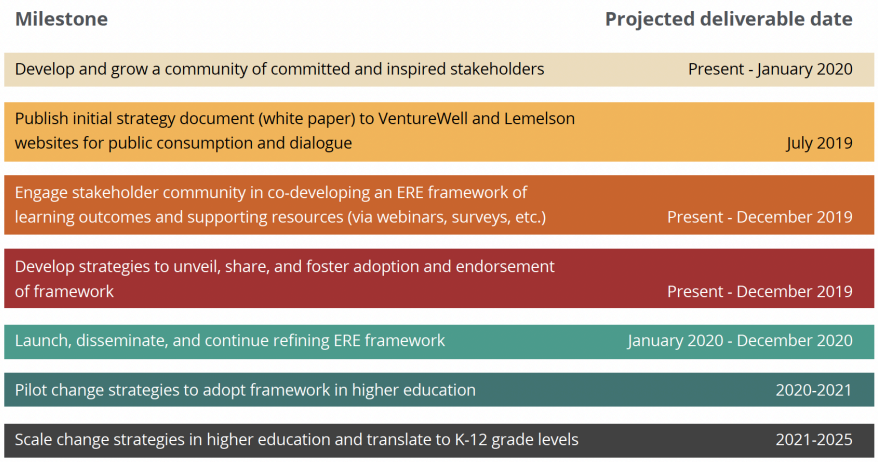

Figure 3: *Seven milestones for the development and launch of the ERE Framework as outlined in the white paper entitled, "Engineering for One Planet: Launching a Collaborative Effort to Proliferate Principles of Environmentally Responsible Engineering in Higher Education Institutions" [19]. Adapted with the author's permission.*

Community Co-creation of the ERE Framework

2019 - Draft ERE Framework Co-creation

As is listed above, the community of engaged stakeholders identified a critical milestone to co-develop and launch an ERE Framework of student learning outcomes (LOs). These were viewed as the "what" graduating engineering students would need to know to maximize their positive influence and impacts on society and the environment while minimizing potential negative impacts. Efforts to embed environmental sustainability into engineering education had existed for decades, and the ERE Framework sought to build upon these past and existing efforts, including numerous related frameworks, courses, programs, and definitions (e.g., sustainable engineering, green engineering, green chemistry, and circular economy).

The Lemelson Foundation, VentureWell, and Alula Consulting collaborated with hundreds individuals over several years to organize and orchestrate the co-creation of the EOP Framework, building on past research and curricular change efforts. As a starting place, a 15-page draft document was generated that listed dozens of ideas, broadly categorized student LOs that had been generated through numerous interviews, conversations, surveys and focus groups with over 200 expert stakeholders between 2017-2019. The draft was shared with the public as a Google document available for review and for contributors to share new ideas, suggestions and feedback by inserting comments. The link to the document was distributed via direct mailing and through partner organizations' contact lists, as well as through social media, etc. The draft document was shared with several thousand professionals from academia, industry, consultants, nonprofits, governmental agencies and professional societies, as well as students. The draft was open for public comment between September and November 2019.

During the three-month open commenting period nearly 90 stakeholders from across sectors, geographies, lived experiences, and disciplines contributed 430 comments to the draft ERE Framework document. The co-developers used inclusive approaches including synchronous and

asynchronous public commenting methods, such as shared documents and virtual meetings, to capture ideas, concerns, questions, and feedback, and to resolve unclear or contradictory comments. All comments were resolved by the community. Through these community collaborations and opportunities for feedback during 2019, the original EOP Framework —formerly known as the *Draft ERE Definition and Framework* (ERE Framework)—was publicly soft launched in 2020 to serve as a catalyst to help infuse sustainability into engineering courses and programs. At this time there were 82 student LOs (43 core and 39 advanced) that fell into 9 topic areas .

From an accreditation standpoint, taking environmental considerations into account has been in ABET's Criteria for Accrediting Engineering Programs—the accepted attainment standards that will prepare graduates to enter the professional practice of engineering—for over a decade. However, ABET student outcomes do not require graduating engineers to acquire a specific depth of knowledge, skills, experiences, and understanding. ERE Framework contributors recommended that engineering programs utilize the framework LOs not only to achieve but to go beyond ABET's current requirements of exposure to foster the formation of critical thinking and substantial sustainability-focused knowledge, skills, and mindsets in engineering students. The ERE framework specifically supports engineering programs that achieve five of ABET's seven student learning outcomes that call out sustainability and the environment [16]. (Note: in the 2022 revision to the framework all seven ABET outcomes were mapped to the framework LOs.).

To make the framework as useful to engineering programs and faculty members as possible, the LOs were mapped to the five ABET student outcomes that involved impact on the environment, as outlined in the ABET Criteria for Accrediting Engineering Programs [16], and aligned with the 17 United Nations (UN) Sustainable Development Goals [20]. The ERE Framework was mapped specifically to UN SDG #12 —ensuring sustainable consumption and production patterns— due to its direct alignment with engineering and design.

2019 - ERE Approaches Report

During the open commenting period of the draft ERE Framework, The Lemelson Foundation commissioned an internal follow up study with Alula Consulting to conduct research and analysis on potential approaches for facilitating the adoption of the ERE Framework for higher education. Whereas the ERE Framework was intended to provide the content —the "what"— that higher education institutions would integrate to ensure all engineers are equipped with fundamental principles of environmental responsibility, there was also a need to determine the approaches for integrating the ERE Framework —the "how" of creating curricular change. This research study focused on revealing approaches for curricular change by analyzing several existing frameworks and related curricular change approaches, many with a sustainability or impact lens, to glean lessons learned and pitfalls to avoid, as well as to discover unique learnings and patterns for success. Eleven implementation or curricular change efforts for higher education settings were investigated, and two for use in other educational settings. The research built upon The Lemelson Foundation's prior research findings [14] and [17] with deepened understanding and approaches suggested by academics and innovators and the addition of new perspectives from curricular framework implementers. The report summarized the key findings from engaging with 56 people through 23 individual interviews, 19 people via two online conversations, and 14 individual online surveys. Through the research four interrelated sets of

approaches emerged for the implementation of the ERE Framework and to effect long-lasting change to engineering programs across the United States: 1. Approaches to support pre-launch of effort (e.g., form advisory committee to guide the launch of a central initiative), 2. Approaches to launch effort (e.g., cultivate faculty champions, support pilot schools to test the ERE Framework, etc.), 3. Approaches to support faculty implementation efforts (e.g., develop teaching resources, provide faculty funding, etc.), 4. Approaches to create supporting processes for implementation (e.g., create a landscape tool to map sustainability-focused institutional assets, etc.) [21].

2020 - EOP Initiative Launch

The Lemelson Foundation and VentureWell catalyzed the EOP initiative in 2020 with a goal of equipping all future engineers with fundamental skills, knowledge, and understanding in environmental responsibility, which was later broadened to social and environmental sustainability. During EOP's launch phase (2020-2022), the 14-person EOP Advisory Group provided strategic advice on the EOP initiative, and included students and professionals with experience in academia, industry, and the public sector who are passionate about advancing sustainable engineering. The Draft EOP Framework was soft launched during this period to invite stakeholder feedback during the next two years of vetting.

Community Vetting of the EOP Framework

2020 - 2022 EOP Pilot Grant Program

In 2020, The Lemelson Foundation launched and funded an EOP Pilot Grant Program to support the integration and vetting of the draft EOP Framework. The two-year program included five pilot grantee schools that ranged in size, number of engineering students, types of engineering programs, geographical region, and institution type (e.g., R1, MSI, etc.,). The grantees —Arizona State University (ASU), Villanova University, Oregon State University (OSU), The University of Maryland (UMD), and University of Central Florida (UCF)— were initially funded up to $30,000 to test the integration of the LOs from the EOP Framework in their curricular offerings from June 2020 to June 2022. They were tasked with changing or creating a minimum of one course and were asked to share teaching resources/tools created and to provide lessons learned and feedback on the use of the EOP Framework in curricular changes. Grantees were also offered up to $10,000 in supplemental funds to address challenges and opportunities that emerged after the first year, which was marked by the COVID-19 pandemic. The project was guided by an evaluation plan co-created with VentureWell and The Lemelson Foundation, and VentureWell supported peer learning through a Community of Practice.

2022 - Scaling for Impact Workshop

In June 2022, with the support of the National Science Foundation (NSF) and the collaboration of The Lemelson Foundation, VentureWell hosted the *EOP Scaling for Impact Workshop* to engage a broader group of stakeholders in order to increase awareness of the initiative, attract new supporters and champions, and inform a scaling strategy. Participants recognized that a scaling strategy must foster both propagation (defined as the action of widely spreading and promoting related ideas or tools to foster systems change), and institutionalization (defined as the action of establishing related ideas or tools across and within an organization or institution).

Over 100 participants from across sectors (academia, industry, government, and nonprofit organizations) came together for the two-day workshop to achieve the following goals:

- Highlight best practices from the extant literature about the integration of sustainability concepts and tools into engineering curriculum.
- Share lessons learned from the EOP pilot grant program grantees for how to infuse the EOP Framework into curricula and programs.
- Make recommendations to inform the design of a five-year roadmap to scale the EOP initiative, that included incorporation of diversity, equity, inclusion, and justice (DEIJ), approaches to cultivate both propagation and institutionalization, and a revision of the EOP Framework.

The workshop generated 12 approaches to scale the EOP initiative that ranged from working with key stakeholders —such as ASEE, industry, and student groups— to the development or modification of engineering courses and teaching resources to include sustainability-focused competencies. A summary of outcomes from the workshop [22] and recommendations for the future were published as a ASEE conference paper in 2023 [23] and as a summary report by VentureWell in 2024 [24].

2022 - EOP Framework Revision

In 2022, EOP used three stakeholder feedback mechanisms to revise the EOP Framework.

1. An external evaluator gathered confidential feedback from EOP Pilot Grantees via one-on-one interviews to understand what was working with the EOP Framework, what could be improved, etc. [25],
2. As part of the NSF-funded EOP Scaling for Impact Workshop in 2022, 101 experts from across sectors working in the area of sustainability and/or engineering provided feedback on the EOP Framework [22], and
3. EOP invited its global community of stakeholders to review and comment on the draft EOP Framework as a Google Document. It was available for comment during the first six months of 2022.

With testing through pilot grants and further community input, the EOP Framework evolved from its early focus on "environmental responsibility" to reflect the broader lenses of social and environmental sustainability. Other refinements included ensuring LOs are measurable by aligning them with the 2010 Bloom's Taxonomy [26] and mapping all seven ABET student outcomes [16], as relevant, to each of the EOP LOs (which was an expansion from the original ERE Framework that mapped to five ABET student outcomes; see Figure 4 for priority refinements). Over 600 comments were collected and incorporated into the revised version released in December 2022 [27] and is available to the public for free on the EOP website www.engineeringforoneplanet.org [9], including the names of over a hundred collaborators and contributors to the EOP Framework [28].

Figure 4: *Eight priority areas of refinement of the EOP Framework that were undertaken during the 2022 revision process.*

The EOP Framework: Essential Sustainability-focused Learning Outcomes for Engineering Education (2022) (Figure 5) is now the 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 and improve our planet and our lives [27]. The EOP Framework is not a research framework but a practical implementation tool that supports educators in integrating environmental and social sustainability concepts and tools into engineering courses, programs, and departments. It provides a vetted list of 93 core and advanced sustainability-focused student learning outcomes, including professional and leadership skills, that fall into nine topic areas that all engineering students should acquire. The EOP Framework is aligned with ABET's seven required student outcomes [16], as well as UN SDG #12 [20] and Bloom's Taxonomy [26].

The EOP Framework was designed for 1) engineering faculty members, educators, students, and administrators who want to integrate sustainability education into a diverse assortment of courses, programs, departments, and institutions, and can also be applied by 2) professional engineering educators who want to provide practicing engineers with sustainability skills, knowledge, understanding, and mindsets, and 3) educators looking for resources to integrate sustainability into other science, technology, and math disciplines, as well as K-12 education [29].

Figure 5. *"The EOP Framework: Essential Sustainability-focused Learning Outcomes for Engineering Education (2022)" [27]. Shown from left to right: cover image and nine topic areas of the EOP Framework in graphic and list form. Adapted with the author's permission.*

2022: ASEE EOP Mini-Grant Program Launch

In 2022, The Lemelson Foundation-funded EOP Mini-Grant Program (EOP-MGP) was launched through the American Society for Engineering Education (ASEE) to integrate the EOP Framework LOs and support faculty teams as they pursue ways to integrate sustainability into their courses and programs [30]. Teams were matched with mentors for guidance, and received $8,000 to support the piloting and implementation of their projects. Since its inception, 27 faculty teams have been selected to participate in the EOP-MGP —13 in the first cohort, and 14 in the second cohort in 2023. The third cohort will be launched in 2024. Teams were selected from pools of more than 100 applicants each year.

A key goal of the EOP-MGP is to engage diverse faculty and institutions and foster the inclusion of people from historically marginalized and low-income communities who are disproportionately negatively affected by climate and environmental degradation as partners in creating change. In the first two cohorts, 41% (n=11) of the grants were awarded to MSIs as follows: three Historically Black Colleges and Universities (HBCUs); six Hispanic-Serving Institutions (HSIs), and two Asian American and Native American Pacific Islander-Serving Institutions (AANAPISs). The teams are geographically dispersed and represent a mix of institutional sizes and programs, including engineering and non-engineering disciplines. Faculty are also ethnically and racially diverse.

2023: EOP Framework Companion Teaching Guides Co-Creation & Launch

During the revision process for the EOP Framework, contributors expressed that in addition to having guidance on "what" skills, knowledge, and understanding graduating engineering students would need to acquire, as outlined by the EOP Framework, it would be helpful to have guidance on "how" to bring the learning outcomes into courses and programs. To meet this need, three EOP Framework companion teaching guides were co-created and shared with stakeholders for early feedback. All three EOP Framework companion teaching guides (Figure 6) were developed by EOP with input and feedback from stakeholders, launched in 2023, and are available to the public for free at www.engineeringforoneplanet.org [9].

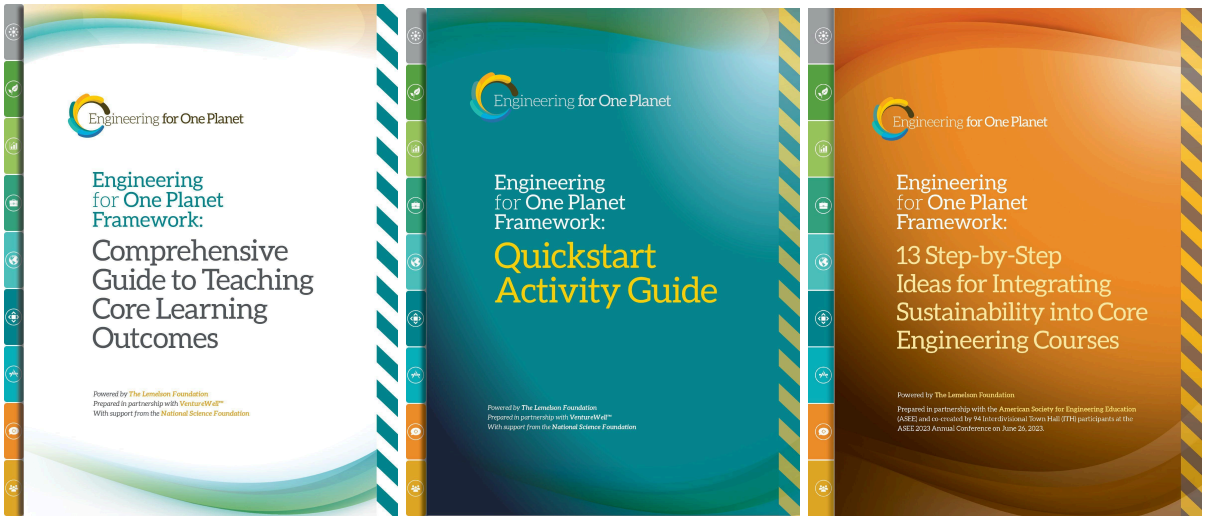

Figure 6. *Three EOP Framework companion teaching guides launched in 2023. All are available for free on the EOP website [9]. Shown from left to right: "EOP Framework: Comprehensive Guide to Teaching Core Learning Outcomes" [31], "EOP Framework: Quickstart Activity Guide" [32], and "EOP Framework: 13 Step-by Step Ideas to Integrate Sustainability into Core Engineering Courses" [33]. Adapted with the author's permission.*

In 2022, The Lemelson Foundation commissioned Alula Consulting and an associate practice professor of engineering at the University of Pennsylvania, who is also an ABET Program Evaluator in the EAC, to draft an initial teaching guide in response to the requests from the EOP community. The goal of the *EOP Framework: Comprehensive Guide to Teaching Core Outcomes* (see Figure 6) companion teaching guide was to provide curated and vetted teaching resources and activities (e.g., videos, reading materials, classroom activities, examples of student work, case studies, etc.,) for each of the core learning outcomes outlined in the framework [31]. All teaching materials were required to be available for free online and easily accessible to everyone.

During the development process it was determined that the amount of information provided in the guide might be overwhelming to instructors that were new to teaching sustainability. EOP co-created the *EOP Framework: Quickstart Activity Guide* (see Figure 6) to overcome this challenge [32]. This guide was intentionally designed for use for instructors that are new to teaching sustainability and introduces only one core learning outcome for each of the nine topic areas of the framework. It leads the reader through specific, freely available online teaching resources to achieve that core outcome in their classroom.

Two online webinars were hosted in November 2022 by the guide creators to gather input and feedback from the public. The webinars were advertised on social media as well as through the EOP Newsletter on November 1, 2022. All feedback was incorporated and final versions were shared publicly on the EOP website on the Resources page, through social media channels, and in the EOP Newsletter on February 21, 2023.

The most recent EOP Framework companion teaching guide created —*EOP Framework: 13 Step-by Step Ideas to Integrate Sustainability into Core Engineering Courses* (see Figure 6)—

was developed in an entirely different way from the other two [33]. On June 26, 2023, during the Interdivisional Town Hall (ITH) event at the 2023 ASEE Annual Conference, 94 participants divided into random teams worked together to create 11 of the 13 teaching examples found in the EOP teaching guide [34]. To ensure the guide would provide at least one example for each of the nine topics in the EOP Framework, EOP added two examples.

During the ITH event, participants were given a brief 10-minute introduction to the history and background of the EOP initiative. Teams were formed with the people sitting at the same tables. Each table was pre-assigned one of the nine topic areas from the EOP Framework (e.g., Systems Thinking). Then teams were guided through a five-step process with a worksheet (see below) to capture their ideas for the integration of a single core learning outcome from the EOP Framework —of their choice— into an existing core engineering course of their choice. Within 30 minutes each team produced a curricular example. Each of the teams' examples were reviewed, edited and curated as part of a new collaboratively co-created, open source EOP teaching guide. Each of the examples in the new guide lists a core engineering course title and level, provides a core LO from the EOP Framework, details an integration example and provides supporting resources with links to free teaching and learning tools available online.

The new guide is attributed to the 94 contributors that were participants on the 11 teams at the ITH session. On October 5, 2023, The Lemelson Foundation published the new guide on the EOP website on the Resources page, shared it with all contributors via direct email and distributed it via social media channels. It was also shared in the EOP Newsletter on December 12, 2023.

Implementation and Impacts of EOP Framework Teaching Resources

EOP resources impact data are mostly limited to findings from EOP Grantee Program efforts. However, in addition to the various EOP grant program outcomes described below, numerous EOP community members have been utilizing the EOP Framework since 2020 to bring sustainability into engineering courses [29], as well as degree programs [35], without funding from The Lemelson Foundation. Since the EOP initiative launched in 2020, hundreds of engineering courses —including core and required courses— have been created or modified to infuse sustainability into the engineering curriculum by dozens of faculty members that have reached more than 10,000 students.

EOP Grantee Programs Reach

<u>EOP Pilot Grantee Program</u>

- Over the course of two years, the five pilot schools modified or created 61 courses reaching 5908 students, and 80 faculty used the EOP Framework in course modifications [36].
- In 2023, The Lemelson Foundation published a synopsis of the diverse approaches the schools utilized to integrate the EOP Framework, resulting impacts, and key lessons learned from the EOP Pilot Grant Program [36].
- Faculty members from several EOP Pilot Grantees have published findings from efforts to integrate sustainability into engineering courses —including about courses created or modified using the EOP Framework, faculty training, and student impacts that were

obtained within the grant period— through blog articles [37] and at various professional engineering and education conferences including ASEE in 2021 [38] and 2022 [39], [40].

ASEE EOP MGP

- Over 7 months in 2022, the first cohort of the ASEE EOP-MGP modified or created 34 courses reaching 1615 students, and supported 48 faculty in the use of the EOP Framework [41].
- Over 7 months in 2023, the second cohort of ASEE EOP-MGP grantees modified or created 65 courses reaching 1798 students, and supported 68 faculty in the use of the EOP Framework [42].
- Final videos and team posters presented at the annual ASEE EOP-MGP Online Symposium are available at: https://eop-mgp.asee.org/ [30]
- Faculty members from ASEE EOP-MGP institutions have shared early work utilizing the EOP Framework at professional conferences including at ASEE in 2023 [43].

Key Takeaways from EOP Grantee Programs

- There is no one "right" way to integrate sustainability. EOP faculty change agents and grantee schools have used a range of strategies and will benefit from considering existing assets (e.g., other faculty, students, existing courses, leadership support, EOP teaching tools, etc.), and sources of support (e.g., internal and external grants, corporate partners, etc.) they can tap to facilitate their efforts.
- While there is no "right" way to integrate sustainability, it is helpful to leverage the EOP Framework and related tools to create common language and facilitate sharing of teaching insights and tools among faculty.
- For faster impact that conveys sustainability as part of all engineering practice, integrate into existing courses. Be cautious about focusing on creating new standalone sustainability-focused courses. Standalone sustainability courses can be helpful for deeper understanding, but curricular change will not be transformative if only offered in isolation from regular engineering content.
- To maximize reach and integration of change efforts, prioritize core and required courses
- Scaffold learning across all stages of degree, not just in first year courses, design courses, or capstones
- Engage industry partners in curricular and co-curricular activities to demonstrate the relevance to careers
- Incorporate sustainability skills, as well as professional and leadership skills such as critical thinking, communication, and teamwork.
- Faculty mentorship or a community of practice support is ideal for sustained faculty engagement and curricular change and to foster deeper understanding
- Share ideas, lessons learned and curriculum with peers
- Use free online resources
- Plan and prepare for assessment before starting the project to secure Institutional Review Board (IRB) permissions, if necessary, and to develop baseline measurements and measure short- and long-term impacts. Assess impact on faculty and students. Consider assessing not only learning, but also other impacts that may be of interest to the institution, including beliefs about the relevance of sustainability and career priorities.

- Capture key performance indicators (KPIs) (e.g., number and proportion of faculty trained, number and proportion of students reached, number of courses modified and created, etc.,) from the outset of an implementation to measure short- and long-term impacts
- Develop supportive communities and culture that prioritizes sustainability to facilitate change

EOP Resources Downloads

EOP supports open educational resources development and sharing, and all EOP Framework-related teaching resources published by The Lemelson Foundation are licensed under Creative Commons to support accessibility, adoption, and adaptation for a diversity of uses. Tracking of EOP resources downloads did not begin until January of 2023, three years after the original soft launch of the EOP Framework, thus download data is not representative of the entire use period. Google Analytics downloads data from the EOP website show that the following EOP resources were downloaded by unique users more than 1,000 times in 2023. Note that each EOP resource was made available on the EOP website at different times throughout 2023, as delineated by the symbols in Table 1 below.

EOP Resource Title	Number of total times downloaded	Number of downloads by unique users
[α]The EOP Framework: Essential Sustainability-focused Learning Outcomes for Engineering Education (2022) [27]	596	494
[β]EOP Framework: Comprehensive Guide to Teaching Core Learning Outcomes [31]	310	222
[β]EOP Framework: Quickstart Activity Guide [32]	303	223
[γ]EOP Framework: 13 Step-by Step Ideas to Integrate Sustainability into Core Engineering Courses [33]	122	99

Table 1: *Google Analytics downloads data from the EOP website in 2023. [α]Available from January through December 2023; [β]Available from March through December 2023; [γ]Available from October through December 2023.*

Future Work

Revision of the EOP Framework & Companion Teaching Guides

All EOP teaching resources have been created, implemented, vetted, and revised in collaboration with the EOP community and EOP will continue to use this methodology in the future. The EOP Framework will undergo another open commenting period in 2025 to collect input and feedback from the public. EOP encourages faculty to implement the various EOP resources and to share curricular materials and lessons learned with their peers to scale the integration of sustainability into engineering education at a more rapid pace.

New EOP Resources
EOP will launch at least three new teaching resources in 2024 with partner organizations and/or academic institutions.

- *EOP Framework: AHEP4 Mapping to the Essential Sustainability-focused Learning Outcomes for Engineering Education* is a new guide to support the adoption of the EOP Framework and integration of sustainability into engineering courses and programs in the United Kingdom (UK). Created in partnership with the UK's Engineering Professors Council (EPC) [44] and Engineers Without Borders UK (EWBUK) [45], the EOP Framework's student learning outcomes are mapped to fourth edition of The Accreditation of Higher Education Programmes (AHEP 4) [46] at the Chartered Engineer (CEng) level to ensure that UK educators can more easily align these outcomes and corresponding resources with the learning activities, coursework, and assessments within engineering modules. Due for release on EOP, EPC, and EWB-UK websites in March 2024.
- Villanova University, an EOP Pilot Grant Program school, is leading the Spanish translation of the EOP Framework. Due to be launched on the EOP website in 2024 to facilitate wider adoption of EOP.
- In collaboration with Arizona State University —an EOP Pilot Grant Program school— EOP will offer an interactive, hands-on workshop at the ASEE annual conference in June 2024. An outcome of the workshop is to co-create the next open source EOP Framework companion teaching guide that will focus on sustainability-focused active learning activities for engineering classrooms that will be launched by the end of 2024.

Addressing Gaps
Since the earliest research EOP initiative strives to listen to critical stakeholders from across sectors to understand the greatest needs and gaps that are obstacles to the integration of sustainability into engineering education. EOP intends to work with key stakeholders to address current gaps that have been raised by the EOP community including:

- Developing assessment guidance and resources to better understand the effectiveness of the EOP teaching resources (e.g., impacting students' learning, experiences, and career path, etc.),
- Working with industry to build stronger bridges between engineering programs, student job training opportunities (e.g., apprenticeships, internships, practicums, co-op programs, etc.,) and hiring practices, and sustainability-focused jobs and careers,
- Creating an engagement strategy for leadership from academia (e.g., deans, chairs, presidents, etc.,), and
- Understanding if there is a compelling need for a repository for EOP-focused curricular resources and/or a community platform for sharing resources and ideas, and to foster collaborative partnerships and mentorships.

Conclusion
EOP open source resources that are community co-created are intended to provide easy to access and easy to understand and use teaching materials to support the integration of sustainability-focused competencies into engineering courses, programs, and institutions, no matter what an instructor's background, the type of engineering course, or institution. EOP

resources will be periodically updated with stakeholder input to keep them relevant and useful as the sustainability field continues to evolve and they continue to be field tested by the EOP community. The authors encourage any faculty interested in bringing sustainability into engineering coursework to utilize and disseminate the EOP Framework and companion teaching guides to support the training of sustainability-focused engineers that will be equipped with the skills, knowledge, understanding, experiences, and mindsets to face humanity's greatest challenges.