A Toolkit for Expanding Sustainability Engineering Utilizing Foundations of the Engineering for One Planet Initiative

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A Toolkit for Expanding Sustainability in Engineering Utilizing Foundations of the Engineering for One Planet Initiative

Abstract

Recently, there has been a significant push to prepare all engineers with skills in sustainability, motivated by industry needs, accreditation requirements, and international efforts such as the National Science Foundation's 10 Big Ideas and Grand Challenges and the United Nations' Sustainable Development Goals (SDGs). This paper discusses a new toolkit to enable broad dissemination of vetted tools to help engineering faculty members teach sustainability using resources from the Engineering for One Planet (EOP) initiative. This toolkit is to be used as a mechanism to engage a diversity of stakeholders to use their voices, experiences, and connections to share the need for national curricular change in engineering education widely. This toolkit can foster the integration of sustainability-focused learning outcomes into engineering courses and programs. This is particularly important for graduating engineers at this crucial time when we collectively face a convergence of national- and global-scale planetary crises that professional engineers will directly and indirectly impact.

Catalyzed by The Lemelson Foundation and VentureWell, the EOP initiative provides teaching tools, grants, and support for the EOP Network —a volunteer action network— comprising diverse stakeholders collectively seeking to transform engineering education to equip all engineers with the understanding, knowledge, skills, and mindsets to ensure their work contributes to a healthy world. The EOP Framework, a fundamental resource of the initiative, provides a curated and vetted list of ABET-aligned sustainability-focused student learning outcomes, including core and advanced. It covers social and environmental sustainability topics and essential professional skills such as communication, teamwork, and critical thinking. It was designed as a practical implementation tool — rather than a research framework — to help educators embed sustainability concepts and tools into engineering courses and programs at all levels. The Lemelson Foundation has provided a range of grants to support curricular transformation efforts using the EOP Framework. With support from The Lemelson Foundation, ASEE launched an EOP Mini-Grant Program in 2022 to engender curricular changes using the EOP Framework. The EOP Network is working to extend the reach of the Framework across the ASEE community beyond initial pilot programs by implementing an EOP Toolkit for EOP Network members and other stakeholders to use at their home institutions, conferences, and informative workshops. This article describes the rationale for creating the EOP Toolkit, the development process, content examples, and use scenarios.

Keywords: Sustainable Engineering, Sustainable Development Goals, Bloom's Taxonomy, Environmental Engineering, SDGs

Introduction and Background

The Sustainability Gap in Engineering Education

During the 21st century, there have been various strategic initiatives to advance engineering education toward more holistic approaches that push engineers to think outside the box when

designing tools for the world [1]. These initiatives began in 2000 with the release of the Grand Challenges in Engineering, which has been followed by more recent and interdisciplinary calls to action in engineering education, including the United Nations Sustainable Development Goals (SDGs) in 2015 and the National Science Foundations Big 10 Ideas [2]–[4]. These calls are primarily targeted toward higher education institutions which have led university systems to bring sustainability, public health, and other service-oriented practices into their research and teaching portfolios [5]. These initiatives are broad and do not only scope the future of engineering. In this paper, we will present the Engineering for One Planet (EOP) Toolkit as a means to increase access to resources to support the education of engineers who are well-versed in social and environmental sustainability.

Engineers and designers impact nearly everything human-made. From consumer goods to hardware and software products to buildings and modes of transportation, their decisions regarding design, algorithms, source materials, production, distribution, and disposal can make positive or negative impacts now and for generations to come [6].

Despite significant growth in sustainability topics in engineering education, most engineering students are not learning sustainability-focused concepts, tools, and methodologies [7], [8]. Educators perceive sustainability as a complex topic, and many educators themselves need to be more comfortable and familiar with the ways to bring sustainability into the classroom [9]. This has led to a gap in sustainability curriculum development in engineering education [10] and sustainability knowledge in the workforce after graduating [11]. Fewer than 1% of the nearly 150,000 engineering graduates in the US are majoring in environmental engineering [12]. The professional demand for engineers with core skills and mindsets in environmental, social, and economic sustainability is outpacing the supply, with renewable and environmental jobs increasing by nearly 250% in the last five years alone [13].

Engineering education can produce individuals equipped to address and prevent environmental and social issues such as environmental toxicity, air and water pollution, and climate change. Numerous studies have shown that chemical toxicity, environmental degradation, and pollution have disproportionately burdened people of color, yet people of color have been historically excluded from engineering education [14]. Justice- and impact-oriented STEM careers and educational pathways may help attract and retain people of color in STEM fields and produce solutions to planetary damages [15]. A study of EOP Framework implementation at Oregon State University demonstrated that integration of environmentally-responsible engineering concepts in first-year engineering courses increased student enthusiasm for engineering, suggesting potential for improving student retention, including students from groups historically underrepresented in engineering [16].

The global demand for environmental and climate justice and planetary protections comes from all stakeholders – from students, educators, and professionals to citizens, consumers, and advocates to corporations and governments [17]. Organizations like ABET (formerly the Accreditation Board for Engineering and Technology) and professional engineering associations highlight the need to accelerate the integration of competencies in environmental and social sustainability across engineering education [18]. With such a significant gap in the sustainability curriculum, actions need to be taken to help bring new sustainability resources to engineering education. In 2019, the original EOP Framework was co-developed with hundreds of

stakeholders including dozens from the engineering education community— and proposed as a catalyst to help infuse sustainability into engineering courses and programs [19].

Figure 1. *Engineering for One Planet Framework Graphic. Adapted from [20] with the author's permission.*

Background on Engineering for One Planet

EOP is an initiative to transform engineering education and equip all engineers across all disciplines with the fundamental competencies of social and environmental sustainability [19] and related leadership skills such as communications, critical thinking, and teamwork. The vision of EOP is that sustainability will become a core tenet of the engineering profession. This aligns

with the growing demand in the industry for engineers with sustainability skills for post-graduate careers. Recent studies show that the demand for sustainability skills across fields, including engineering and sectors, is increasing faster than the supply of professionals equipped with these skills [21], [22].

The Lemelson Foundation and VentureWell catalyzed EOP in collaboration with hundreds of sustainability advocates across sectors; the EOP initiative envisions a world in which all engineers play a critical role in ensuring that the solutions of today do not become the problems of tomorrow, restoring and regenerating our environment, and improving lives for all. EOP is working with a community of stakeholders and other aligned change efforts. These individuals and organizations aim to foster a future where engineers account for social and environmental impact as much as they do for cost and user experience. They envision a future where solutions to the world's biggest problems will simultaneously contribute to the care of our planet. This is because sustainability will have been stitched into the fabric of the engineered approaches and solutions.

There has been leadership from educators utilizing the EOP Framework in their curriculum to help evaluate the competencies of this program [23]–[25]. This manuscript focuses on addressing the large sustainability gap in engineering education. To achieve this, an EOP Toolkit has been developed. The EOP Network and non-network members are working to disseminate the EOP Framework and related sustainability tools, practices, and teaching resources. The aim is to expand the reach of these resources beyond the traditional academic community. By doing so, it is hoped that more engineers will be equipped with the knowledge and skills to incorporate sustainability into their work. The desired outcomes of this initiative are twofold. Firstly, it aims to maximize the impact and scope of sustainability practices in engineering. This will be achieved by facilitating the understanding and adoption of vetted educational tools and practices. Secondly, the EOP Toolkit will be leveraged to engage diverse stakeholders. These stakeholders will be encouraged to use their voices, experiences, and connections to share the need for national curricular change in engineering education widely. By doing so, it is hoped that a larger group of people will be motivated to take action toward incorporating sustainability into engineering practices.

Developing the Engineering for One Planet Theory of Change and Strategy

EOP was formed and continues to evolve based on significant stakeholder input. Research to develop the EOP initiative began in 2017 with a qualitative study to understand the barriers and opportunities for integrating environmental responsibility in higher education [26], [27]. The study revealed existing efforts to bring sustainability into mainstream engineering that were frustrated by a lack of academic support, resources for curricular change, and limited industry demand.

Further conversations with hundreds of stakeholders between 2018-2019 highlighted growing interest in imbuing sustainability in engineering education from engineering professionals, faculty, leaders, and students. 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.).

With this input, EOP catalyst organizations developed an initial Theory of Change (ToC) and three interrelated strategic actions to help realize the ToC [28]:

1. The co-creation of core learning outcomes all engineering students needed to learn to be environmentally responsible (i.e., the first draft of the EOP Framework)
2. The launch of catalytic grants to demonstrate curricular change using the EOP Framework, starting with the EOP Pilot Grant Program, which provided seed funding and a supported Community of Practice for five universities, and
3. The formation of collaborative change efforts involving academics, industry professionals, funders, and nonprofit professionals (e.g., the National Science Foundation-funded EOP Scaling for Impact Workshop and the EOP Network).

Strategic Action 1: The EOP Framework

EOP stakeholders identified a critical initial need to define "what" graduating engineering students would need to know to maximize positive impacts while minimizing potential negative impacts. In response, in 2019, a multi-year collaborative effort led to the development of the EOP Framework launched in 2020. A revised version was released in 2022 and is publicly available for free at www.engineeringforoneplanet.org. With testing through pilot grants and further community input, the EOP Framework has evolved from its early focus on "environmental responsibility" to reflect the broader lenses of social and environmental sustainability, among other refinements based on over 600 comments that were collected and incorporated into the revised version released in 2022.

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 (**Figure 1** & **Figure 2A**) [20]. Aligned with ABET's seven required student outcomes, it provides faculty members 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. The desired outcome from using the EOP Framework in curricular transformation is a pipeline of engineers, inventors, and innovators who create structures, designs, products, and services that help people and nature flourish.

What is the EOP Framework?

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 92 core and advanced sustainability-focused student learning outcomes that all engineering students should acquire that was co-created by a community of hundreds of experts from a range of identities, lived experiences, geographies, and sectors, including academia, industry, nonprofit, government, and philanthropy [20], [29].

Why do we need the EOP Framework?

The results of a thematic assessment through in-person interviews and conversations with engineering practitioners and educators and the results of the EOP Literature Review Report demonstrate the need for a sustainability implementation tool such as the EOP Framework as follows [20]: engineers play a critical role in creating a healthy, flourishing world, and their work has outsized impacts on our world. Engineers must possess sustainable mindsets, skill sets, and professional preparation. This is necessary because the industry demands it and to ensure that the engineering solutions of today do not become the problems of tomorrow. However, the majority of engineering students are not learning sustainability-focused concepts, tools, and methodologies through their engineering educational training. Therefore, there is a need to incorporate these concepts into engineering education. Engineers must also be knowledgeable about and understand the history and implications of racist, classist, and patriarchal practices in engineering and social systems. They should be prepared to support the abolishment of these practices. Furthermore, engineers need to understand the social and cultural influences of their work and be prepared to support environmental justice. By doing so, engineers can contribute to creating a more equitable and sustainable world.

Who is the EOP Framework for?

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 [20].

Foundations of the EOP Framework

The Lemelson Foundation, VentureWell, and Alula Consulting collaborated with hundreds of individuals over several years to organize and orchestrate the co-creation of the EOP Framework, building on past research and curricular change efforts. Efforts to embed environmental and social sustainability into engineering education have existed for decades, and the EOP Framework seeks 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). Hundreds of representatives from across sectors — academia, nonprofits, government, and industry— as well as disciplines, geographies, lived experiences, etc., have been involved in creating and refining the EOP Framework.

The co-developers of this collaborative effort used inclusive approaches. They offered synchronous and asynchronous public commenting methods, such as shared documents and virtual meetings, to capture ideas, concerns, questions, feedback, and more when crafting the framework. They drafted student learning outcomes that could be integrated into new and existing courses across various engineering disciplines. To ensure measurable learning outcomes, they aligned them with the 2010 Bloom's Taxonomy [30]. Additionally, they assembled a large-scale, global volunteer community of self-motivated and self-interested individuals and

organizations to foster collective impact. Finally, they gathered and shared lessons learned and resources to serve as models for initiatives new to EOP and other communities and disciplines outside of engineering.

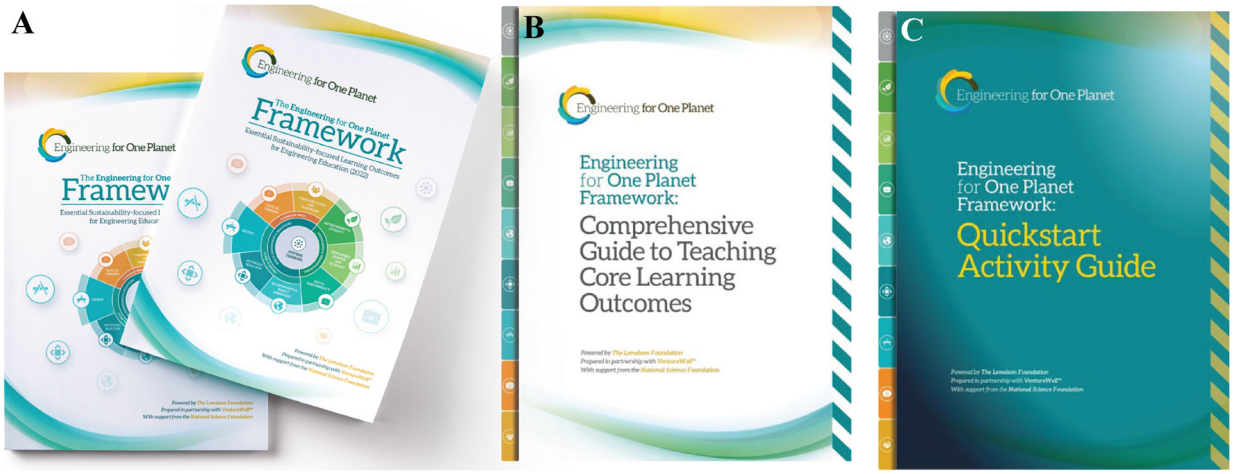

Figure 2. *Primary EOP Toolkit documents for curricular change in engineering education. All are available for free on the EOP website. A) The EOP Framework: Essential Sustainability-focused Learning Outcomes for Engineering Education (2022)[20], B) EOP Framework: Comprehensive Guide to Teaching Core Learning Outcomes [31], and C) EOP Framework: QuickStart Activity Guide [32].*

To make the EOP Framework as useful to engineering programs and faculty members as possible, the framework is mapped to the seven ABET student outcomes, as outlined in the ABET Criteria for Accrediting Engineering Programs [18]. Additionally, it aligns with the 17 United Nations (UN) Sustainable Development Goals. It is mapped to UN SDG #12 —ensuring sustainable consumption and production patterns— due to its direct alignment with engineering and design [25].

Relevance to Engineering Accreditation

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 [18]. However, ABET student outcomes do not require graduating engineers to acquire a specific depth of knowledge, skills, experiences, and understanding. EOP Framework contributors have recommended that engineering programs utilize the core student outcomes outlined in the EOP Framework 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 [22].

EOP Framework Companion Teaching Guides

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, two EOP Framework companion teaching guides were co-created and shared with stakeholders for early feedback. They were both launched in 2023 and are available to the public for free at www.engineeringforoneplanet.org. The *Quickstart Activity Guide* (**Figure 2C**) is intended for those new to teaching sustainability. It introduces 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 outcome in their classroom [32]. The *Comprehensive Guide to Teaching Core Outcomes* (**Figure 2B**) shares a wealth of teaching resources and activities for all 46 core learning outcomes outlined in the framework [31].

Strategic Action 2: Catalytic Grants

After the first draft of the EOP Framework was launched in 2020, The Lemelson Foundation awarded seed grants to engineering faculty members at five universities —Arizona State University, Oregon State University, the University of Central Florida, the University of Maryland, and Villanova University— to test the EOP Framework in curricular change efforts over two years. Grantees were asked to create or modify at least one course using the EOP Framework and to participate in a Community of Practice managed by VentureWell. Project approaches varied, with grantees choosing the learning outcomes and changing methods that best fit their situations. The pilot grantees exceeded expectations, modifying or creating 60 courses and impacting over 4000 students. The pilot grants yielded valuable insights into curricular change and opportunities to refine the EOP Framework.

In 2022, with support from The Lemelson Foundation, ASEE launched the EOP Mini-Grant Program (ASEE EOP MGP) to provide seed funds to a range of higher education institutions and programs to support diverse curricular change efforts using the EOP Framework [33]. The inaugural ASEE EOP MGP received over 100 applications, and ASEE made awards to 13 institutions, including five minority-serving institutions. The ASEE EOP MGP will continue in 2023 and 2024.

Strategic Action 3: Fostering Collaboration

Stakeholders identified the need for sustained collaboration to drive top-down and bottom-up approaches to transforming engineering education. The creation of the EOP Network was a response to this need. A firm with expertise in network formation, Converge, was contracted to guide the formation and launch of the EOP Network. To define the scope and purpose of the EOP Network, Converge held three listening sessions with dozens of diverse stakeholders from the engineering community before launching the EOP Network. Designed to foster collaborative actions among students, faculty members, higher education leaders, and industry/nonprofit/government professionals, the EOP Network requires an application to create shared expectations. Still, it does not require a minimum number of hours or commitment. The network is voluntary and self-governed and is staggering the intake of new members to foster

trust, relationships, and effective collaboration among a committed group of members. However, there is significant national and international interest in joining the EOP Network.

Launched virtually in 2021 with 40 members, the EOP Network now has 72 members and a growing waitlist of prospective members for future expansion. EOP Network members convened in person for the first time in October 2022. Convening facilitators engaged participants in activities and exercises to cultivate trust and foster collaboration for systems change. Participants identified diverse project ideas, and nine new teams were formed to collaborate on the projects. One of the teams focused on developing a presentation toolkit that EOP Network members could use to create proposals and presentations to drive awareness of the EOP initiative and facilitate the adoption of the EOP Framework. The team sought to create a toolkit that would be flexible and adaptable to facilitate sharing in diverse situations, from professional networking meetings to internal presentations for faculty and leadership to major conferences.

The EOP Network is a non-hierarchical, volunteer-based action impact network supported by a paid network manager who facilitates member collaboration and project teams, plans and delivers events, and ensures the network operates effectively. With impact networks, responsibility for advancing the purpose of a network is shared among all network members. Members participate at varying levels based on the shifting and emergent needs of the network and the availability of the individual [26]. EOP Network members develop and evolve the EOP Network Charter [28] (a living document aligned with the vision of the EOP initiative), suggest and promote projects and activities aligned with the network's purpose, and advance four strategic priority areas (i.e., making the case, broadening participation, sharing best practices, and transforming education).

The EOP Toolkit

Critical areas of the EOP Network's efforts include broadening participation in EOP and increasing awareness of the EOP initiative and its resources, including the EOP Framework and other supporting resources. As such, the EOP Toolkit was developed to allow members to share consistent information about the EOP initiative within their communities. The EOP Toolkit serves several purposes, as outlined below:

1. It is a practical way to ensure that those who wish to share and further the vision and tools of the EOP initiative and the purpose of the EOP Network can do so with accurate, clear, and consistent messaging and branding,
2. It makes it easier for individuals to participate in disseminating materials without reinventing the wheel each time they want to present materials,
3. It is a convenient collection of materials for network members to refer to when participating in EOP activities,
4. It makes it easier for various individuals to learn about and engage with EOP and can help diversify the people and institutions involved in efforts to integrate sustainability in engineering education,
5. It serves as a mechanism for all engaged and interested stakeholders to raise their voices to emphasize the imperative for change in engineering education at this crucial time.

The EOP Toolkit is modeled after a toolkit developed by the American Association for the Advancement in Science (AAAS) Science & Technology Policy Fellowships program to allow their alumni to promote the fellowship opportunity [34].

What is in the EOP Toolkit, and how is it used?

The EOP Toolkit is currently being developed as a pilot resource and will evolve based on users' needs and feedback. A core component of the toolkit is a branded slide deck that can serve as a template for presentations about EOP, along with several pre-filled slides describing the EOP initiative as a whole, the EOP Framework, and the EOP Network. The toolkit also contains materials including the EOP Framework, two framework companion teaching guides, a literature review conducted for the EOP initiative, case studies highlighting how the framework has been used to date, branding guidelines and logos, an EOP overview video, and template social media posts that can be used to promote presentations, events, convenings, the network, resources, among others (**Figure 3** & **Figure 4**).. Also in development are a one-pager of relevant talking points for the EOP initiative, lists of conferences that may be valuable opportunities to share about EOP messaging, etc. Future toolkit components may include workshop guides to share the EOP Framework, templates for developing EOP-related sessions at conferences, and a repository of members' EOP-related presentations.

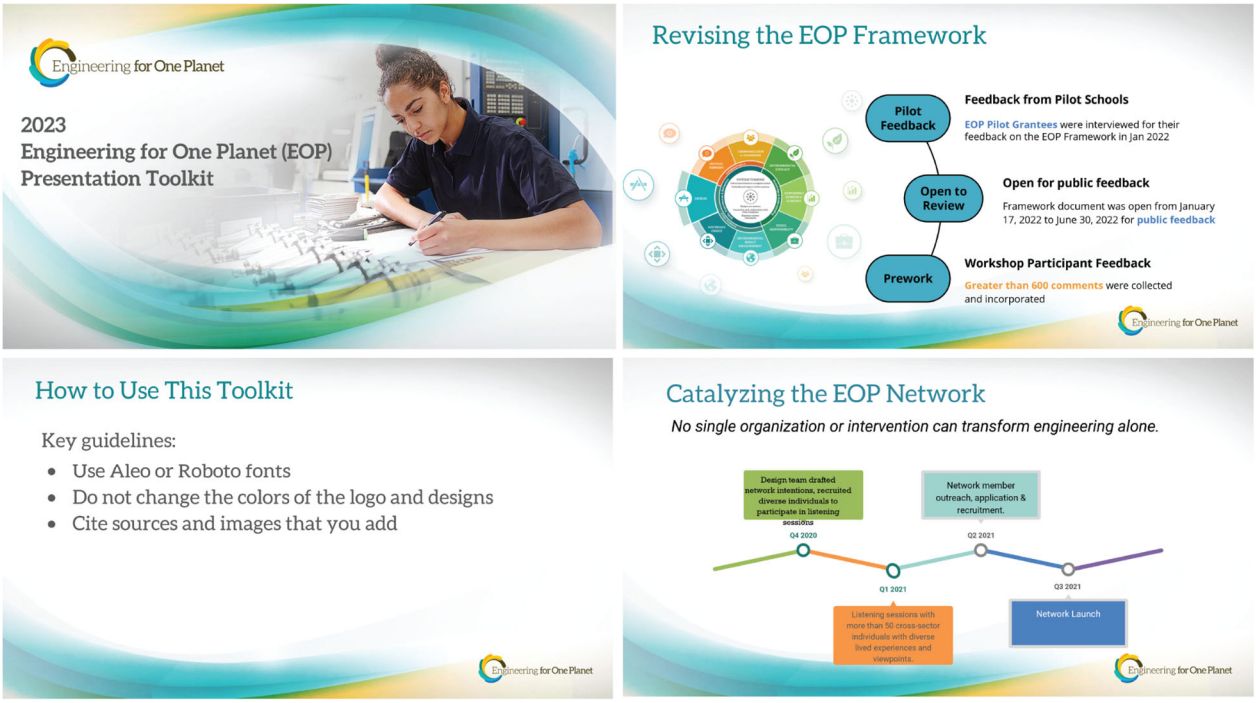

Figure 3. *EOP Toolkit includes multiple items for various dissemination methods. This EOP Toolkit slide deck. This slide deck includes information for presenters of the slide deck as well as additional items for those who would present the work at any of the dissemination scenarios and case studies presented later in the paper.*

The EOP Toolkit is intended to be accessible to all network members and, upon request, with guidance for non-network members. EOP Network members can self-select to serve as champions of the toolkit, developing expertise in its contents to aid non-network members in its

implementation. All network members interested in developing an outreach opportunity for the EOP vision have access to the toolkit through a shared online folder and are asked to complete a brief online form so that the EOP Network can track outreach events information and attendee numbers, etc. For individuals outside the network, an email request to use the toolkit may be sent to the manager@engineeringforoneplanet.org. The EOP Network manager will respond to the request and put the requester in touch with a toolkit champion who will provide access to the materials and an opportunity to discuss and brainstorm ideas for the outreach opportunity. Additionally, a resource pack will be made accessible on the EOP website to support any outreach opportunities and framework sharing and implementation efforts.

The EOP Toolkit can also be helpful when there are opportunities for broad dissemination, such as coordinated campaigns on social media for upcoming events featuring EOP.

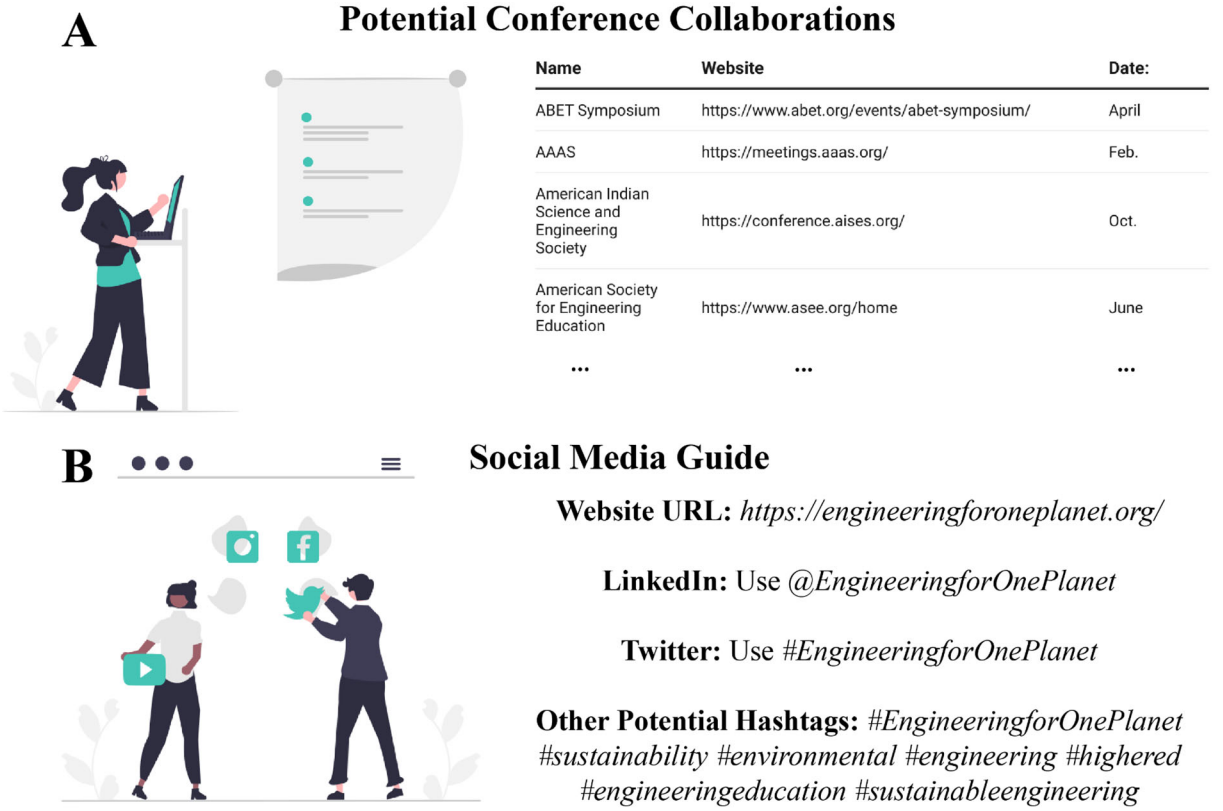

Figure 4. *EOP Toolkit includes multiple items for various dissemination methods, in addition to the Slide Deck in Figure 3. It also includes A) Various conferences where EOP Network members plan to disseminate the EOP Framework to other engineering education communities. B) Social media example postings for EOP dissemination. Illustrations were used from Undraw.co and visualization done in Datawrapper.de.*

Evaluating the Toolkit

As a pilot program, the EOP Toolkit will benefit from user feedback. A brief survey will be developed for toolkit users, and toolkit champions will be encouraged to reach back out to users after their outreach event to solicit feedback. With permission from the user, the user's

presentation may also be stored in a repository of materials that other users can adapt and share its benefits.

EOP Network members can use the EOP Toolkit to disseminate the EOP Framework and other EOP materials. This information can be disseminated in many different modes, both in formal university spaces, professional associations, and non-academic-based spaces (e.g., conferences, workshops, etc.). In the following subsections, we share outtakes from case studies written by EOP Network members from across sectors, including faculty members at higher education institutions, to those involved with nonprofits.

In the last two years, faculty have used the EOP Framework to create or modify dozens, possibly hundreds, of diverse design and engineering courses in the United States and globally. A few of these change efforts have been funded and therefore tracked and shared by The Lemelson Foundation, but many have been advanced by faculty members working independently. The EOP website includes case studies, examples, lessons learned, and tools to help faculty interested in adapting and adopting curricular change practices. While curricular change is always challenging, lessons learned are shedding light on approaches that yield success [21].

Internal or University-Based Dissemination Scenario

Case study 1: Using the EOP Framework in an existing course and undergraduate sustainability minor.

Implementation: Jorge Loyo of Rice University and the NSF Center for Nanotechnology-Enabled Water Treatment (NEWT) teaches an undergraduate course at Rice University called *Sustainable Water Purification for the Developing World* (CEVE 314), a project-based course on sustainable strategies for safe water supply in low-income and developing regions. Originally, the course focused mainly on the engineering design elements of building a point-of-use drinking water treatment device for a household in such a region. In addition, the course also discusses factors beyond technology (e.g., social, economic, political) that influence the adoption of a new technology/purification method and how, in most cases, the main barrier to safe drinking water access is not the lack of technology, but one of these factors.

After teaching this course several times, Loyo became interested in incorporating more systems thinking concepts into the course and came across the EOP Framework online. Reading through the student learning outcomes outlined in the framework, he realized that he was already addressing many of them. However, having a framework allowed him to have a more coherent and better-organized structure of the course's learning goals.

Lessons Learned: As with any significant course restructuring, the main challenge in redesigning this course was time. The EOP Framework facilitated the work by providing a blueprint allowing Loyo to gradually change the course. He started the process by mapping learning outcomes already covered in the course, identifying outcomes that need to be introduced from the framework, and planning activities to achieve these outcomes. Another important challenge was to learn new sustainability-focused concepts that needed to be incorporated into the course. For example, Loyo plans to make systems thinking as much of a focus of the course as engineering design currently is, but identifying specific learning outcomes and their

corresponding activities represented a greater learning curve than he initially expected. In this instance, however, the EOP Framework has also served as a guideline to modify the course, greatly facilitating the work.

Currently, CEVE 314 students are not explicitly aware of the EOP Framework per se, only the individual learning outcomes. Still, Loyo recently started using the framework to advise students of Rice's Energy and Water Sustainability undergraduate minor. The framework serves as a blueprint to plan their elective courses, selecting those that address the learning outcomes they still need to acquire.

Case study 2: Using the EOP Framework in a new course cross-listed between an undergraduate engineering program and a graduate design program.

Implementation: Dustyn Roberts of the University of Pennsylvania Mechanical Engineering & Applied Mechanics Department co-developed then co-taught a course called *How To Make Things* with Taylor Caputo after being awarded a VentureWell Course and Program Grant in 2021. The proposal focused on the development of the course, and sustainability was a required element. They used the EOP Framework and some exercises on VentureWell's Tools for Design and Sustainability website [35] to integrate sustainability concepts methodically throughout the semester-long course. Projects and lesson plans included aspects of the design, materials selection, and environmental impact assessment sections of the EOP Framework.

Lessons Learned: Unlike implementation in existing classes where the EOP Framework material might displace or change content that has been part of the class for semesters (or decades), implementing the EOP Framework in a new class is much more straightforward. In backward course design [36], a new course is designed by first identifying the desired results, then determining acceptable evidence, and finally by planning learning experiences and instruction. When the EOP Framework is used as a tool to identify the desired results and learning outcomes, then learning experiences and instruction can be designed such that students can demonstrate evidence of having achieved the learning outcomes.

A project was developed as part of the class that leveraged both the Design and Materials Selection topic areas of the EOP Framework. The students had to integrate aspects of sustainability into an original cast product. Examples include (**Figure 5A**) cardboard panel connectors cast with plastic along with shredded cardboard and (**Figure 5B**) knitting looms made with plastic along with a shredded canvas. In both cases, discarded material (cardboard or canvas) was used to displace up to 40% of the volume of plastic that would have otherwise been needed to cast the product.

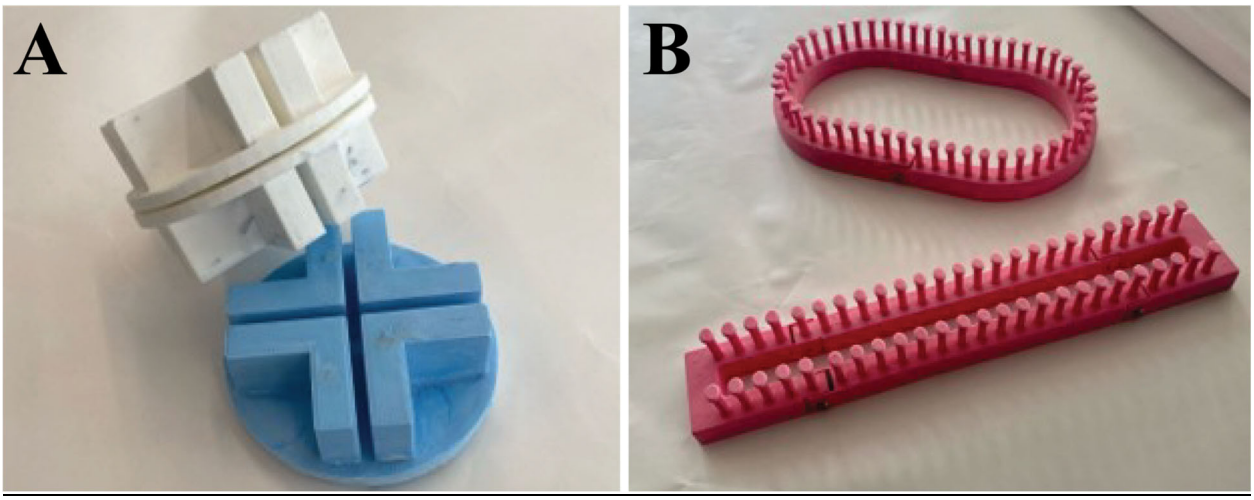

Figure 5*: A) cardboard panel connectors cast with plastic along with shredded cardboard and B) knitting looms made with plastic along with a shredded canvas.*

However, it can be challenging to design learning experiences that address the EOP Framework outcomes at the appropriate Bloom's Taxonomy level and fit within a semester (or trimester or quarter) schedule and everything else that should be covered. For this reason, instructors should start by prioritizing the most important outcomes from the EOP Framework and focus on quality over quantity within a single course. Additionally, many of the outcomes relate to or overlap, so instructors should reference the EOP Framework: Comprehensive Guide to Teaching Core Outcomes to choose outcomes that maximize student exposure to the nine different topic areas of the EOP Framework [31].

Case study 3: Using the EOP Framework in a project-based course, senior design team, and undergraduate student competitions.

Implementation: Andrew Schulz of Max Planck Institute of Intelligent Systems, formerly at Georgia Institute of Technology School of Mechanical Engineering, developed and taught a course centering on conservation technology at Georgia Tech, helping engineers work on sustainability solutions for preventing the sixth mass extinction [1], [4]. Systems Thinking is the central topic in the EOP Framework which is critical in a senior design project. Using the EOP Framework in early reports with the students, we worked on integrating connections to disciplines outside of the traditions of mechanical engineering. Additionally, at Georgia Tech, we are connecting students in the classroom with the tools of education of green engineering. We connect these students with green engineering through Conservation Tools and Tool Generation in the form of computer vision, mechanical design, and more [37], [38]. This course at Georgia Tech has become a student organization, and the EOP Framework has helped form the objectives and visions of the student organization.

When designing a student organization, there is usually an organizational purpose, organization objectives, bylaws, and constitution. Using the EOP Framework with a leadership team, we constructed our objectives and purpose based on the foundational objectives of the EOP initiative and its overlap with our organization's goal of Conservation Technology. Additionally, the

student organization looked to other student organizations, including Engineers Without Borders (EWB) and the Society of Women Engineers (SWE), to create more formalized documents of bylaws and constitutions.

Lessons Learned: Students often focus on senior design and the deliverables that are graded and assessed. In this case, the EOP Framework implemented into their project was not a graded portion. In future senior design classes, it would be essential to add the framework as a graded assessment category. It became clear that it was not a priority for students as several other graded deliverables needed to be accomplished, and the framework fell by the wayside.

Case Study 4: Using the backward design method mapped to the EOP Framework for an introductory engineering seminar course.

Implementation: Nelson Granda of West Carolina University School of Engineering and Technology used the EOP Framework —mapped to the backward design method— to develop a new undergraduate first-year seminar course focusing on basic sustainability knowledge. The backward design method was first presented by Wiggins and McTighe in 2005 [39] and later revised by the Indiana Center of Innovative Teaching and Learning. This method is effective for implementing new content or revising courses and broader curricula in any discipline. The backward design method begins by asking two questions: *1) What do I want my students to be able to think and do by the end of this course? 2) How will my students be different by the end of the course?*

Lessons Learned: Granda found the EOP Framework to be flexible to implement. Faculty members can choose which student learning outcome(s) their course will address. Using the guidance found in the integration flowchart in **Figure 6,** educators can take advantage of the backward course design method, the EOP Framework, and other EOP resources to infuse sustainability skills and knowledge in current courses or can design a completely new course, as is demonstrated by **Table 1**.

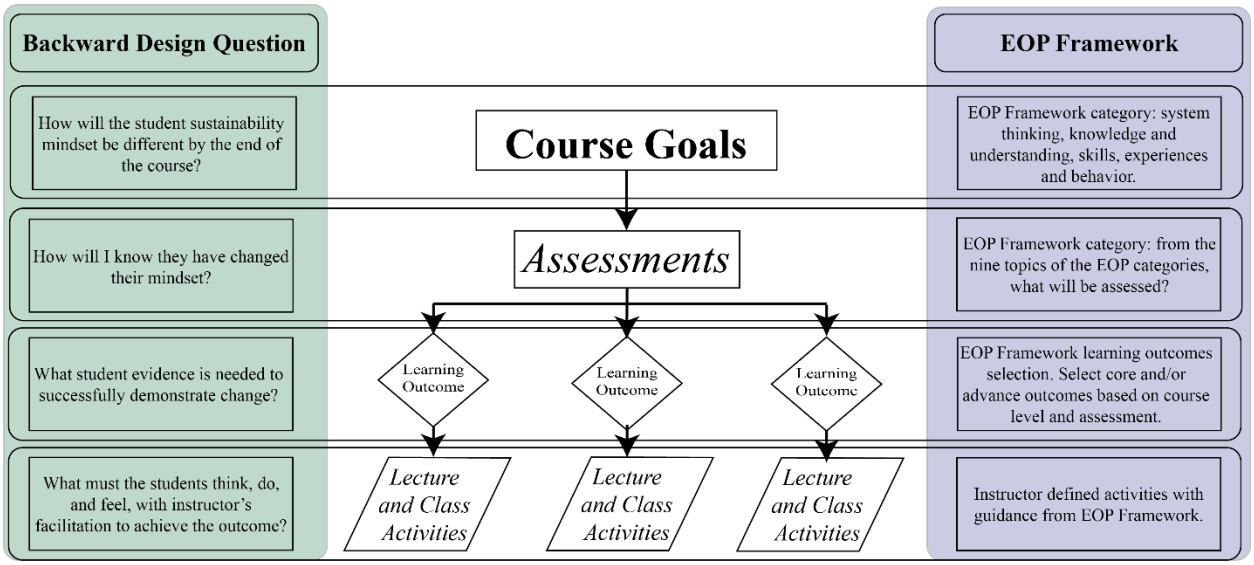

Figure 6*: EOP Framework and backward course design integration guidance for Case Study 4.*

Table 1: Leveraging Backwards Design & the EOP Framework Categories. *Backward Design Method mapped to the student learning outcomes, as an example of integrating the EOP Framework into an introductory seminar engineering course.*

Level	Guided Question	Systems Thinking	Knowledge & Understanding	Skills, Experiences, and Behaviors
Course Goals	What will the students learn to be different?	Students shall recognize the world as a complex system of interconnected environmental, economic, and social factors.	Students shall understand and recognize basic sustainability-focused theories and concepts.	Students shall use critical thinking, communication, and teamwork related to basic sustainability skills.
Global Assessments	How will I know if the students have changed as expected?	Students bring to discussion topics of local, national, and global impact related to sustainability.	Students use correct environmental literacy, social responsibility, and responsible business and economy concepts.	Students research and present local, regional, or global issues of interest to them. When students states their opinion and recognizes others respectfully.
Learning Outcomes (LO)	What quantitative and qualitative evidence is needed for the students to demonstrate their changes?	CORE LO 2: Identify dynamic impacts between and among different parts of the system (i.e., social, environmental, and economic considerations).	CORE LO 2 Environmental Literacy: Explain the whole life-cycle and closed-loop systems thinking related to their work's impact (e.g., understanding life-cycle burdens of design alternatives). CORE LO 1 Social Responsibility: Identify the United Nations Sustainable Development Goals. Advanced CORE LO 2& Responsible Business & Economy: Explain sustainable use and disposal practices to consumers & locate funding sources for public infrastructure.	CORE LO 5 Critical Thinking: Examine norms, biases, and values that underlie one's behaviors (i.e., normative thinking and cognitive dissonance. ADVANCED LO 2 Communication & Teamwork: Develop and maintain relationships through interpersonal skills, identify and relate to different perspectives
Course Activities	What must the students think, do, and feel to achieve the outcomes with the instructor's facilitation?	Weekly sustainability-related news discussions. Students reflect on local, state, national, and global news, looking for interconnects of social, environmental, and economic issues. Reflection Paper, Small-Group Discussions	Learn the basics of Life-Cycle Assessment (LCA) methodology. Read LCA cases and present a summary of journal articles. Learn about the SDGs and the UN 2030 Agenda. Learn and understand how the recycling system on campus works. Learn and apply to opportunities for funding offered by the university to implement sustainability initiatives.	Research bases for climate change proponents and deniers, work in teams, and debate each side—individual and group presentations. In the final projects, research one SDG and present it to the classroom showing a local or national effort supporting the SDG presented.

External or Non-University-Based Modes

Case Study 5: Sharing the EOP Framework at conferences.

Implementation: Cindy Anderson of Alula Consulting, an independent sustainability-focused consulting firm, has shared the EOP Framework at numerous professional conferences through plenaries, lectures, and workshops, as well as through webinars and focus groups. Key recent conferences include the ABET Symposium 2023, Annual Colloquium on International Engineering Education (ACIEE) 2022, the Association of Advancement of Sustainability in Higher Education (AASHE) 2019, Engineering Change Lab USA Summit 2020 [40], Deshpande Symposium 2020, Green Chemistry and Engineering 2020, KEEN National Conference 2020, National Academy of Inventors (NAI) 2020 [41]. Others have also shared about the EOP Framework at conferences, including ASEE 2021 [23], ASEE 2022 [25], and VentureWell's OPEN 2021 [42].

Lessons Learned: During most presentations, there are two common questions raised by audience members: 1) The EOP Framework is excellent, but *how* do I implement the framework? 2) Where can I find sustainability-focused resources and tools in my classrooms? We now have two "how to" EOP Framework companion teaching guides that support the implementation of the EOP Framework (**Figure 2B-C**, [31], [32]), which link to freely available online teaching materials and resources to address these two commonly asked questions.

Case study 6: Using the EOP Framework in a Non-profit setting.

Implementation: Supraja Kumar of the Smart Surfaces Coalition served as a project manager and volunteer with EWB-USA, working on environmental engineering projects in developing regions during and following her undergraduate program in mechanical engineering. Throughout Kumar's experience with EWB-USA, sustainability was a crucial part of successful implementations and lasting impact. One of her projects was focused on developing a clean and reliable water source for a village in western Kenya while collaborating with local partners, engineering contractors, and NGOs. While she was unfamiliar with the EOP Framework at the time, the topical areas of Systems Thinking, Social Responsibility, and Environmental Literacy, along with core competency in Design, Materials Selection, and Critical Thinking, were all directly applicable to reaching the goals of this community-led water project.

Lessons Learned: When implementing engineering principles in fieldwork, especially in a developmental context, integrating high-level technical core competencies with community needs and culture is critical. Some key challenges, in this case, were tying together elements of communication and environmental literacy with design principles, as the team had not previously worked in this village. However, after taking time to communicate with community leaders and better understand their needs effectively, it became very straightforward to do so. The EOP Framework serves as a natural guideline for non-profit engineering endeavors, making it easy to incorporate these principles in the planning process and better define the path to desired outcomes.

Applications to Environmental Justice and Diversity, Equity, and Inclusion.

While these different case studies demonstrate use cases to implement the EOP Framework, it is essential to understand that in disseminating knowledge about sustainability and the environment, we must also consider the historical influences and cultural impacts of this framework, including the applications to the field of environmental justice (EJ) as well as diversity, equity, and inclusion (DEI).

If contemporary engineers consider climate change a "carbon problem," how do they frame sustainability [43]? An engineering education paradigm shift is required to change how engineers frame and solve challenges to protect the planet's health and all species. Engineers tend to technologize their way out of problems, often without considering their solutions' life-cycle assessment or societal implications. Others have already proposed changing engineering education to be more holistic, so engineers are also taught to evaluate problems and solutions socially and ecologically [44]. This alternative prepares engineers to gather non-technical knowledge from those they are trying to help, whether in communities or groups of individuals with similar needs. Since engineering is a profession centered around ethics and professional duties, engineers need to be appropriately trained in non-technical knowledge to fulfill their responsibilities to society.

Service learning helps engineering students engage and retain knowledge [45] while increasing social responsibility [46]. However, a mismatch exists [47] between being a capable engineer and possessing cultural and environmental awareness related to engineering applications. Furthermore, there is a negative association between community group experience and White-identifying engineers and income [30],[48]. It is important to note that female students are more likely to study engineering to have a positive impact on society [49]. Successful community-type collaborations, which often focus on cultural and environmental challenges, require engineers to have experience in such collaboration styles to gain the necessary knowledge, skills, and cultural awareness. Time availability, funds, rapport, and knowledge deficit are the main barriers to collaborating with community groups. The same study found a desire "that institutions help augment knowledge and educate participants on community issues" [48]. Unfortunately, a STEM education can diminish one's community concerns [49], [50]. To increase the attraction and retention of minoritized engineering students, social responsibility, sustainability training, and community collaboration must be further incorporated into engineering education.

Conclusion

The intention of this newly launched and continuously evolving EOP Toolkit is to enable broad dissemination of vetted tools to help engineering faculty members teach sustainability using resources from the EOP initiative and to serve as a mechanism to engage a diversity of stakeholders to use their voices, experience, and connections to share widely about the need for national curricular change in engineering education to foster the integration of sustainability-focused learning outcomes into engineering courses and programs. This is particularly important for graduating engineers at this crucial time when we collectively face a convergence of national- and global-scale planetary crises that professional engineers will directly and indirectly impact. The authors encourage EOP Network members and other stakeholders from the engineering

education community to leverage the EOP Toolkit to disseminate and utilize the EOP Framework and associated teaching materials to foster the development of sustainability-focused engineers.

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References:

[1] A. Schulz *et al.*, "A Foundational Design Experience in Conservation Technology: A Multi-Disciplinary Approach to Meeting Sustainable Development Goals," in *American Society of Engineering Education*, ASEE Conferences, Jun. 2022.

[2] L. O. Gostin and E. A. Friedman, "The Sustainable Development Goals: One-Health in the World's Development Agenda," *JAMA*, vol. 314, no. 24, pp. 2621–2622, Dec. 2015, doi: 10.1001/jama.2015.16281.

[3] R. E. Gropp, "NSF: Time for Big Ideas," *BioScience*, vol. 66, no. 11, p. 920, Nov. 2016, doi: 10.1093/biosci/biw125.

[4] A. Schulz, C. Greiner, B. Seleb, C. Shriver, D. L. Hu, and R. Moore, "Towards the UN's Sustainable Development Goals (SDGs): Conservation Technology for Design Teaching & Learning," in *American Society of Engineering Education*, Mar. 2022.

[5] W. Leal Filho *et al.*, "Sustainable Development Goals and sustainability teaching at universities: Falling behind or getting ahead of the pack?," *J. Clean. Prod.*, vol. 232, pp. 285–294, Sep. 2019, doi: 10.1016/j.jclepro.2019.05.309.

[6] J. R. Mihelcic *et al.*, "Sustainability Science and Engineering: The Emergence of a New Metadiscipline," *Environ. Sci. Technol.*, vol. 37, no. 23, pp. 5314–5324, Dec. 2003, doi: 10.1021/es034605h.

[7] R. Lozano *et al.*, "A review of commitment and implementation of sustainable development in higher education: results from a worldwide survey," *J. Clean. Prod.*, vol. 108, pp. 1–18, Dec. 2015, doi: 10.1016/j.jclepro.2014.09.048.

[8] B. M. Reynante, "Engineering for One Planet Literature Review Report," 2022.

[9] S. Anastasiadis *et al.*, "Teaching sustainability: complexity and compromises," *J. Appl. Res. High. Educ.*, vol. 13, no. 1, pp. 272–286, Jan. 2020, doi: 10.1108/JARHE-02-2020-0029.

[10] The Lemelson Foundation, "Resource Constraints Demand Smarter Approaches to Invention," *Invention Notebook*, Feb. 10, 2020. https://medium.com/invention-notebook/resource-constraints-demand-smarter-approaches-to-invention-82706af7468e (accessed Nov. 17, 2022).

[11] The Lemelson Foundation, "The Surge in Climate Action Requires a Surge in Green Talent, but How on Earth to Fill the Gap?," *Invention Notebook*, Apr. 13, 2022. https://medium.com/invention-notebook/the-surge-in-climate-action-requires-a-surge-in-green-talent-but-how-on-earth-to-fill-the-gap-4bfc97bd34a5 (accessed Nov. 17, 2022).

[12] ASEE, "Engineering and Engineering Technology by the Numbers 2021," American Society of Engineering Education, 2021.

[13] LinkedIn Economic Graph, "Global Green Skills Report," LinkedIn, 2022.

[14] M. K. M. Lane *et al.*, "Green chemistry as just chemistry," *Nat. Sustain.*, pp. 1–11, Jan. 2023, doi: 10.1038/s41893-022-01050-z.

[15] E. O. McGee and D. O. Stovall, *Black, Brown, Bruised: How Racialized STEM Education Stifles Innovation*. Cambridge, Massachusetts: Harvard Education Press, 2020.

[16] M. Smith, "Impacts of Environmentally Responsible Engineering (ERE) Concepts in a New FirstYear Engineering Program," 2022.

[17] D. Schlosberg and L. B. Collins, "From environmental to climate justice: climate change and the discourse of environmental justice," *WIREs Clim. Change*, vol. 5, no. 3, pp. 359–374, 2014, doi: 10.1002/wcc.275.

[18] ABET, "Criteria for Accrediting Engineering Programs, 2019 – 2020 | ABET," 2019.

Accessed: Feb. 14, 2023. [Online]. Available: https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2019-2020/
[19] The Lemelson Foundation, "Inventing for One Planet," *Invention Notebook*, Feb. 10, 2020. https://medium.com/invention-notebook/inventing-for-one-planet-f9b14c60adeb (accessed Nov. 17, 2022).
[20] The Lemelson Foundation, "Engineering for One Planet Framework," 2022.
[21] The Lemelson Foundation, "How to Integrate Sustainability Into College Engineering Curricula," *Invention Notebook*, Dec. 14, 2022. https://medium.com/invention-notebook/how-to-integrate-sustainability-into-college-engineering-curricula-8930cc99b3f5 (accessed Nov. 17, 2022).
[22] C. Boone and K. C. Seto, "Green jobs are booming, but too few employees have sustainability skills to fill them – here are 4 ways to close the gap," The Conversation, 2023. Accessed: Feb. 14, 2023. [Online]. Available: https://theconversation.com/amp/green-jobs-are-booming-but-too-few-employees-have-sustainability-skills-to-fill-them-here-are-4-ways-to-close-the-gap-193953
[23] J. Larson, W. M. Barnard, A. R. Carberry, and D. Karwat, "Student Recognition, Use, and Understanding of Engineering for One Planet Competencies and Outcomes in Project-based Learning," presented at the 2021 ASEE Virtual Annual Conference Content Access, Jul. 2021. Accessed: Jan. 12, 2023. [Online]. Available: https://peer.asee.org/student-recognition-use-and-understanding-of-engineering-for-one-planet-competencies-and-outcomes-in-project-based-learning
[24] J. Taylor and R. Oulton, "Engineering for People and Planet: A Multidisciplinary Course Proposal for Engineers on the UN Sustainable Development Goals," presented at the 2020 ASEE Virtual Annual Conference Content Access, Jun. 2020. Accessed: Jan. 12, 2023. [Online]. Available: https://peer.asee.org/engineering-for-people-and-planet-a-multidisciplinary-course-proposal-for-engineers-on-the-un-sustainable-development-goals
[25] V. Smith, S. Shrestha, A. Welker, and K. Sample-Lord, "Including Principles of Sustainability in Design by Implementing the Engineering for One Planet Framework," presented at the 2022 ASEE Annual Conference & Exposition, Aug. 2022. Accessed: Jan. 12, 2023. [Online]. Available: https://peer.asee.org/including-principles-of-sustainability-in-design-by-implementing-the-engineering-for-one-planet-framework
[26] The Lemelson Foundation, J. Faludi, and C. Gilbert, "Teaching Environmentally Responsible Inventing: Higher Education Environmental Landscape Research and Analysis, Phase I," 2018.
[27] J. Faludi and C. Gilbert, "Best practices for teaching green invention: Interviews on design, engineering, and business education," *J. Clean. Prod.*, vol. 234, pp. 1246–1261, Oct. 2019, doi: 10.1016/j.jclepro.2019.06.246.
[28] The Lemelson Foundation and VentureWell, "Engineering for One Planet: Launching a Collaborative Effort to Proliferate Principles of Environmentally Responsible Engineering in Higher Education Institute."
[29] The Lemelson Foundation, "EOP Framework Collaborators and Contributors | Engineering For One Planet," Nov. 08, 2022. https://engineeringforoneplanet.org/transforming-curricula/how-to-transform-curricula/contributors/ (accessed Nov. 17, 2022).
[30] P. Armstrong, "Bloom's Taxonomy," Vanderbilt University Center for Teaching.

[Online]. Available: https://cft.vanderbilt.edu/guides-sub-pages/blooms-taxonomy/
[31] The Lemelson Foundation, "Engineering for One Planet Framework: Comprehensive Guide to Teaching Core Learning Outcomes," 2023.
[32] The Lemelson Foundation, "Engineering for One Planet Framework: Quickstart Activity Guide," 2023.
[33] The Lemelson Foundation, "ASEE Awards 13 Grants to Support Sustainability in Engineering Education," *The Lemelson Foundation*, Jul. 12, 2022. https://www.lemelson.org/asee-awards-13-grants-to-support-sustainability-in-engineering-education/ (accessed Nov. 17, 2022).
[34] AAAS, "STPF Virtual Outreach Toolkit | S&T Policy FellowsCentral," 2023. Accessed: Feb. 14, 2023. [Online]. Available: https://www.aaaspolicyfellowships.org/stay-involved/stpf-virtual-outreach-toolkit
[35] VentureWell, "Tools for Design and Sustainability," 2022. Accessed: Feb. 14, 2023. [Online]. Available: https://venturewell.org/tools_for_design/introduction/
[36] N. Graff, "'An Effective and Agonizing Way to Learn': Backwards Design and New Teachers' Preparation for Planning Curriculum," *Teach. Educ. Q.*, vol. 38, no. 3, pp. 151–168, 2011.
[37] A. Schulz *et al.*, "Conservation Tools: The Next Generation of Engineering--Biology Collaborations." arXiv, Jan. 03, 2023. doi: 10.48550/arXiv.2301.01103.
[38] A. Schulz, S. Stathatos, C. Shriver, and R. Moore, "Utilizing Online and Open-Source Machine Learning Toolkits to Leverage the Future of Sustainable Engineering." arXiv, Apr. 21, 2023. doi: 10.48550/arXiv.2304.11175.
[39] G. Wiggins and J. McTighe, *Understanding By Design*, Expanded edition. Alexandria, VA: Association for Supervision & Curriculum Development, 2005.
[40] Engineering Change Lab (ECL) USA, "Engineering Ideas Institute, Session 2: Leadership for Environmentally Responsible Engineering," 2020.
[41] *NAI ScholarShare: An Educational Tool for a Sustainable Future - A Framework for ERE*, (Jun. 16, 2020). Accessed: Jan. 28, 2023. [Online Video]. Available: https://www.youtube.com/watch?v=yMbmt2XiAhk
[42] *Engineering for One Planet (Presented at OPEN Conference, March 19, 2021)*, (Apr. 12, 2021). Accessed: Jan. 28, 2023. [Online Video]. Available: https://www.youtube.com/watch?v=oghAmjLtHx0
[43] D. M. Karwat, "On the Combustion Chemistry of Biofuels and The Activist Engineer," 2012.
[44] D. M. A. Karwat, W. E. Eagle, M. S. Wooldridge, and T. E. Princen, "Activist Engineering: Changing Engineering Practice By Deploying Praxis," *Sci. Eng. Ethics*, vol. 21, no. 1, pp. 227–239, Feb. 2014, doi: 10.1007/s11948-014-9525-0.
[45] C. Scherrer and J. Sharpe, "Service Learning Versus Traditional Project-Based Learning: A Comparison Study in a First Year Industrial and Systems Engineering Course," *Int. J. Serv. Learn. Eng. Humanit. Eng. Soc. Entrep.*, vol. 15, no. 1, Art. no. 1, Apr. 2020, doi: 10.24908/ijsle.v15i1.13569.
[46] A. Bielefeldt and N. Canney, "Social Responsibility Attitudes of First-Year Engineering Students and the Impact of Courses," in *2014 ASEE Annual Conference & Exposition Proceedings*, Indianapolis, Indiana: ASEE Conferences, Jun. 2014, p. 24.1089.1-24.1089.16. doi: 10.18260/1-2--23022.
[47] P. Bourdieu, *Sketch for a Self-Analysis*. Chicago, IL: University of Chicago Press, 2008.

Accessed: Jan. 26, 2023. [Online]. Available: https://press.uchicago.edu/ucp/books/book/chicago/S/bo5896652.html

[48] J. L. Boucher, A. M. Levenda, J. Morales-Guerrero, M. M. Macias, and D. M. A. Karwat, "Establishing a Field of Collaboration for Engineers, Scientists, and Community Groups: Incentives, Barriers, and Potential," *Earths Future*, vol. 8, no. 10, p. e2020EF001624, 2020, doi: 10.1029/2020EF001624.

[49] N. E. Canney and A. R. Bielefeldt, "Gender Differences in the Social Responsibility Attitudes of Engineering Students and How They Change Over Time," *J. Women Minor. Sci. Eng.*, vol. 21, no. 3, 2015, doi: 10.1615/JWomenMinorScienEng.2015011109.

[50] E. A. Cech, "Culture of Disengagement in Engineering Education?," *Sci. Technol. Hum. Values*, vol. 39, no. 1, pp. 42–72, Jan. 2014, doi: 10.1177/0162243913504305.