Integrating Sustainability into Engineering Education: Building a Pathway to Scale

Victoria Matthew[1], Cynthia D. Anderson[2], Cindy Cooper[3], Surbhi Lipkin-Moore[4]
VentureWell[1], Alula Consulting[2], The Lemelson Foundation[3], Amplify Evaluation[4]

Abstract

Sustainability, including environmental and social sustainability, has been identified across all sectors, from government to industry to academia, as a critical area for action. Sustainability goals and actions, by necessity, require input from many fields, but engineers play a potentially outsized role due to the structures and products they build, and the associated choices they make. 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. Much has been achieved to date by the EOP initiative, through a process of multi-stakeholder engagement, in both understanding and piloting solutions to realize the EOP vision. However, in order to achieve the far reaching systemic changes desired, a roadmap for a Collective Impact-informed, cross-sector, collaborative initiative was developed. This roadmap leverages the approaches yielded from the recent National Science Foundation (NSF)-funded EOP Scaling for Impact Workshop, the lessons learned and results achieved from the initiative to date, and key considerations drawn from a Collective Impact approach that centers equity. This roadmap calls for stakeholders—including academia, industry, accrediting and professional organizations, community organizations, non-profits, funders, and those communities most impacted by the negative impacts of environmental and social sustainability challenges— to move beyond singular programmatic interventions, and instead work to collaboratively understand and construct coordinated solutions, to integrating sustainability into engineering education and the engineering profession. The roadmap's call to action invites collaborators to join this initiative and engage with the roadmap as a starting point for their work together; the roadmap provides immediate action steps, and invites collaborators to further shape the roadmap into a collective, achievable plan for systems change, that they, their institutions/organizations, and other cross-sector collaborators can embrace. For systems change is never complete and the solutions not finite; it is only through ongoing, collective action that we can fully understand, and learn how to address the lack of sustainability in engineering as the complex, social problem it is.

Keywords: collective impact, roadmap, sustainability, engineering education

Introduction

Converging national- and global-scale crises —including climate change, air and water pollution, access to education, and poverty— are leading stakeholders across sectors to demand solutions to protect and regenerate the environment, ensure environmental justice, and advance human health, welfare and prosperity.[1,2] These crises we collectively face also disproportionately impact marginalized communities due to longstanding systemic injustice and discrimination.[3,4] Maintaining the status quo—in industry, education, government, or otherwise—will not suffice if we are to advance the economic, social, and environmental wellbeing of all people today and in the future.

The Need to Imbue Sustainability Across Engineering

Governments, governmental agencies, non-profits, accreditation bodies, and large industrial firms are increasingly prioritizing sustainability as a means to advance leading edge solutions to complex crises, and recognize the importance of sustainability to future national competitiveness and growth.[1,2,5–7] Educators and students are similarly rallying for changes to better address and forestall environmental and social challenges through sustainability. Engineers are poised to help create this sea change because they impact nearly every industry and everything human-made. Through their design and execution decisions, engineers directly and indirectly influence the creation of everything from consumer goods to hardware and software products to buildings and modes of transportation, thus their decisions make positive or negative impacts on the planet and its people, today and into the future.[5] For engineers to contribute in a positive and even restorative way, they must be literate in the tools, concepts, and principles of sustainability, and trained, through their education, to integrate these skill sets and mindsets into their practice, whether they become professional engineers or decide to pursue roles as policymakers, educators, researchers, inventors, entrepreneurs, etc. Yet, due to numerous challenges, including time and resource constraints, most academic institutions are not yet able to ensure that their graduates are equipped with the knowledge and competencies needed to build and become leaders of a sustainable and just future, despite student and industry demand for it.[5,6]

A recent study with nearly 7000 student respondents from around the world found that 90% of students were concerned about the effects of climate change, and felt that sustainable development should be universally taught in higher education yet only 26% of respondents felt their coursework was covering these issues in depth.[7] Despite sustainability becoming a more popular topic in engineering education programs in recent years, a few key hurdles remain that are preventing or slowing the pace of curricular change, to more fully integrate sustainability across engineering courses and programs.[8] Barriers include: 1) belief that there is no space to integrate sustainability into already jam-packed engineering courses, 2) lack of confidence or lack of familiarity with how to bring sustainability into the classroom, and 3) trust one-off modules, seminars, or a distinct specialty, will suffice for teaching sustainability principles rather than the need for integration throughout engineering courses, programs, and departments is sufficient. As a result, a majority of engineering students graduate without adequate training in how to solve problems, communicate and collaborate across disciplines, and make critical design decisions (e.g. related to design, materials sourcing, manufacturing, distribution, disposal, etc.), all of which are fundamental to preparing engineers to succeed in their profession and meet

today's sustainability-related challenges by developing cutting-edge technological solutions that are not only more sustainable but net zero and even regenerative.

Integral to this work is fundamentally and systemically changing who will want to become an engineer, graduate as a trained engineer, and pursue a career as a professional engineer; Black, Hispanic, American Indian/Alaska Native, and Native Hawaiian/Pacific Islander students are still markedly underrepresented within engineering education at the undergraduate and graduate levels.[9] Additionally, it is imperative that the marginalized communities —who bear much of the burden and harm due to human-caused impacts on the planet— are able to and encouraged to share their perspectives, knowledge, and lived experiences.[10,11] Their leadership and contributions must be sought, respected, and integrated into future technological and political solutions.

Engineering for One Planet (EOP), an initiative catalyzed by The Lemelson Foundation and VentureWell, seeks to remove the barriers to integrating sustainability into the engineering curriculum while prioritizing Diversity, Equity, Inclusion and Justice principles. The goal is to transform engineering education to ensure that all future engineers across all disciplines are equipped to design, build, and create in environmentally and socially sustainable ways. Critical to this process is ensuring historically minoritized and marginalized groups become engineers and/or engage in the prioritization and creation of solutions. This paper examines the work of EOP to date, and approaches needed to accelerate the desired fundamental and systemic changes to engineering education and the engineering profession.

Using a Collective Impact Approach

The kinds of systemic changes needed to ensure sustainability is a core tenet for all engineers and the engineering profession, cannot be achieved by an individual organization alone, or even an individual sector.[12] Rather such change requires a coordinated effort from across the different sectors that engage with, are impacted by, and have the potential to effect these systems. This type of networked approach is referred to as Collective Impact (CI). By adopting this approach, stakeholders are positioned to work together to fully understand the complex landscape, to innovate and learn together, and to contribute their expertise, experiences, and sphere of influence and authority, in a coordinated way, in order to foster systemic change.[13]

Prior to commencing a CI initiative, it is recommended that three preconditions be in place to motivate and enable the work, i.e.: "…an influential champion, adequate financial resources, and a sense of urgency for change."[14] From there, five conditions are adopted:[12]

1. *A Common Agenda:* Participants work together to develop a shared understanding of both the problem and how best to solve it collectively.
2. *Mutually Reinforcing Activities*: Participants engage in different activities, each determined by the strengths/areas of focus of the individual participating groups, all contributing to a coordinated plan.
3. *Continuous Communication*: Frequent and ongoing communications are critical to developing the trust and mutual respect needed for such complex, coordinated work. Such communications also enable members to see they are collectively working towards a common goal.

4. *Backbone Support Organization:* An organization that coordinates the efforts is critical. Typical responsibilities of a backbone organization include, facilitation, communications management, data collection, and logistical and technological support. The lack of such an organization is often cited as the most common cause of failure of a CI initiative.
5. *Shared Measurement Systems*: Shared measurement systems help ensure all are truly aligned with regard to the common agenda, they provide indicators of lessons learned and progress made, and foster accountability.

Building upon these pre-conditions and conditions, the field of CI increasingly emphasizes the importance of incorporating equity throughout, with an emphasis on systems change, the inclusion of those community members most negatively impacted by the systems, and a focus on shifting and sharing of power, leadership and accountability.[15] Given the complexities of a CI approach, there is benefit in mapping the pre-conditions, conditions, and the initiative's timeline to the phases of a CI initiative as shown below [Table 1, adapted from[14]]

Components of Success	**Phase 1 Initiate Action**	**Phase 2 Organize for Impact**	**Phase 3 Sustain Action and Impact**
Governance and Infrastructure	Identify champions and form a cross-sector group	Create infrastructure (backbone and processes)	Facilitate and refine
Strategic Planning	Map the landscape and use data to make the case	Create a common agenda (goals and strategy)	Support implementation (alignment to goals and strategies)
Community Involvement	Facilitate community outreach	Engage community and build public will	Continue engagement and conduct advocacy
Evaluation and Improvement	Analyze baseline data to identify key issues and gaps	Establish shared metrics (indicators, measurement and approach)	Collect, track and report progress (process to learn and improve)

Table 1. Phases of Collective Impact (CI) Initiative

Background

The Engineering for One Planet (EOP) Initiative

Catalyzed by The Lemelson Foundation (Lemelson) and VentureWell, Engineering for One Planet (EOP) is an initiative to transform engineering education to reflect the growing importance of sustainability in all engineering functions.[16] EOP was developed and is evolving through collaborations among hundreds of sustainability advocates across sectors, geographies, and lived experiences. EOP seeks to ensure all future engineers, across all disciplines, learn the fundamental skills and principles of social and environmental sustainability.

The EOP Framework was first launched in 2020 and is a cornerstone of the EOP initiative. The framework is the first of its kind in that it incorporates to guide to 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 (see Appendix A).[17] It provides faculty with a vetted menu of competencies — presented as 92 learning outcomes that were co-created by hundreds of stakeholders from across disciplines and sectors[18] — that every graduating engineer, regardless of subdiscipline, needs to acquire to design, code, build, and implement solutions that are socially and environmentally sustainable. Framework outcomes are mapped to the seven student outcomes published by the engineering education accreditation body, ABET[19] (see Appendix B for a description of ABET and other partners), as well the United Nations Sustainable Development Goals (UN SDGs)[20]. The desired result of the EOP Framework is a pipeline of engineers, inventors, and innovators who create structures, designs, products, and services, which help people and nature flourish, today and in the future. It will foster a future in which engineers account for social and environmental impact as much as they do for cost and user experience — a future in which solutions to the world's biggest problems will simultaneously contribute to the care of our planet because sustainability will have been stitched into their fabric from the start.

Other areas of the EOP initiative are also anchored and informed by engaged stakeholder groups. Five universities were selected to receive two-year seed funding ($30,000 each with the opportunity for an additional grant supplement of $10,000 each) from 2020-2022 to pilot the integration of the EOP Framework to drive curricular changes in diverse engineering courses.[22] In 2021, the EOP Network, a volunteer action network was launched with more than 40 members. With a professional network manager and convenings supported by Lemelson, The EOP network supports collaborative member efforts. Through a grant to the American Society of Engineering Education (ASEE) in 2022 Lemelson also supported the ASEE EOP Mini Grant Program (MGP). The MGP provided seed grants to 13 diverse higher education institutions, including 5 minority-serving institutions, to use the EOP Framework in curricular change.[23] These EOP curricular change efforts have impacted thousands of students and are yielding teaching resources and insights on curricular transformation aligned with the EOP Framework.

Building on this momentum, the EOP initiative hosted the Scaling for Impact Workshop to engage a larger and broader group of stakeholders in order to increase awareness of the initiative, attract new supporters and champions, and inform a scaling strategy.

EOP Scaling for Impact Workshop

Workshop Design and Outcomes

With the support of the National Science Foundation (NSF), the EOP initiative was able to expand its reach and attract a wider circle of stakeholders who play a critical role across engineering education, by hosting the *EOP Scaling for Impact Workshop*. Aligned with the multi-sector, community engagement approach of a CI initiative, this virtual, multi-day event was designed to convene, "...individuals from a range of identities, lived experiences, geographies, and sectors including academia, industry, government, and nonprofit spaces…"[23], in order to achieve the following goals:

- Share lessons learned from the extant literature regarding how to embed sustainability into the curriculum, and lessons from the EOP pilot grantees regarding how to integrate the EOP Framework into curricula and programs.[24,25]
- Surface approaches and recommendations to inform the design of a roadmap to achieve the EOP vision at scale, which incorporates:
    - Participant recommendations for refining and scaling the EOP Framework, including measuring the integration of the Framework across engineering programs nationally.
    - Diversity, equity, inclusion and justice (DEIJ). See Appendix C for definitions.
    - Approaches that foster propagation (defined as the action of widely spreading and promoting EOP-related ideas or tools to foster systems change), and institutionalization (defined as the action of establishing EOP-related ideas or tools across and within an organization or institution).

The workshop recruitment strategy, participant application process, and the workshop itself were designed through the collaboration of VentureWell workshop organizers and facilitators, and an eight-person Workshop Organizing Committee (WOC). The WOC was composed of individuals from sectors including industry, engineering education (both faculty and students), and accreditation bodies that could contribute expertise and lived experience with regard to the EOP Framework, DEIJ, sustainability, and institutional change.

The workshop outreach and application recruitment strategy included newsletter and social media campaigns from professional organizations, targeted and personalized invitations, and requests for nominations of individuals who fit target groups. Through these mechanisms over 35,000 individuals were invited to apply, which ultimately yielded 139 workshop applicants who identified as follows:

- 68% were from academia,13% from industry, and 10% from the philanthropy/non-profit sector
- 70% of those from academia were from U.S.-based academic institutions
- 25% of those from academia were from a Minority-Serving Institution (MSI),
- 58% were men
- 48% were White Non-Hispanic and 22% were Asian Non-Hispanic
- 25% were from an underrepresented minority (URM) group (identified as Black, Latino/a/x, Indigenous)[23]

The application review process was similarly designed to seek demographic diversity and representation from each sector, while also considering each applicant's passion or alignment with the EOP vision, their experience with the various workshop topics (propagation, institutionalization, DEIJ, evaluation/assessment, and social or environmental sustainability). and their belief that participating in the workshop would benefit them, their organization, and constituents.

Eighty-nine individuals were selected to register. Of those, 72 chose to register and attend, and identified as follows:

- 60% were men

- 74% identified with a group that is not underrepresented in Science and Technology Innovation and Entrepreneurship
- 52% were at least moderately or extremely familiar with the EOP initiative or Framework
- 69% were from academia
- 50% identified as white non-hispanic

See Appendix D for a graphical representation of the demographic makeup of reviewed applicants (n=121) compared to reviewed and invited attendees (n=72). Of the 101 Workshop participants, 29 had some involvement in planning or execution of the Workshop (VentureWell staff, Lemelson staff, NSF staff, EOP pilot grantees, WOC members, and invited speakers).

The Workshop took place June 21-23, 2022, for three hours each day, hosted entirely online. Participants were provided with a stipend to support their time away from work, studies, family or other activities. Prior to the workshop, participants were invited to provide feedback on the EOP Framework, review lessons learned from the EOP pilot grantees[25], review the literature review containing examples of how to embed sustainability into the curriculum[24], and develop a personal introduction. During the workshop, whole group activities were utilized to share presentations from prominent partners including Lemelson, NSF, ABET, and VentureWell, which communicated both the importance of the work to each partner and their commitment to it (see Appendix B for the list of partners). Additionally lessons learned were shared by EOP Pilot grantees, by grantees funded by NSF to transform engineering undergraduate education, and by participants with experience in the broader field of institutional/organizational change, culture change and DEIJ.

Participants spent the balance of the time in one of 20 different breakout teams comprising 4-5 participants. Each team developed their own approach to scale EOP that leveraged their pre-work, the presentations and data shared, and their own expertise and lived experiences. Unfortunately, though, due to time constraints, workshop teams were not adequately engaged in a process for integrating DEIJ or metrics into their plans.Throughout the three days the teams iterated upon their plans, gathered feedback from other teams, and then pitched their final approach to the whole group. Upon analysis, the 20 proposed approaches, developed by the teams, yielded 12 overlapping, synthesized approaches as captured in Table 2 below. Approaches are listed in the order of frequency that they were proposed.

Table 2: Twelve Recommended Approaches for Scaling the EOP Initiative Generated at the EOP Scaling for Impact Workshop.

1. EOP / ASEE create a sustainability Division with a web hub/platform to share resources, host training and professional development opportunities, and foster and support communities of practice or a fellows program to move the EOP initiative forward.
2. EOP leads public campaigns around sustainability and EOP initiative to foster cultural change.
3. Industry (or community organizations) and higher education institutions collaborate to change their culture/environment around sustainability.

4. Fund (or increase funding) to include support for sustainability-related projects, programs, courses, research, and/or assessment.
5. Modify the licensure process to more strongly emphasize sustainability and train students accordingly.
6. Connect student organizations with professional organizations and/or industry working towards sustainability.
7. Institutions develop long-term vision on sustainability-related investments and supporting systems.
8. Development of national inter-collegiate collaborations and competitions.
9. Institutions develop a cross-campus, multidisciplinary university-based committee to promote sustainability.
10. Engineering faculty use a student- centered approach to match students' needs/demands for sustainability with opportunities to practice via internships, capstones, or special projects.
11. Engineering departments and faculty have early required coursework in sustainability.
12. Creation of new courses and modification of existing courses to include sustainability-focused competencies (vertical and horizontal integration, broadly).

Workshop Outcomes

The 12 approaches described above aid in the development of a roadmap for scaling EOP. The strategies yielded are also validating because they demonstrate alignment with work that has already happened as a part of EOP or is already underway. Figure 1 below demonstrates this overlap and shows how much groundwork has already been laid as a part of the EOP initiative with regard to understanding the landscape and engaging champions and the community; Appendix E provides further details, mapping current and past efforts onto the 12 approaches. It is worth noting, however, that figure 1 below also captures how earlier EOP-focused work spans a myriad of efforts undertaken by loosely connected groups of stakeholders. While such efforts increase awareness of and engagement in EOP, and serve to move the EOP initiative forward, their disparate nature limits the outcomes that might otherwise result from a more collective, coordinated action. Such potential outcomes include innovation and learning, and a focus on broader, systemic change.[13]

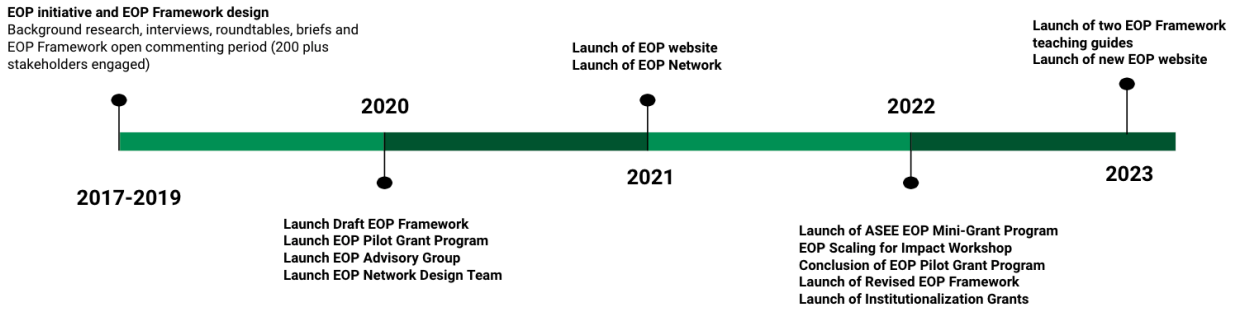

Figure 1: Timeline of different EOP activities prior to the EOP Scaling for Impact Workshop

By way of contrast, Figure 2 captures the current suite of EOP programmatic initiatives, contributed to and utilized by EOP Community members, as if they were a part of a collaborative

CI initiative; the outer circle represent the wraparound and grounding nature of the CI conditions, and the bubbles represent the connected, mutually reinforcing activities. The addition of these CI conditions represents something of a contrast with 12 approaches, which demonstrate a bias towards programmatic support, as opposed to laying a foundation for coordinated and equity-centered, systemic change.[18]

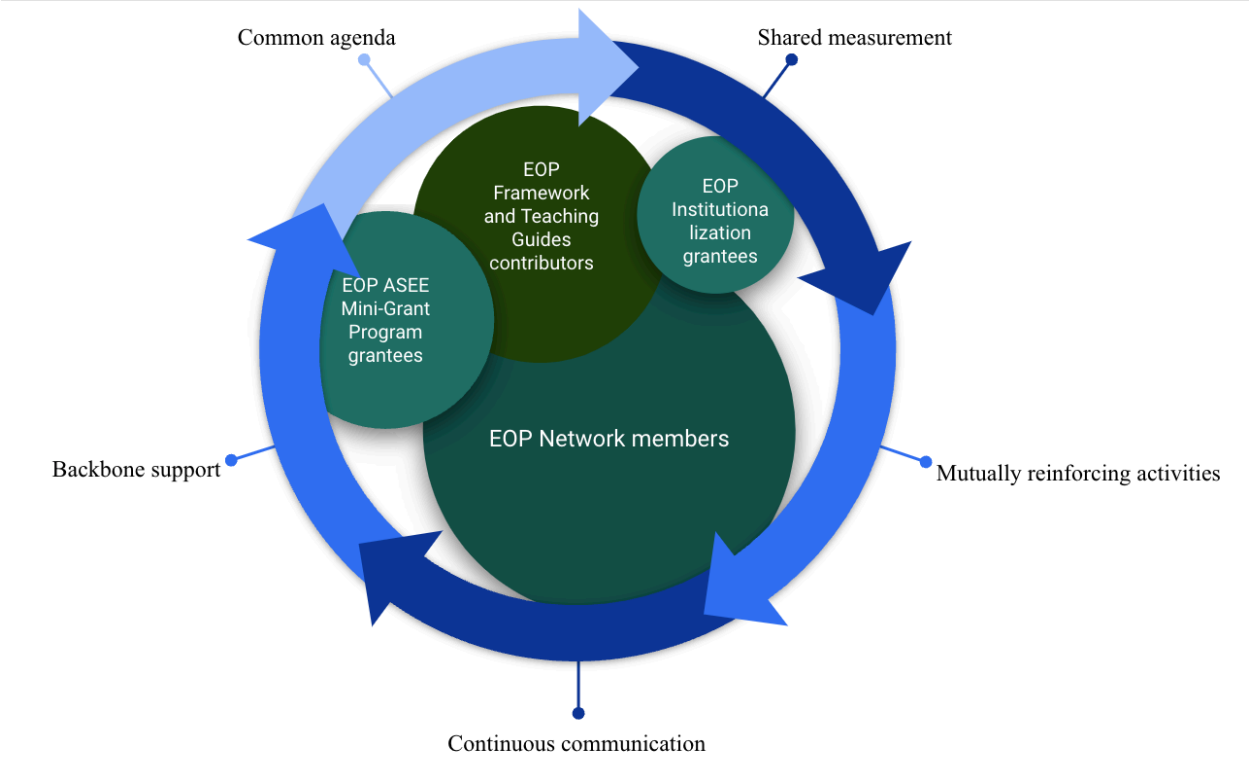

Figure 2. Current EOP programmatic initiative activities contributed to and utilized by EOP Community members, recast as a singular CI initiative

Building on the approach captured in Figure 2, what follows is a roadmap that leverages the 12 approaches yielded, integrates elements needed to foster systems change, and gathers all disparate EOP efforts into a singular, phased, CI initiative, capturing both what is underway in each phase and the important work ahead.

Roadmap

Phase 1: Initiate Action

Phase 1 of a CI initiative sets the careful groundwork for all that lies ahead by, "Identify[ing] champions and form[ing] cross-sector groups; Map[ping] the landscape and us[ing] data to make the case; Facilitat[ing] community outreach; Analyz[ing] baseline data to identify key issues and gaps."[14] Figure 1 above captures the attention that has already been paid to different aspects of this important phase by gathering data to understand the landscape and making the case for the work (2017-2018), and engaging stakeholders and community members in EOP Framework design and revision (2019-2022). Community outreach efforts have also been

undertaken, which utilized the newly created EOP website and EOP newsletter, along with social media campaigns, all under the guidance of the newly formed EOP advisory group (2020-2022). A network design team was convened and listening sessions hosted with over 50 stakeholders, to inform the design of the EOP Network (2020-2021). While not captured in Figure 1, prior to the Scaling for Impact Workshop, presentations at relevant professional conferences were made to raise awareness about the EOP initiative and related resources and opportunities (e.g., the Association of Advancement of Sustainability in Higher Education 2019, Engineering Change Lab USA Summit 2019 and 2020, Deshpande Symposium 2020, Green Chemistry and Engineering Conference 2020,[26] KEEN National Conference 2020, National Academy of Inventors 2020,[27] ASEE 2021,[28] and 2022,[29] VentureWell's OPEN 2021[30] and 2022).

While not mentioned explicitly as a part of Phase 1, it is worth noting that the preconditions for a CI initiative are also important to include. While the aforementioned landscape mapping and the use of data to foster the requisite "sense of urgency for change" are important, the presence of, "an influential champion, [and] adequate financial resources…" are also critical.[14] At the outset, prior to the Workshop, Lemelson was the primary champion and source of funding. However, over time additional champions and funding have become a part of the initiative, namely by cultivating key relationships with various collaborators from across sectors, including non-profit, governmental agencies, professional associations, accrediting bodies, industry, independent consulting groups, as well as individuals that represent each of these sectors. For example, (1) VentureWell, a partner on the EOP pilot grantee program and the Workshop, (2) NSF, the funder of the EOP Scaling for Impact Workshop, (3) ASEE, a partner and funder on the ASEE EOP MGP,[31] funded by Lemelson, that launched in 2022 with small seed grants to 13 US-based higher education institutions to effect curricular changes through the integration of the EOP Framework, (4) ABET demonstrated their interest and commitment to sustainability and EOP by collaborating with Lemelson on articles, participating in the EOP Network,[19,32] and sharing presentations at professional conferences (e.g. International Federation of Engineering Education Societies 2020,[33] World Engineering Education Forum-Global Engineering Deans Council 2020 and 2021, and (5) Siemens Digital and Boeing which have collaborated with the EOP initiative on strategic ideation, presentations, and events. Other partners include Alula Consulting, who works with Lemelson and VentureWell to execute on various EOP initiative goals and tasks (e.g. research [34,35], resource development and dissemination, community support, event planning, etc.), and Amplify Evaluation, who support EOP evaluation planning and assessment efforts.

Phase 2: Organize for Impact

This phase incorporates the creation of infrastructure, the creation of a common agenda (goals and strategy), engagement of the community, building of public will, and the establishment of shared metrics (indicators, measurement and approach). A backbone organization is essential to this phase because, as described earlier, a backbone organization is the "support infrastructure" for a CI initiative.[36] This simple statement encapsulates the broad and complex swath of duties of a backbone organization, which includes the management of all aspects of this phase of the CI initiative and more specifically, guiding vision and strategy, supporting activities, establishing shared measurement practices, building public will, advancing policy and mobilizing funding.[37] In the same way that Lemelson was the initial, primary champion, Lemelson has played the primary role of the backbone organization in collaboration with VentureWell. Over time, other stakeholders have started to take on aspects of that role. VentureWell collaborated on gathering

early stakeholder input, developing the EOP Framework and served as the facilitator and evaluation partner on the EOP Pilot Grantee Program and was the primary designer, participant recruiter, and facilitator for the Scaling for Impact Workshop. ASEE served the role of grantee recruiter, grant administrator, mentor recruiter, and community of practice facilitator in the ASEE EOP MGP. Lemelson also funded and recruited a manager for the EOP Network and an evaluator to develop an approach for shared metrics. Given that the lack of a backbone organization is a common cause for the failure of a CI initiative, the successful scaling of the initiative is dependent on the recruitment of additional stakeholders to fulfill backbone roles [37] Some important considerations when seeking backbone collaborators include experts that are positioned to address gaps or challenges of the existing backbone organization. Common areas of challenge include the establishment of shared metrics, and building additional public will (one of the recommended 12 approaches).[37] It will also be important to consider the pros and cons of different types of backbone organizations. For example, while a funder backbone organization is able to provide funding and bring others to the table, there may be a lack of broad buy in if the initiative is perceived to be run by one funder, and there may be a perceived lack of neutrality.[14] A suite of backbone collaborators might therefore be considered from across non-profit organizations and independent groups, such as consultants, (given their perceived neutrality and subject-matter expertise), existing non-profits (given their credibility and existing infrastructure), existing funders (to provide ongoing financial support and provide credibility), credentialing bodies and professional organizations (to lend credibility to the initiative, demonstrate their seal of approval, and utilize their reach), and a steering committee (to enable broad buy-in across different sectors, regions, and lived experiences).[14]

However, no matter which backbone organizations are recruited, without a common agenda the work cannot effectively proceed. Getting a varied group of stakeholders to agree on an agenda with, "sufficient clarity to support a shared measurement system and shape mutually reinforcing activities" is challenging.[14] The creation and launch of the EOP Framework, as captured in Figure 1, was an important first step in moving stakeholders towards a common agenda as a platform for change —both as a curricular implementation tool and as key pillar of the EOP initiative, given its emphasis on learning outcomes to train sustainability-focused engineers (the "what") as well as the vision, goals (the "why"). However feedback on the EOP Framework demonstrated a need and desire for implementation guidance and examples. As discussed below in Phase 3, this is something that was undertaken. In addition, the EOP Network collaborated to develop and refine its Charter including a shared purpose statement, which might also be considered a common agenda for the Network's work together.[38]

Strategic action frameworks are another key component of an effective common agenda. It is recommended they include, "...a description of the problem informed by solid research; a clear goal for the desired change; a portfolio of key strategies to drive large scale change; a set of principles that guide the group's behavior; and an approach to evaluation that lays out how the collective impact initiative will obtain and judge the feedback on its efforts."[14] The EOP Network Charter[38] includes each of these components and is thus a great strategic action framework for the network programmatic component of the broader initiative. The charter will need to be revisited if it is to serve as a foundational document for the initiative writ large.

Another shared agenda consideration that the EOP initiative is currently grappling with is boundaries. Any shared agenda must contend with how far and wide to define its boundaries in

order to operate effectively within resource constraints. The EOP initiative, currently funded primarily by one funder, has focused on supporting change efforts in the U.S. while also engaging stakeholders internationally, and making all of its knowledge and learning available freely for use and adoption anywhere by anyone. Indeed, stakeholders in the UK, India, and South America are or will be using the EOP Framework to guide curricular changes and the development of other resources to fit their needs. However, EOP stakeholders, including EOP Network members, are interested in greater international engagement to address needs in areas most negatively impacted by social and environmental challenges and to foster global impact. Such expansion, however, requires a greater understanding of a global landscape order to define gaps, opportunities, existing players, etc., which would then be used to create a strategic theory of change and a roadmap to support a global landscape. It also requires the resources to effectively and equitably support broader and geographically dispersed stakeholder engagement (e.g. event participation, travel, scheduling to accommodate time zones, etc.). EOP currently has a systemic level Theory of Change (see Appendix F), which emphasizes U.S. higher education engineering programs as both the key actors and beneficiaries of the outcomes of the initiative. The very possibility of supporting global expansion, is an important reminder that the theory of change should be developed in a way that provides sufficient flexibility to enable iteration and innovation based on learning.[14]

Once the common agenda has been established, shared measurement systems can then be developed. Building upon the work already done to establish its charter/common agenda, the EOP Network has begun creating shared measurement systems with key performance indicators (KPI). The Workshop did not elevate this need, likely because, due to time constraints, a discussion of metrics was not integrated into the workshop. As work continues on the refinement of EOP Network KPIs, it will be important to ensure that the shared measurement systems enable a, "…facilitated process that establishes comparative performance metrics, coordinates [organizations'] efforts, and enables them to learn from each other."[39] Such a measurement system fosters alignment of goals across organizations and enables said organizations to work and learn collaboratively, and together tackle large, systems issues in an ongoing fashion, because maintaining healthy systems requires continual work.[39,40] The EOP Network is putting measurement systems in place that allow flexibility for themes and interests that emerge over time. Developing such shared systems of measurement is expensive, complex, and time consuming. In the development phase, leadership is needed to engage multiple organizations, independent of funder oversight. During the implementation phase of what will be a voluntary approach to usage, infrastructure is needed to both support users and perform ongoing testing.[39] In the case of the EOP Network, diverse network members are leading the work to define, implement and govern measurement approaches, with input and support from Lemelson. Lemelson seeks high-level alignment with the EOP initiative goals rather than control over measurement tactics, thereby enabling network members the flexibility they need to direct projects over time.

As discussed earlier, the social and environmental challenges we face disproportionately impact marginalized communities, and in order to realize the solutions sought, it is critical to foster DEIJ in engineering education and the engineering profession. The initiative must therefore ground the work in data that enables the initiative to address inequities. It must also shift the power dynamics such that power is spread across all sectors and crucially among those most impacted. Finally, while programs and services play an important role, there needs to be an emphasis on

systems change. This requires a change at the structural level, which, aligned with the 12 approaches, emphasizes changes to, "...policies, practices, and resource flows."[15] However systems change also requires, "...relational change—specifically, relationships and connections, and power dynamics among people or organizations…[and] transformative change—the mental models, worldviews, and narratives behind our understanding of social problems."[15] This can happen by shifting the power dynamics and building trust among those most impacted, and leveraging data that demonstrates the challenges of those most impacted. The EOP Network efforts and the EOP Scaling for Impact workshop have begun to lean into this by prioritizing engagement with diverse individuals from a plethora of demographic, geographic, and sector backgrounds with guidance from experts in DEIJ.

Phase 3: Sustain Action and Impact

CI initiatives have been described as "messy and fragile."[14] This final phase— with its emphasis on implementation, continued engagement and advocacy, and ongoing refinement—is no exception, especially given how reliant this phase is on the degree to which the earlier phases laid a strong foundation for implementation and learning. As discussed above, the common agenda, including the strategic action framework will need to be flexible enough to incorporate the perspectives and priorities of new partners to the initiative, and encompass new learnings. The portfolio of strategies integrated into the strategic action framework must incorporate "quick wins" to help ensure ongoing engagement of initiative partners.[14] Also, the shared measurement system developed must have the capacity to enable learning across the initiative since this will impact the degree to which the initiative can bring to bear the collective capacity of several organizations to foster the systemic changes envisioned.[39] One might argue that the systemic changes being sought represent perhaps the most challenging aspect of the EOP initiative. In addition to requiring collaboration and collective learning across stakeholder groups, systemic change also requires shifts in power dynamics and world views, both of which are hard won.

Despite these concerns, the achievements thus far of the EOP initiative, and the programmatic work underway, is a testament to the broad commitment to the shared vision. This work also demonstrates that phase 3 implementation efforts are well underway. As can be seen in the EOP Initiative Timeline above (figure 1), and as mentioned earlier in this paper, there were several programmatic and awareness-building efforts underway before the Workshop.

Since the Workshop, additional and expansive programmatic efforts have begun to intentionally elevate the awareness, and broaden the reach and scale the impact of the EOP initiative in support of the 12 recommended approaches from the Workshop (see Table 2). All but three approaches —licensure (#5), and institutional investments and an institutional sustainability committee (#7 and 9, respectively)— have either commenced, been maintained or been expanded since the Workshop. Refer to Appendix E, for a progress report on current efforts with examples of work underway related to each of the 12 approaches generated at the Workshop.

Key efforts include but are not limited to:

1) Revision and refinement of the EOP Framework: The EOP Framework that was originally launched in 2020 and tested by EOP Pilot Grantees, went through a public commenting period, revision process, and launch of a new EOP Framework version in 2022.[22] Feedback and input was collected from hundreds of stakeholders from academia, industry, and public and nonprofit

sectors, including Workshop participants. Special emphasis during the revision process was placed on refining learning outcomes related to social and environmental sustainability, and environmental justice issues, as well as to mapping the EOP Framework's learning outcomes to the seven ABET Student Outcomes,[19] Bloom's Taxonomy,[41] and the UN SDGs.[20] The EOP Framework is available for free download on the EOP website. The EOP Framework supports the integration of sustainability and related professional competencies into engineering coursework, which aligns with four recommended approaches from the Workshop (raise awareness of sustainability and EOP (#1), sustainability-focused course competencies (#12),student projects (#10), and early, required courses in sustainability (#11). See Appendix E.

2) Creation of two companion teaching guides for the EOP Framework: As a result of community-based suggestions gathered during the public commenting period described above, two EOP Framework companion teaching guides —the *EOP Framework: Quickstart Activity Guide*[42] and the *EOP Framework: Comprehensive Guide to Teaching Core Learning Outcomes*[43]— were created with feedback from the EOP community. The goal of these guides is to support the integration of the EOP Framework into engineering courses and programs by providing specific and freely available teaching materials and resources for each of the EOP Framework's learning outcomes (see Appendix A). Both are available for free download on the EOP website. The teaching guides directly support the integration of sustainability competencies into engineering coursework by demonstrating how to utilize the framework and providing clear guidance and examples for bringing sustainability-focused teaching materials into any engineering classroom. Prior to the guides' creation, integration was a common obstacle for many faculty who do not know how to begin that process or feel confident doing so. Overcoming this barrier is critical in supporting the implementation of the framework and the integration of sustainability competencies into engineering courses, programs, and departments. These efforts align with three interrelated recommended approaches from the Workshop (sustainability-focused course competencies (#12),student projects (#10), and early, required courses in sustainability (#11). See Appendix E.

3) Continued support and expansion of the EOP Network: Lemelson continues to fund an EOP Network manager to support network member activities and projects, organize regular full network convenings, and conduct assessments of network health, connectivity, and participant engagement. In an effort to broaden participation in the EOP Network, since its launch in 2021, a rigorous and broad-reaching open application process was developed with intentional approaches for increasing participation from both historically marginalized groups and students. As of October 2022, the EOP Network has grown to over 70 members who are focused on several collaborative efforts, aligned with the 12 approaches generated at the Workshop, to advance the EOP initiative These approaches include contributing ASEE conference publications (approach #1 ASEE partnership), designing an EOP competition (approach #8 (inter-collegiate collaborations and competitions), creating an EOP Toolkit[44] to support outreach efforts (approach #2 raise sustainability awareness), developing a student guide to support student hiring in engineering industries and an industry-based internship program (approaches #3 industry partners, #10 sustainability-focused student projects, and #6 student orgs and industry).

4) Additional and expanded funding opportunities: Lemelson has committed to continue to expand grant opportunities since the Workshop. The ASEE EOP MGP[31] will continue in 2023 and 2024 with the sponsorship of 12 additional $8,000 seed grants per year in 2023 and 2024.

This work directly aligns with the first of the 12 approaches recommended at the Workshop. In addition, Lemelson has already awarded three and anticipates awarding more EOP Institutionalization Grants to several US-based higher education institutions to broadly implement the EOP Framework into engineering courses. One EOP Network project team is focused on understanding and documenting the landscape of aligned funders. These actions align with and are working to advance the recommended approach #4 (funding) generated at the Workshop (see Appendix E). As the EOP initiative continues to grow, more champions from across different sectors, along with sources of funding will need to be sought in order to support institutionalization, propagation and scaling efforts in EOP.

5) Exploration of industry partnerships: Concerted efforts are being made to deepen, establish, and cultivate relationships and projects with industry partners. Before and since the Workshop, Lemelson has been working to establish relationships with several companies (e.g. Siemens, Boeing, DuPont, etc.) to better understand industry interest and demand for engineers prepared with core sustainability skills. Lemelson has also forged connections through professional engineering organizations (e.g. American Society of Mechanical Engineers and Engineering Change Lab-USA). Additionally, an EOP Network team —led by an engineer and EOP champion at Boeing— is working to establish relationships with other industry partners to understand the need and willingness to establish an internship program between industry partners and academic institutions to support the professional training of sustainability-focused engineers. Another Network team led by students is working to create a professional development guide for students to aid students in the creation of sustainability-focused resumes, and prepare students for industry interviews, etc. These efforts are working to advance three interconnected, industry-focused recommended approaches generated at the Workshop: #3 (industry partners), #6 (connecting student organizations and industry), and #10 (sustainability-focused student projects). Refer to Appendix E for more details. As the EOP initiative continues to grow, more industry partnerships will need to be cultivated in order to build the bridge between educational programming, student training opportunities, and industry demand for sustainability-focused engineers.

6) Raising awareness of sustainability and the EOP initiative: Since the Workshop, EOP news has been shared on social media, and through a quarterly EOP newsletter about aligned events, engagement opportunities, and resources. In 2023, a newly revised EOP website was launched that includes new resources including a promotional video about the EOP initiative, the newly revised EOP Framework and two new companion teaching guides. The website also invites individuals and organizations to be EOP signatories, to demonstrate their commitment to advancing EOP. Since the Workshop, several professional presentations have been made at professional conferences and symposiums for engineering faculty and professionals to raise awareness about the EOP initiative e.g. Annual Colloquium on International Engineering Education in November 2022, , VentureWell's annual OPEN conference in March 2023, Engineering Change Lab USA's Engineering Education Summit in March 2023, a panel at ASEE's annual Engineering Deans Institute in April 2023, a plenary keynote, panel, and workshop at ABET's Annual Symposium in April 2023. In June 2023, at the ASEE annual conference, EOP will deliver a topical plenary and launch the EOP Toolkit, providing key tools and resources needed to enable EOP Network members and other interested EOP community members to share branded information about the EOP initiative. Additionally, the EOP Network team focused on the EOP Competition is working to raise awareness about EOP through the

launch and promotion of the competition and this also aligns directly with recommended approach #8 (inter-collegiate collaborations and competitions). VentureWell is also working on creating and disseminating a 5-year roadmap; based on this ASEE paper, VentureWell's externally-facing roadmap is a call to action, in shorter form, to ignite collaboration among stakeholders from academia, industry, government and the social sector, to realize the EOP vision over a 5-year timeframe. All of these interrelated outreach efforts are working to achieve the recommended approach #2 (raise sustainability and EOP awareness) from the Workshop. Refer to Appendix E for details.

Next Steps and Calls to Action

To date, much has been achieved by the EOP initiative. Prior to the Workshop, with Lemelson and VentureWell at the helm as backbone organizations, research was undertaken, and stakeholders and the community were engaged, to make a case for the work, understand the landscape, and develop the EOP Framework, which served as both a call to action and an early-stage common agenda. This work set the stage for early implementation work in the form of the EOP Pilot Grantee Program, which engaged a first round of institutions in piloting the integration of the framework, with VentureWell as a backbone partner providing support to that work. Additional work with stakeholders led to the founding of the EOP Advisory Group, providing a collaborative partnership in steering the direction of the initiative. Further work with stakeholders led to the design and launch of the EOP Network and the partnership with ASEE, another backbone partner, to launch and administer the ASEE EOP MGP[31].

The Workshop marked the beginning of partnership explorations with NSF as a funder and ABET as a key strategic partner. It also served to engage and attract a broader and more diverse group of expert stakeholders from across different sectors, regions, and lived experiences, and led to the identification of 12 strategic approaches for scaling the EOP initiative. The 12 approaches demonstrated alignment with ongoing outreach and partnership efforts, and programmatic work initiated through the EOP Framework, EOP Pilot Grantee Program, the EOP Network, and the ASEE EOP MGP[31], which generated examples of how to integrate EOP learning outcomes into early required coursework, and into new or existing engineering courses. The 12 approaches also provided directionality for several additional programmatic initiatives undertaken by EOP Network project teams including cultivating connections with student organizations and industry partners, the creation of inter-collegiate collaborations and competitions, and setting the stage for sustainability-focused student projects. Additionally, the approaches suggested have encouraged a deepening of the partnership with ASEE, further efforts to increase awareness of EOP with a view to fostering cultural change, work to engage industry partners, and efforts to identify and cultivate funders. Approaches suggested that have yet to be addressed include (1) modifying the licensure process to more strongly emphasize sustainability, (2) supporting institutions in their development of long-term vision on sustainability-related investments and supporting systems, and (3) supporting institutions in their development of a cross-campus, multidisciplinary university-based committee to promote sustainability (see Appendix E).

The Workshop was only a 1.5 day virtual event so the workshop teams were not adequately engaged in a process for considering the integration of DEIJ or the development of metrics. This

omission highlights some of the key missing pieces from the initiative as it currently stands and some key challenges that lay ahead. The 12 approaches generated also demonstrate a bias towards action and programmatic interventions, versus laying the complex groundwork for collective action. Additionally, while the initiative has and continues to undertake important foundational work including the refinement of the EOP Framework (Appendix A),n the creation of two companion teaching guides, the development of the EOP Theory of Change, and the development of shared measurement systems, more work is needed to ensure the various programmatic interventions are connected and supported under a CI umbrella.

Table 3 below is a CI-infused call to action to current and future cross-sector EOP collaborators—including leaders from academia and industry— to work collectively and continually strive to achieve the vision of systemic change to engineering education and the engineering profession.

Table 3: A call to action to current and future cross-sector EOP collaborators

ALL COLLABORATORS

- Indicate and communicate your interest in being a part of and learning more about the EOP initiative by becoming a signatory of EOP via the EOP website.
- Identify and discuss with EOP initiative members (plus colleagues and leaders in your organization/institution) the way you might further the EOP agenda (see below for suggestions).
- Engage in the refinement of the EOP common agenda and shared measurement systems, with a goal of crafting an aspirational roadmap for the engagement of your institution/organization, and other collaborators.
- Identify champions across your institution/organization, including those in leadership positions, to engage in the EOP Initiative
- Utilize your credibility and network to publicly support the work of the EOP initiative through presentations, articles, position statements, etc.
- Lean into the discomfort of EOP as a systemic change initiative, requiring both a shift in power dynamics and in the way we may currently understand sustainability as a social problem.[15]

ACADEMIA (FACULTY AND ADMINISTRATORS)	**ACADEMIA (STUDENTS)**	**INDUSTRY**	**ACCREDITING BODIES/ PROFESSIONAL ORGANIZATIONS**	**COMMUNITY ORGANIZATIONS**	**NON-PROFIT ORGANIZATIONS**	**FUNDERS**
- Integrate EOP learning outcomes into early, required coursework, new or existing courses, and internships, capstones, or special projects. - Integrate sustainability into your institution and department's mission and vision. - Develop a long-term vision for sustainability-related investments and supporting systems. - Develop a cross-campus, multidisciplinary committee to promote sustainability. - Collaborate with industry and community organizations on curricular and extracurricular offerings. - Connect student organizations with professional organizations and/or industry. - Develop and/or engage in national inter-collegiate collaborations and competitions.	- Share your desire for integrating sustainability with campus faculty and administrators. - Join/found a student group with a sustainability focus - Identify student champions to engage in the EOP initiative. - Join student groups, with no sustainability focus, and make them aware of the importance of the work. - Engage in sustainability-related classes, programs, competitions, internships, capstones, or special projects.	- Integrate sustainability into your organization's mission, vision and culture. - Invest in the professional development of your employees on sustainability skills. - Prioritize sustainability skills in your hiring strategies - Develop a long-term vision on sustainability-related investments and supporting systems. - Collaborate with academic institutions, including student organizations, on sustainability-focused internships, capstones, special projects and inter-collegiate competitions, and academic courses and programs.	- Integrate sustainability into licensure or credentialing requirements. - Begin a new sustainability-focused chapter or division - Integrate sustainability into your vision and mission, along with systems and funding to support it. - Collaborate with student organizations, academic institutions and industry to advance sustainability.	- Integrate sustainability into your organization's mission, vision and culture. - Develop a long-term vision on sustainability-related investments and supporting systems - Collaborate with academic institutions, including student organizations, on sustainability-focused internships, capstones, special projects and inter-collegiate competitions, and academic courses and programs.	- Integrate sustainability into your organization's mission, vision and culture. - Develop a long-term vision on sustainability-related investments and supporting systems - Utilize your expertise to support the EOP initiative as a backbone partner.	- Adopt a trust-based approach to providing funding that emphasizes sharing power with grantees, leading with trust and being open to emergent learning.[45] - Impartially support the development and implementation of shared measurement systems.

Conclusion

Environmental and social sustainability have been identified across all sectors, from government to industry to academia, as critical for the health of our planet and lives. Engineers play an outsized role in the environmental and social sustainability-related, global challenges we are currently facing, and will face in the future, due to the structures and products they design and build, and the associated choices they make. These challenges are complex and systemic, and require the collaboration of cross-sector partners including academia, industry, accreditation bodies, as well as the communities disproportionately impacted, to create systemic changes to engineering education to prepare future engineers. Starting in 2017, the EOP initiative has made significant strides in engaging collaborators, from across different sectors, in visioning and implementing approaches for integrating sustainability into engineering education and the engineering profession. However, the outcomes have been limited in scale. A multi-sector roadmap for scaling the impact of EOP has been developed that combines the 12 approaches yielded from the EOP Scaling for Impact Workshop, the lessons learned and results achieved through the EOP initiative, and a CI approach. Cross-sector stakeholders are invited to join with the initiative, through the calls to action outlined, to collaboratively work to understand and influence the complex landscape of engineering education in order to teach and train engineering students, who will become professional engineers, with the sustainability competencies they will need to address the greatest environmental and social challenges of our time.

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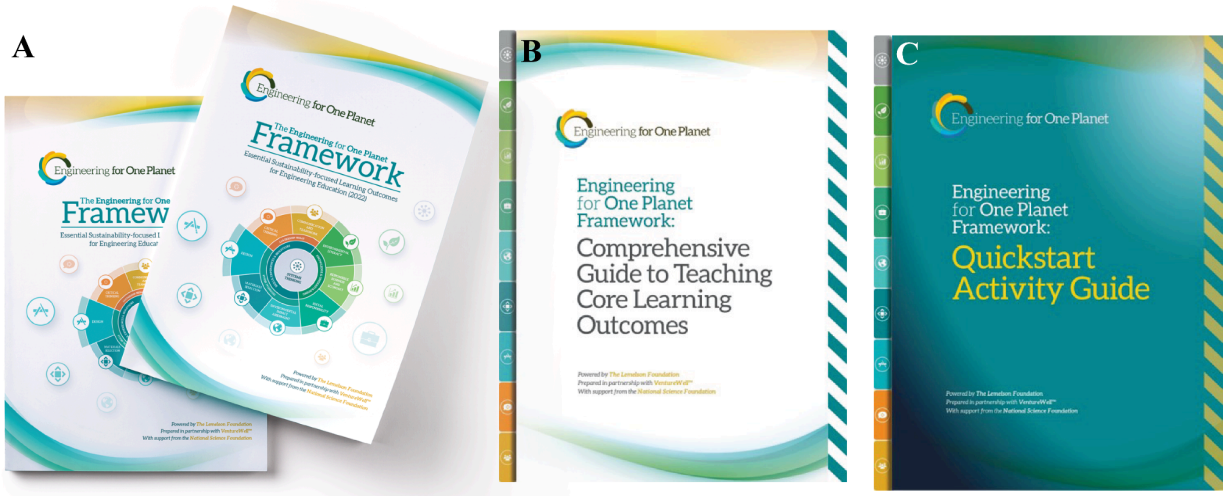
Appendix A

EOP documents to support 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),[22] B) EOP Framework: Comprehensive Guide to Teaching Core Learning Outcomes,[43] and C) EOP Framework: Quickstart Activity Guide.[42] Images taken from the EOP website.[16]



Appendix B

Engineering for One Planet Catalysts, Partners, and Consultants

Partner Name	Abbreviation	Description
The Lemelson Foundation	Lemelson	The Lemelson Foundation is a private family foundation whose mission is improving lives through invention. With its partners, The Lemelson Foundation works to cultivate the next generation of impact inventors, and strengthen the supporting systems that allow invention-based businesses to thrive.
VentureWell	VentureWell	VentureWell is an educational non-profit, founded in 1995, to ensure science and technology innovators have the support, training, and access to networks and resources they need to solve the world's most difficult problems.
National Science Foundation	NSF	NSF is a federal governmental agency, established in 1950 by Congress, to promote the progress of science, advance the national health, prosperity and welfare and secure the national defense.
ABET	ABET	A nonprofit, ISO 9001 certified organization, founded in 1932 that accredits college and university programs in applied and natural science, computing, engineering and engineering technology, that assure that engineering programs meet the quality standards that prepare graduates to enter the professional practice of engineering.
Alula Consulting		An independent consulting company that specializes in innovative sustainability- and online-focused research and curriculum projects for academic institutions, non-profits, government and corporations.
Amplify Evaluation		An independent evaluation consulting company that works collaboratively with community or institutional partners to assess how organizations or programs can promote positive development among individuals exposed to systemic barriers.

Appendix C

Definitions for Diversity, Equity, Inclusion, and Justice (DEIJ) used at the EOP Scaling for Impact Workshop and in this paper. Taken from EOP Scaling for Impact Internal Report.[23]

Diversity: Diversity exists when varied characteristics are consistently present, honored, and lifted up within a group.

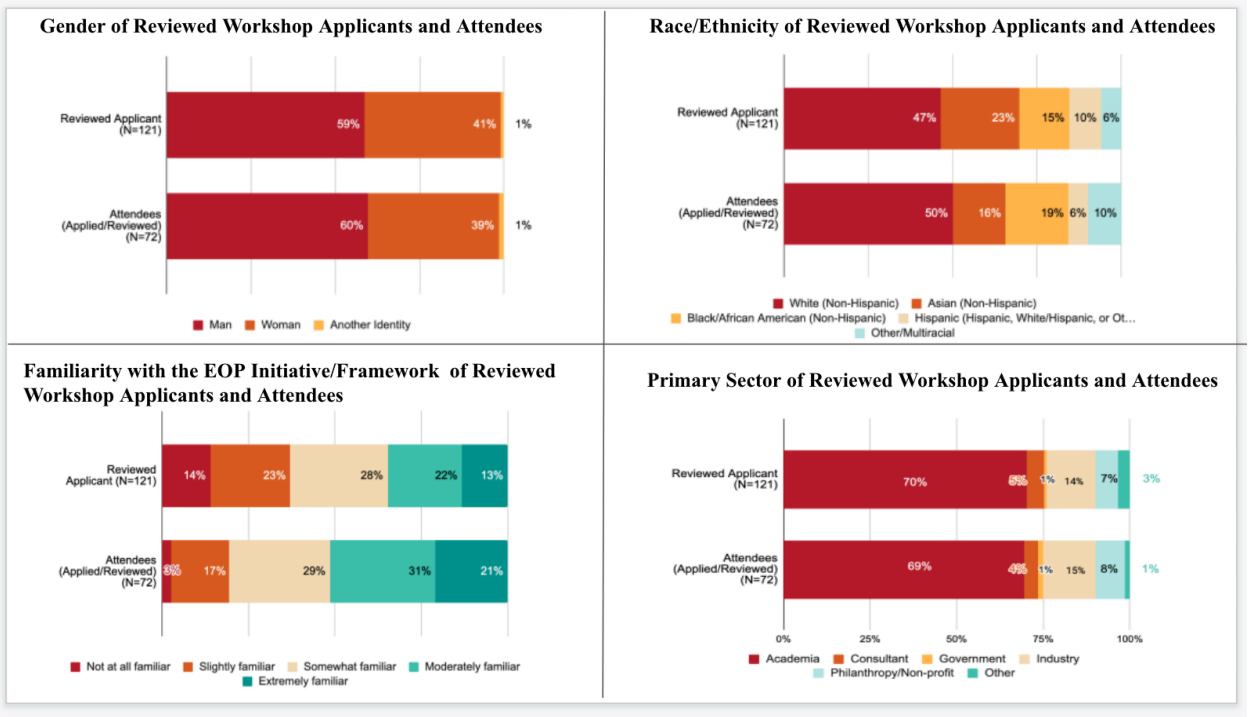
Equity: Equity occurs when barriers to access and power based on one or more aspects of identity are examined and removed.

Inclusion: Inclusion is authentically seeking out and engaging traditionally excluded individuals and/or groups with opportunities to thrive.

Justice: Fair treatment, access, opportunity and advancement for all people, achieved by intentional focus on their disparate needs, conditions and abilities.

Appendix D

Demographic makeup of reviewed applicants (n=121) compared to reviewed and invited attendees (n=72)



Appendix E

Progress and current efforts on the twelve approaches identified at the EOP Scaling for Impact Workshop. Listed in order of frequency of recommendation by teams.

Summary of Approach	Who is working on this?	Stage of progress?	Current efforts
1. ASEE partnership	EOP Network: Team ASEE Collaborations	Planning & collaborating with external partners	Since fall 2022, working with contact in ASEE's Environmental Engineering Division to formalize SEED (Sustainability and Environmental Engineering Division) in the ASEE chapter for future conferences. EOP collaborators have been presenting papers at the annual ASEE conference since 2021 to foster awareness and uptake of EOP.
	ASEE: ASEE EOP MGP	Implementation /completion/ continuation	In 2022, TLF provided funding to ASEE to support 13 US-based academic institutions to integrate the EOP Framework into courses. All schools completed their work in January 2023.[46] The ASEE EOP MGP will continue with between 12-14 schools in 2023 and 2024.
2. Raise sustainability and EOP awareness for cultural change	Lemelson	Implementation	Before and since the Workshop, Lemelson has maintained social media accounts to share events, updates, Medium blog articles, and resources about the EOP initiative, including a LinkedIn Group. In 2023, Lemelson launched an expanded website to promote the EOP initiative as well as a promotional video.
	VentureWell	Implementation	Before and since the Workshop, VentureWell has maintained an EOP-focused webpage on their website and has incorporated the EOP Framework into their annual Green Launchpad Educators Workshop.
	EOP Network	Planning	In 2023, the EOP Network will launch a LinkedIn Group for the EOP Network to promote EOP events, activities, and resources to foster cultural change.
	EOP Network: Team EOP Toolkit	Planning & implementation stages	In 2023, the EOP Network will launch an EOP Toolkit to support the awareness-building and dissemination of EOP resources within and outside of the EOP Network for use at events, conferences, and in classrooms, etc. The EOP Toolkit will be launched at the 2023 ASEE annual conference and a paper will be presented at that time.[44]
3. Industry partnerships	Lemelson: industry partnerships	Planning & collaborating with external partners	Before and since the Workshop, Lemelson has been working to establish relationships with several companies (e.g. Siemens, Boeing, DuPont) to better understand industry interest and demand for engineers working with fundamental sustainability knowledge and skills. Lemelson has also forged connections with industry leaders through Industry Advisory Boards of professional organizations (e.g. American Society of Mechanical Engineers (ASME). In partnership with Siemens in 2022, a sustainability thought-leadership group was formed and meets regularly

			to discuss the development of a global, open-access sustainability toolkit that will provide case studies and curricular examples of how to integrate sustainability into engineering classrooms.
	EOP Network: Team Industry Internships	Planning & collaborating with external partners	This team, led by an engineer and EOP champion at Boeing, is working to establish relationships with other industry partners to understand the need and willingness to establish an internship program between industry partners and academic institutions to support the professional training of sustainability-focused engineers.
	EOP Network: Team Student Guide	Planning	Since fall 2022, this team has been working to create a professional development resources guide (e.g. example interview questions, interview preparation information including key sustainability competencies and background for resumes, etc.) for students to support their efforts to work in sustainability-focused fields.
4. Funding	Lemelson & VentureWell: EOP Pilot Schools Grants	Completion	Before and since the Workshop in 2020, five $30,000 grants were awarded to five US-based higher education institutions to implement the EOP Framework into engineering courses. All schools have completed their work. Early progress and findings have been shared at conferences including at the 2022 ASEE Annual Conference.[28,29,47]
	ASEE: ASEE EOP MGP	Completion & Continuation	In 2022, $8,000 ASEE EOP MGP grants were awarded to13 US-based higher education institutions to implement the EOP Framework into engineering courses. All schools have completed their work and presentations were shared during a public online symposium on January 25, 2023.[46] Note: This program will continue in 2023 and 2024 to support 12-14 schools per annum.
	Lemelson: EOP Institutionalization Grants	Planning & Implementation	Lemelson funded two institutionalization grants in 2022 and anticipates funding additional institutionalization grants in 2023.
	EOP Network - Team Funder Landscape	Planning	Since fall 2022, working to develop a database of potential funders to support the EOP initiative in various capacities.
5. Licensure	N/A	N/A	No progress made to date.
6. Student orgs & industry partnerships	Lemelson & Engineers Without Borders (UK)	Planning & collaborating with external partners	Since 2023, working with EWB UK to establish shared resources; researching open source platforms to share findings and resource materials between students, organizations, and industry.
7. Institutional investments & supporting systems	N/A	N/A	No progress made to date.
8.Inter-collegiate collaborations & competitions	EOP Network - Team EOP Competition	Planning	Since fall 2022, focused on a soft launch of an EOP competition in March 2023 (during Engineering Week), with a view of raising funds in time to do a full launch in September 2023 during Global Goals Week 2023.
9. Institutional committees	N/A	N/A	No progress made to date.

10. Sustainability-focused student projects (internships, capstones, or special projects, etc.)	EOP Network - Team Industry Internships	Planning & collaborating with external partners	Since fall 2022, led by an industry representative from Boeing, this team is working to create a stronger "pull" from industry, reinforcing students' interest in sustainable engineering practices and providing opportunities for them to gain practical experience. They are currently working to establish industry connections by engaging with others (e.g. International Society of Sustainability Professionals (ISSP).[48]
	ASEE EOP MGP Grantee	Planning & implementation & assessment	For example, Lanju Mei of University of Maryland-Eastern Shore, developed a sustainability module to integrate in the Senior Design Project using sustainability priorities and the Whole System Mapping methodology outlined on VentureWell's Tools for Design and Sustainability website.[5,46,49]
11. Early required coursework in sustainability	EOP Pilot grantees	Planning & implementation & assessment	For example, Darshan Karwat and his team at Arizona State University modified a core, second-year course that uses project-based learning as a vehicle to deliver EOP Framework content to students across multiple engineering disciplines; the modified course was taught in a total of 14 sections, reaching 400 students.[28]
	EOP MGP grantees	Planning & implementation & assessment	For example, Roneisha Worthy of Kennesaw State University utilized the EOP Framework to help foster student ownership of education in sustainability by modifying an introductory engineering course. Students approach their choice of profession, professional respect, major retention, and dominant images within their discipline, through a justice, equity, diversity, and inclusion lens.[46]
	EOP Institutionalization grantees	Planning & implementation & assessment	For example, with the support of an EOP Institutionalization grant from TLF, a team at University of Maryland is working to expand their early EOP Pilot Grant Program efforts where EOP Framework learning outcomes were introduced into 10 required courses, including early coursework, in Civil and Environmental and Mechanical Engineering which together enroll 1,550 undergraduate students.[47]
	EOP Network members	Planning & implementation & assessment	Dustyn Roberts of the University of Pennsylvania Mechanical Engineering and Applied Mechanics Department co-developed then co-taught a course called *How To Make Things* with Taylor Caputo. They used the EOP Framework and materials from VentureWell's *Tools for Design and Sustainability* website[49] 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. Also, an EOP Network team focused on EOP Course Activities is working on creating pedagogic materials to use in STEM classes to introduce students to EOP and DEIJ concepts.
	EOP broader	Planning &	For example, Dustyn Roberts and Taylor Caputo of

	community	implementation & assessment	University of Pennsylvania's Mechanical Engineering & Applied Mechanics Department and recipients of a VentureWell Course and Program Grant, developed a sustainability-focused project for an existing core class that leveraged both the design and materials selection topic areas of the EOP Framework in which the students had to integrate aspects of sustainability into an original cast product.[44]
12. Sustainability-focused course competencies (vertical and horizontal integration, broadly), in new or existing courses	EOP Pilot grantees	Planning & implementation & assessment	For example, Andrea Welker and her team at Villanova University, introduced 16 faculty to the EOP Framework, trained them in sustainability concepts through intensive workshops, and supported them through a year-long community of practice to foster the integration and assessment of numerous framework outcomes into several civil engineering courses reaching 36% of undergraduate students and 26% of graduate students.[29]
	ASEE EOP MGP grantees	Planning & implementation & assessment	For example, Alireza Mohammad and his team at the University of Michigan-Dearborn, used the EOP Framework to bring sustainability into 4 different existing robotics courses (robotics manipulation and mobile robotics) at the 300, 400, and 500-level.[46]
	EOP Institutionalization grantees	Planning & implementation & assessment	For example, with the support of an EOP Institutionalization grant from Lemelson, a team at Arizona State University is training faculty to integrate learning outcomes from the EOP Framework into new and/or existing courses.
	EOP Network members	Planning & implementation & assessment	For example, Jorge Loyo of Rice University and the NSF Center for Nanotechnology-Enabled Water Treatment (NEWT) teaches *Sustainable Water Purification for the Developing World*, a project-based, 300-level undergraduate course on sustainable strategies for safe water supply in low-income and developing regions.[44]
	EOP broader community	Planning & implementation & assessment	For example, Marjan Eggermont, director of Sustainable Engineering in the Schulich School of Engineering at the University of Calgary oversaw an interdisciplinary engineering task force that developed a new major for the program where systems thinking is central to the new major's learning outcomes, where early sustainability coursework is required, and has mapped additional EOP Framework learning outcomes to the evolving curriculum.[50]

Appendix F

EOP Initiative Theory of Change (ToC). Taken from EOP Scaling for Impact Internal Report.[23]