Engineering for One Planet

The Engineering for One Planet Framework:

Essential Learning Outcomes for Engineering Education

Powered by ***The Lemelson Foundation***
Prepared in partnership with ***VentureWell™***

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INTRODUCTION

Engineering education creates master problem-solvers who have put a man on the moon, built the underpinnings of today's digital culture and saved countless lives through advanced medical technologies. However, there is growing recognition among leading engineering schools around the world that long-held standards of engineering excellence must shift in order to meet the rapidly changing technical and business landscape. A recent report published by MIT's School of Engineering, The Global State of the Art in Engineering Education, indicates such shifts must include integrated, student-centered approaches, multi-disciplinary learning and greater focus on socially-relevant, work-based curricula.[1]

Global environmental challenges are among the most pressing social and economic issues engineers across all disciplines are facing today. Many of these challenges are exacerbated by the products, structures and services designed, built, distributed, consumed and thrown away. Further, negative environmental impacts disproportionately impact people from historically underrepresented and marginalized backgrounds.

Generating the best solutions while minimizing potential negative environmental consequences requires that engineers be equipped to anticipate and avoid those consequences. And because engineers impact nearly everything human-made, all engineers – no matter what subdiscipline - must be equipped to protect our planet and the life it sustains. This requires a fundamental change in the approach to preparing the engineers of tomorrow. Integration of the skills, knowledge, experiences and mindsets of the Engineering for One Planet Framework across engineering disciplines is critical to engineering education excellence now and in the future.

Engineering education operates within a complex system of interdependent stakeholders and policies, all of which exert forces on education but do not work in unison. Among these stakeholders are professional engineers, engineering employers, professional engineering societies, engineering education accreditation bodies, government regulators and consumers. Efforts to change engineering education, such as the Engineering for One Planet initiative, must acknowledge, account for, understand, and engage the interests of diverse stakeholders and foster collaboration.

Challenge

As the world becomes more crowded, the constraints of the planet become more clear – natural resources are being consumed at unprecedented rates, waste is literally choking wildlife and the Earth's carbon dioxide level has reached a potentially irreversible level. Despite the significant growth in course and program offerings that focus on a number of sustainability topics (e.g., Sustainable Engineering, Green Engineering, Environmental Engineering, etc.), engineering students are not ubiquitously prepared with the fundamental skills, knowledge and competencies needed to effectively navigate planetary constraints. Higher education faculty, leaders and institutions are seeking to change this, but they need resources and tools to support the requisite scale and urgency of curricular transformation.

Opportunity

Collectively, there is more knowledge than ever about how to both generate solutions to pressing challenges and avoid contributing to future undesirable environmental impacts. Students, professionals, educators, consumers, corporations and governments around the world are demanding greater responsiveness and planetary protection. There is the will to change the engineering profession, and organizations around the world are taking action.

Several National Academy of Engineering (NAE) reports have highlighted the need for changes in engineering education that take into account social, cultural and environmental impact. The NAE Grand Challenges for Engineering, launched in 2008, calls for: "Continuation of life on the planet, making our world more sustainable, secure, healthy, and joyful."[2] A recent report by the National Academies of Sciences included a number of recommendations for advancing sustainability education, including "Academic institutions of higher education should embrace sustainability education as a vital field..."[3]

ABET (The Accreditation Board for Engineering Technology) —the global accrediting body for the applied and natural sciences, computing, engineering, and engineering technology — requires every accredited engineering program to ensure students have "an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts."[4]

Professional engineering associations are also taking action to prepare engineers to consider a broader range of implications of their work. For example, in 2008, the American Society of Mechanical Engineers (ASME) formed the Vision 2030 taskforce to explore the need for change in the mechanical engineering profession and education. Its 2011 report stated, "...students need to lead not only technically but also socially, politically, and ethically. In addition to technical skills, our future engineers need to be given communication and people skills, business sense, a global perspective and an unparalleled understanding of our environment, to foster both compassion and passion for our planet."[5] In 2018, the International Federation of Engineering Societies issued the Peace Engineering and Sustainability Declaration stating that "...just as it continues to enable undreamt improvements in quality of life for many people of the world and to generate abundant material value, so too does technological innovation enable unprecedented crises - this is the law of unintended consequences.

At the core of Peace Engineering is our planet's sustainable future, which is calling leaders to act in concert from a systems mindset...."[6]

By accelerating the integration of core skills in environmental sustainability across engineering education, future engineers will be equipped to design, build, code and invent with the planet and the life it sustains in mind.

BACKGROUND

Engineering for One Planet

Mobilized by The Lemelson Foundation and VentureWell with input from hundreds of stakeholders across myriad sectors, the Engineering for One Planet (EOP) initiative is working to transform engineering education to enable all future engineers to be equipped with fundamental principles of environmental sustainability.[7]

More than 200 stakeholders from academia, industry, policy and non-profit organizations, contributed to the development of the EOP initiative through research, interviews and focus groups. Their feedback led to the development of a draft definition and framework for Engineering for One Planet. People from diverse sectors and disciplines, including a range of engineering disciplines, have been collaborating to co-develop the EOP Framework (Framework) with the goal of making environmental sustainability part of the DNA of all engineering departments.

The first draft of the Framework was initially refined between September and November 2019 through public comment and collaboration from a global network of stakeholders. Nearly 90 individuals from academia, industry, policy and non-profit sectors directly edited the initial draft Framework through more than 430 comments and over 1,000 peer-to-peer interactions. This global network included engineering professors and administrators, designers, inventors, professionals, as well as philanthropic, nonprofit and policy leaders versed in sustainability, sustainable design and engineering with a focus on environmental sustainability. The Framework will continue to evolve as more stakeholders engage with it and educators test it in diverse engineering courses.

The Framework comprises a set of fundamental environmental sustainability learning outcomes believe all graduating engineers, regardless of subdiscipline, need to acquire in order to design, code, build and implement engineering solutions, structures, designs, products and services that minimize negative impacts on the planet and the life it sustains.

Developed for flexible adoption into a diverse range of higher education engineering courses, programs and institutions, the Framework is the first implementation tool of the EOP initiative. Through the process of co-development, collaborators have also been surfacing and sharing relevant curricula and educational tools. From these existing assets, and a growing community of collaborators, the EOP initiative will facilitate the development of new tools and resources to accelerate faculty capacity-building, teaching efforts and institutional change. While engineering is the focal point for the EOP initiative, there may be opportunities to leverage the Framework and learnings to create future curricular change in other disciplines.

Strong Collaborative Community

Broadly, the EOP initiative builds upon, bridges and strengthens the collective efforts of individuals and institutions working to ensure engineers are environmentally conscious in their work. Tactically, it is mobilizing an international community of stakeholders from both inside (i.e., students, faculty, administrators) and outside (i.e., professional associations, industry, government, NGOs) the higher education ecosystem. Working together, this group will continue to identify shared objectives, co-define educational outcomes and accelerate change. In an effort to foster an inclusive and equitable process, the Framework has been and will continue to be shared with a growing network and diversity of stakeholders to ensure that all voices are heard and incorporated —including often marginalized, underrepresented and underserved groups— to shape a new future for engineering that reaches far beyond business as usual.

Terminology and Interdependencies

The term "sustainability" encompasses a vast range of potential practices and definitions.

The Importance of a Collaborative Approach

Engineering graduates are not ubiquitously prepared with EOP knowledge, skills and competencies. Mobilizing the community's collective will and tapping diverse lived experiences and expertise in sustainability, ethics, green engineering, green chemistry, environmental responsibility and other topics, can accelerate changes in engineering courses and programs.

1. A growing number of stakeholders from academia, industry, government and non-profit organizations around the world are calling for urgent action to bring about greater environmental and social responsibility in the products, structures, software and materials that are developed, built, coded, invented and taken to scale. Collaboration among these groups can improve and accelerate progress toward shared goals. Working alone, it can be difficult for individuals to harness the knowledge and resources necessary to achieve and sustain the systemic changes necessary to help support educational and institutional transformation.

2. Diverse voices and perspectives need to be heard in order to ensure that the EOP serves all people, including those who are not only disproportionately negatively impacted by environmental issues but also most likely to have their needs underrepresented in change efforts.

In this document, the phrase "environmental sustainability" references practices that mitigate potential negative impacts and/or enable increased positive impacts on the Earth's living systems.

The EOP initiative originally focused solely on environmental impact considerations. However, this community has also acknowledged that environmental issues are human-based issues with social, cultural and economic impacts, and that it is impossible to solve the environmental problems without considering the context of people, including communities that are often underserved, underrepresented and marginalized. For example, climate change —a global-scale environmental issue— is already becoming a humanitarian crisis negatively impacting millions of lives, and disproportionately so for those with the least access to resources. For this reason, the community has worked together to integrate social/cultural and business/economic factors within the environmental context of this effort. The community has identified numerous interdependencies to achieve the ultimate outcome of preserving human and non-human life and health, which are dependent on natural systems and where the consequences of not doing so are not borne equally across populations (e.g., marginalized groups). Getting there requires equipping future engineers with the knowledge, understanding, skills, experiences and behaviors to be able to target and understand the global issues that we collectively face and to arrive at solutions together.

A Tool for Change

This Framework is intended to be used as a **tool** for organizing and modifying existing curricula and experiences to incorporate core and advanced competencies, in the form of student learning outcomes, into engineering courses and programs according to individual institutional systems and protocols.

Other frameworks that are successfully advancing institutional changes in academic institutions are helping to inform approaches for supporting the integration and implementation of the Framework in engineering courses and programs. These existing efforts demonstrate best practices and provide insights on barriers and pitfalls to avoid, including the fact that institutions vary and accordingly successful pathways will also vary depending on a number of factors, for example: school size, funding, support staff, faculty and dean engagement, existing sustainability programming, etc. Therefore, institutional changes will require different types and levels of support to flourish.

This document does not provide insights into approaches for implementing the Framework ("the how") or provide materials and resources to support the integration and implementation of the Framework. However, concurrent efforts are taking place to facilitate the integration and teaching of EOP. Refer to *Engineering for One Planet* for a list of Critical Tools and Guides, and Pedagogical Approaches and Delivery Methods.[8]

Foundations of the Framework

In addition to the collective knowledge of hundreds of stakeholders, the Framework draws upon numerous existing frameworks, courses, programs and definitions. Sustainability-focused efforts within engineering education have existed for several decades, **sometimes longer**. Further, a growing number of institutions, departments and faculty of engineering —as well as some organizations and industries— are leading outstanding efforts and outcomes in this arena.

In co-developing the Framework, the community of collaborators has drawn upon established disciplines (e.g., Sustainable Engineering, Green Engineering, Green Chemistry). Important approaches in undertaking this effort included the:

- open structure and collaborative approach for co-developing the Framework
- large-scale, global community mobilized and motivated to ensure collective impact
- attempt to create learning outcomes that could be integrated into existing courses, across diverse engineering disciplines
- approach to capturing and sharing of learnings and tools that could be used by other communities

The Framework offers a distillation of competencies considered to be the core student learning outcomes that all engineering students need to learn, understand, experience and put into practice for EOP. If staff time, budget and faculty experience are available, the Framework outlines advanced competencies that build on core learning outcomes to enable students to achieve greater proficiency.

ABET Outcomes Directly Addressed by Framework

1. *an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics,*
2. *an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety and welfare, as well as global, cultural, social, environmental and economic factors,*
3. *an ability to communicate effectively with a range of audiences,*
4. *an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental and societal contexts, and*
5. *an ability to function effectively on a team (see Appendix C: Glossary of Terms) whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan task and meet objectives.*[9]

Relevance to Engineering Accreditation

ABET defines the accepted attainment standards that will prepare graduates to enter the professional practice of engineering. In 2000, ABET moved to a student outcomes-based assessment that included suggestions for environmental considerations. In 2017, the Engineering Accreditation Commission (EAC) approved new ABET language and criteria which *required* accredited programs to ensure students be exposed to social, environmental, and economic considerations, among others (applicable beginning in the 2019-2020 accreditation cycle).[1] All ABET accredited engineering programs must adhere to and achieve accreditation from the EAC and must demonstrate that their programs satisfy all of the General Criteria for Baccalaureate Level Programs. The Framework works within these boundaries and specifically supports engineering programs to achieve five of ABET's seven student outcomes under Criteria 3 (aka, "Student Outcomes"). Two of these student learning outcomes are directly connected to environmental contexts. However, it should be noted that ABET student outcomes do not require graduating engineers to acquire a specific depth of knowledge, skills and experiences. It also does not make a distinction between developing student understanding of the environmental impact of a product (or structure, software, etc.) or the impacts of the materials or processes used in creating, distributing, using and discarding the engineered products, codes, structures, etc. The Framework collaborators recommend —where possible— that engineering programs adopt the core student outcomes identified in the Framework, thereby not only meeting, but also surpassing ABET's current requirements.

Relevance to the United Nations United Nations (UN) Sustainable Development Goals (SDGs)

In September 2015, a UN summit was convened as a high-level plenary meeting of the General Assembly in New York. An instrumental outcome of this summit was the Agenda 2030, considered today as the world's preeminent "plan of action for people, planet and prosperity."[10] At that time it was deemed that, "all countries and all stakeholders, acting in collaborative partnership, will implement this plan," and that together we will, "take the bold and transformative steps which are urgently needed to shift the world onto a sustainable and resilient path." The 17 UN Sustainable Development Goals (SDGs) were announced at the summit. The SDGs, and the UN Millennium Development Goals prior to the SDGs, represent an evolution and continuation of the Bruntland Commission of 1987 which is the origin of the concept of sustainable development.[9] One of the 17 SGDs is directly tied —and highly relevant and influential to— the field of engineering: *Goal #12: Ensure sustainable consumption and production patterns.*

The framework collaborators called for a mapping of the Framework to the SDGs. Because each decision for "responsible consumption and production" as described by Goal #12 affects all other SDGs, this goal offers the best framing for engineering's interconnected social, environmental and economic contexts. Specifically, the Framework maps to the cognitive, socio-emotional and behavioral objectives outlined in Goal #12.[12]

FRAMEWORK STRUCTURE

EOP Defined

A curricular definition and framework of EOP has not previously existed. Like the student outcomes, the following working definition of EOP has been informed through research involving hundreds of stakeholders and was further refined during the online open commenting period of the Framework from September – November, 2019.

Student Learning Outcomes

To be useful, the Framework must be pragmatic for the target audience: engineering faculty and administrators. Therefore, the Framework is designed to be widely adaptable and adoptable. If prescriptive or overly onerous, it risks not being adopted. Still, a framework that lacks sufficient rigor and depth will not adequately advance student knowledge and skills, a key concern that catalyzed the development of the Framework.

The Framework therefore prioritizes the core student outcomes identified as the most critical for integrating into existing curricula.

When defining learning outcomes for students, the Framework uses ABET's (2017) definition of "Student Outcomes" as follows: "*Student outcomes describe what students are expected to know and be able to do by the time of graduation. These relate to the knowledge, skills and behaviors that students acquire as they progress through the program.*"

Engineering for One Planet Framework Defined

The EOP framework outlines the cross-cutting knowledge, awareness and competencies needed to design, build, manage and implement engineering solutions that minimize negative impacts, strive to achieve at least net neutral outcomes, and, ideally, are restorative. EOP will enable engineers to be better equipped to create positive outcomes for the planet and the life it sustains, now and for future generations, and to help ecosystems recover and thrive when possible. Rather than a new discipline, EOP comprises the fundamental learning outcomes that every graduating engineer —regardless of subdiscipline, institution, identity or geography— needs to acquire to excel as engineers operating within our planet's constraints. By possessing the basic knowledge, understanding, skills, experiences and behaviors of EOP, future engineers will be prepared with the competencies to ensure that engineering disciplines do not inadvertently harm but seek to enhance the well-being of humans and the living planet.

Drawing from and aligning with ABET's definition for student outcomes, the Framework is structured around student outcomes under three main categories: "**systems thinking**", "**knowledge and understanding**" and "**skills, experiences and behaviors**."

Systems Thinking

Systems thinking is called out above and beyond the other two categories because the community identified systems thinking *from an environmental perspective* as the most fundamental concept and approach that students must learn. Systems thinking is central to and interconnected with all of the other student outcomes. Despite the fact that 'systems thinking' is ubiquitously taught in engineering programs across the US, the learning outcomes may center on component parts of a design, rather than the consideration for broader boundaries such as the environment. Collaborators believe engineering education must expand the boundary of systems thinking, for example by considering the ecological and social systems they operate in, and to develop more holistic and integrated systems thinking mindsets. Systems thinking is a critical approach for engineers to understand that designs rely upon and exist within systems, to identify the impacts and influences of the different and interconnected environmental, economic and social factors of the design system and to recognize that their designs themselves are systems.

Knowledge and Understanding

The student outcomes listed under the knowledge and understanding category are broadly defined by these questions:

- Why should students learn these theories or concepts?
- What is most critically important that students be aware of, be familiar with, learn, know and understand to become competent environmentally responsible engineers?

The knowledge and understanding category is divided into three main topic areas:

- Environmental literacy
- Social responsibility
- Responsible business and economy

Skills, Experiences and Behaviors

The skills, experiences and behaviors category is broadly defined by these questions:

- What technical and practical skills must all engineers have to become competent to become competent in environmental sustainability?
- What values, behaviors and an ethos of responsibility to society and culture do students need to experience and practice in order to practice environmentally sustainable engineering?

- What skills and behaviors do students need to experience and practice to be leaders of change by influencing others (e.g., collaborators, colleagues and peers; management and shareholders; procurement and supply-chain managers; regulation and policy makers; key project stakeholders; etc.) to practice environmentally sustainable engineering?

The skills, experiences and behaviors category is divided into two subcategories that are further broken down into topic areas as are listed below:

- Technical skills
    - Environmental impact measurement
    - Materials choice
    - Design
- Leadership skills
    - Critical thinking
    - Communication and teamwork

Under each topic area, there is a list of **core student outcomes** followed by **advanced student outcomes**. Core student outcomes are intended as prerequisites to the advanced student outcomes listed below; core outcomes are <u>not</u> repeated in advanced outcomes. The assumption is that core outcomes would be integrated first. Advanced topics are also provided for institutional adoption as resources and interests allow. The community encouraged the adoption of all core and advanced outcomes, but recognized that this will not be possible at every institution due to available “space” in courses, faculty time and expertise, obtainable institutional support, etc.

Despite being listed separately, the student outcomes are interdependent and interconnected. In an effort to ensure that the Framework is pragmatically useful and applicable across engineering disciplines, the community developed distinct categories as a practical solution for organizing topics.

The depth of mastery of student outcomes within the topics vary widely from “is aware of” or “familiar with” to “is able to….” The community considered the following guiding questions to qualify the suggested depth of each student outcome:

- What level of depth is considered sufficient for a student to demonstrate proficiency in the learning outcome?
- When a student becomes proficient in the collection of learning outcomes under each topic area —to the depth and degree articulated— is their overarching knowledge of this topic sufficient?
- When a student acquires each of the core outcomes for each topic area, would they graduate with the ability to approach each of the design problems they will face as professionals with the depth of knowledge, understanding, skills, experiences and behaviors to be empowered to think beyond business as usual?

The EOP Framework

Note: Please see Appendix A for a summary graphic of the core elements of the EOP Framework.

Throughout the Framework the identifier ∞ is used to denote when a Framework student learning outcome is directly tied to the SDG Goal #12 learning outcomes.

The identifier Δ is used to denote when a Framework student learning outcome is directly tied to an ABET student outcome as described in Criteria 3.

SYSTEMS THINKING

- Interconnectedness to ecological system$^{\Delta}$
- Tradeoffs and impacts within systems$^{\Delta}$
- Designs are systems$^{\Delta\infty}$
- Connection and collaboration with other disciplines$^{\Delta\infty}$
- Planetary system boundaries$^{\infty}$

SYSTEMS THINKING

CORE

- Demonstrates whole system awareness with the ability to identify and understand interconnectedness (intersecting, related and/or connected systems; synergies and rebound effects) and how all human-made designs rely upon and are embedded within ecological systems[Δ]
- Is able to consider and understand tradeoffs and identifies impacts between different parts of the system (i.e., environmental, economic and social considerations)[Δ]
- Demonstrates awareness that a design is a system, that users interact with designs and that designs and users are embedded in higher level systems that include environmental ecosystems and the life they sustain[Δ]∞
- Demonstrates awareness that all work is connected to other disciplines and understand when and how to collaborate and consult with others[Δ]∞
- Is able to consider the scale of the activity relative to the planetary system boundaries (i.e., carrying capacities)∞

ADVANCED

- Is aware of the implications of system dynamics in real-world systems —both natural and human-built— by understanding concepts including feedback loops, tipping points and system resilience
- Is able to visually map systems, including causal loop diagramming
- Is familiar with system archetypes (i.e., the tragedy of the commons), ecosystem services and key concepts in system dynamics∞
- Is able to consider temporal outcomes of present decisions (i.e., life-cycle effects through time for future generations)∞

ENVIRONMENTAL LITERACY

CORE

- Demonstrates knowledge of the basic facts and ability to quantify data about important (current/past/future and local/regional/global) environmental issues (e.g., climate change, water use, scarcity and pollution, air quality, waste management, toxicity, etc.)[Δ]∞
- Understands and foresees opportunities to solve environmental challenges (i.e., social, economic and environmental benefits)[Δ]∞
- Demonstrates knowledge and understanding of whole life-cycle and closed-loop systems thinking as related to the impact of their work (e.g., understanding of life-cycle burdens of design alternatives)
- Demonstrates knowledge and understanding of key global ecosystem services (i.e., water, carbon, energy and nitrogen cycles, as well as nutrient cycling, soil formation, pollination, waste decomposition, etc.) and how they are interconnected∞

ADVANCED

Photo: wolfgang-hasselmann

- Is aware of key environmental laws, ethics and policies at the regional, national and global levels and ability to consider ethical implications beyond current compliance and political boundaries[Δ]∞
- Is knowledgeable about abiotic assets (e.g., fossil fuels, minerals, metals) and flows (e.g., wind and solar energy) and biotic natural capital (e.g., ecosystems)∞
- Is knowledgeable about key ecosystem services and functions including provisioning services, regulating and maintenance services, cultural services and supporting services (e.g., material cycles, energy cycles)∞

SOCIAL RESPONSIBILITY

CORE

- Is familiar with the United Nations Sustainable Development Goals (SDGs)∞
- Is able to articulate and understands how engineering activities directly and indirectly cause positive and negative social/cultural impacts throughout the design life-cycle, both to workers producing the products (i.e., labor practices, livelihood, health, etc.) and to communities and society (i.e., resources acquisition, waste production and management, traditional/cultural methodologies, etc.), and is aware that some communities have historically been negatively impacted and/or minoritized$^{\Delta}$∞
- Understands the role of social responsibility in the engineering profession (i.e., policies, laws, social justice, etc.)$^{\Delta}$∞
- Is able to identify relevant cultural implications and influences in the context of their work (e.g., cultural expressions and sensitivities, services and goods procurement, heritage site appreciation) as well as equity awareness (e.g., gender, race, ethnicity, class, etc.)$^{\Delta}$∞
- Is familiar with ways to create robust, dynamic and resilient systems and ways to develop transdisciplinary stakeholder networks

ADVANCED

- Is aware of the breadth of social justice issues, indigenous rights, laws, policies and commitments (e.g., Global Compact (GC))$^{\Delta}$∞
- Is aware as a global citizen of social and cultural implications related to local, regional and global materials use (e.g., land changes, surface and groundwater use and pollution, air pollution, toxins, labor rights, land tenure, etc.) and recognizes that impacts are disproportionately borne by low income and minority groups$^{\Delta}$∞
- Understands ethical implications relative to social impact of their work$^{\Delta}$∞

RESPONSIBLE BUSINESS AND ECONOMY

CORE

- Is able to forecast the near- and long-term costs and value of their work to the environment and society through the efficient use of resources (e.g., efficient for whom?) and socially/culturally responsible engagement with stakeholdersΔ∞
- Is aware of risks and opportunities related to changing environments on their work (e.g., extended costs, value, trade-offs, partnerships, regulations, policies, etc.)∞
- Is familiar with alternative business, revenue and entrepreneurship models (e.g., B Corps, product service systems, sharing economy platforms, cooperatives, indigenous practices/sensibilities, etc.)∞
- Demonstrates high-level understanding that different business models can positively or negatively influence environmental and social systems as a result (e.g., shared ownership models, service models, leasing with take-back instead of asset sales for planned obsolescence, employee-owned, public-private partnerships, business-NGO collaboration models, etc.)∞
- Is able to recognize opportunities and demand for new business models, such as models that leverage product durability (e.g., renting, upgradeability, repairability, modularity, resale, etc.)
- Demonstrates familiarity with alternative forms of capital beyond financial resources (including natural, human, social and physical) and awareness of emerging economic systems intended to promote environmental and social responsibility in economic thinking (e.g., Doughnut Economics (Raworth, 2017), circular economy, etc.)[13]∞

ADVANCED

- Is aware of International Organization for Standardization (ISO) based management systems (e.g., Environmental, Health and Safety (EHS), Global Reporting Initiative (GRI), quality, etc.) as tools to enable systematic integration of environmental impact management into business practices
- Is able to evaluate their supply chain agents, vendors, etc. from environmental and social perspectives∞
- Is aware of and can find funding sources for public infrastructure∞

ENVIRONMENTAL IMPACT MEASUREMENT

CORE

- Is familiar with high-level environmental impact measurements (e.g., basic life-cycle assessments and life-cycle hazards; i.e., how they work, what information they require, how to incorporate their findings into their work)
- Is able to understand eco-labelling systems and certificates (i.e., EPEAT, Energy Star) for sustainable production and consumption∞
- Is able to assess broader energy, climate, water, wastewater, air pollution and land-use implications of their work∞
- Is able to analyze complex or contradictory information and make decisions among tradeoffs (i.e., What is the cost of the decision? Who and what will be most impacted by the decision? Are marginalized communities being considered?)[Δ]∞

ADVANCED

- Is able to conduct basic environmental impact measurements (e.g., life-cycle assessments, carbon footprints, etc.)
- Understands and is able to access EHS standards, data (e.g., chemical hazard assessments, how to research chemical safety, etc.) and specifications for inputs, outputs and performance levels of engineered products and services[Δ]
- Understands and is able to articulate relative impact reduction vs. absolute impact reduction (e.g., greenhouse gas (GHG) emissions)

MATERIALS CHOICE

CORE

- Is able to select materials and consider design alternatives that enable a long functional lifetime, have reduced, minimal, no harm, or are restorative to people and environmental ecosystems$^{\Delta}$∞
- Is aware of the potential impacts of the materials through the supply chain —from raw material extraction through manufacturing, use, reuse/recycling and end of life— with a focus on minimizing negative impacts to the planet and all people (i.e., considering impacts to minoritized groups)$^{\Delta}$∞
- Is able to analyze and understand the environmental and social impacts of designs created by others$^{\Delta}$∞
- Finds, reviews, understands and incorporates current environmental assessment research∞
- Demonstrates working knowledge of physical and structural properties and uses of natural materials (e.g., earth, bamboo, agro-waste, etc.) to an aligned degree of knowledge of industrial materials (e.g., iron, steel, aluminum, etc.)

MATERIALS CHOICE

ADVANCED

- Is able to conduct assessments and weigh trade-offs that guide selection of design-appropriate materials (e.g., technical considerations including strength, weight, cost, material compatibility and thermal properties)$^{\Delta}$∞
- Is able to utilize tools and resources for identifying potential impacts of the materials through the supply chain throughout the entire life-cycle —from raw material extraction through manufacturing, use, reuse/recycling and end of life— with a zero waste and restorative perspective∞
- Understands materials composition and that macro materials include those with structural properties (e.g., concrete, metals, plastics, etc.) and functional properties (e.g., chemicals and intermediaries), and that substances of concern (often micro materials, chemicals and nanoparticles) can be bound up in engineered products
- Is able to apply systems perspective and calculate embodied energy of materials to make informed decisions
- Is able to identify innovation gaps in our existing materials choices and how to help spur appropriate research and development
- Is able to assess EHS aspects of materials (e.g., toxicity, chemical hazard assessments, green chemistry, etc.)$^{\Delta}$∞
- Is able to access and understand sustainability reports and data (e.g., Global Compact, Global Reporting Initiative, etc.) and to draw upon leading research published in relevant journals∞
- Is able to comprehend and articulate the implications of the scale of impacts of material consumption∞

DESIGN

CORE

- Is able to set design goals and use technical analyses to choose strategies that minimize environmental impact$^{\Delta}$∞
- Is able to design for the environment based on discipline-specific technical skills (e.g., light-weighting, design for repairability and durability, design for upgradeability, design for disassembly, flexibility, and reuse, design for part or whole recovery, etc.)$^{\Delta}$
- Creates innovative approaches for tackling environmental problems or preventing negative environmental impacts including creative solutions within supply chains$^{\Delta}$∞

ADVANCED

- Is able to conduct stakeholder user experience/ participatory studies (e.g., design thinking, human-centered design) and social impact assessments to meet user needs in responsible, novel, improved and sustainable ways$^{\Delta}$∞
- Is able to design with approaches that incorporate whole life-cycle and systems thinking$^{\Delta}$
- Works across disciplines to develop creative trans-disciplinary ideas and solutions in engineering contexts along with social and cultural values (e.g., habitat, construction and health that is attuned to and respectful of social values, etc)$^{\Delta}$∞
- Is aware of and is able to seek, evaluate, adapt and give credit back to local craft traditions, indigenous knowledge systems and vernacular practices and innovate inclusive and regenerative solutions$^{\Delta}$∞
- Is familiar with and able to strategically leverage systems dynamics concepts in their designs (e.g., feedback loops, complex cause-effect chains, cascading effects, inertia, tipping points, legacy, resilience, adaptation, etc.)∞
- Is able to design for use in alternative business models and emerging economic contexts$^{\Delta}$

Note: The community of collaborators recognized that while the skills in this section may not typically be identified as specific to engineering, they are necessary to enable engineers to be successful environmental stewards and collaborations across disciplines.

CRITICAL THINKING

CORE

- Is able to define problems comprehensively with consideration of consequences, unintended and intended[Δ]∞
- Demonstrates ability to consider and make discernments among complex ethical and values-based choices, employing empathy when evaluating conflicts of interest, trade-offs and uncertain knowledge and contradictions within problem constraints[Δ]∞
- Demonstrates self-awareness and ability to be a reflective practitioner with values, empathy and guardianship of one's immediate environment[Δ]∞
- Understands and reflects on the norms and values that underlie one's behaviors (i.e., normative thinking)[Δ]∞
- Understands that every person has a role in being environmentally responsible and has the right to be informed about the environmental/social/economic impacts of the products they purchase, consume and discard[Δ]∞

ADVANCED

- Is able to interpret and incorporate qualitative and quantitative research
- Understands the pros and cons of incremental vs. radical innovations
- Considers, understands and experiences different perspectives, opinions, views, etc., and is able to articulate varying standpoints (i.e., normative thinking)[Δ]∞
- Is able to identify, assess and justify issues and actions of environmental and social priority, and is able to evaluate and prioritize appropriate solutions based on the context of the problem in collaboration with other stakeholders and experts[Δ]∞
- Understands and evaluates possible, probable and desirable futures and to create one's own visions for the future∞
- Anticipates and assesses the consequences of one's actions and to deal with risks and changes (i.e., apply the precautionary principle)[Δ]∞

COMMUNICATION AND TEAMWORK

CORE

- Communicates through audience-specific written, graphic/visual, oral and interpersonal communication skills, in order to$^{\Delta}$∞
    - sell, pitch and explain ideas and advance learning
    - advocate for underrepresented groups
    - drive organizational change
    - maximize team effectiveness
    - work well with others, across disciplines and cultures
- Is able to prioritize projects, schedules, and time and manage people equitably$^{\Delta}$
- Is able to lead teams$^{\Delta}$∞
    - demonstrates leadership capability
    - evaluates team effectiveness
    - motivates team
    - recognizes team member strengths/weaknesses
    - contributes to group problem-solving and effectiveness
    - organizes work breakdown structures and project scheduling
- Works within and functions well across disciplines$^{\Delta}$∞
    - participates actively
    - demonstrates initiative
    - participates in group decision-making
    - shares workload
- Interacts with, collaborates on and leads multidisciplinary teams, effectively representing an engineering perspective in a comprehensible manner through project-based work$^{\Delta}$∞
- Is able to debate, negotiate and champion the ER values and approaches (e.g., to management, procurement, marketing, etc.) to maintain the integrity of design criteria across environmental and human dimensions$^{\Delta}$∞

COMMUNICATION AND TEAMWORK

ADVANCED

- Is able to build and maintain relationships through quality interpersonal skills$^{\Delta\infty}$
    - displays emotional intelligence and is empathic
    - communicates on teams effectively
    - is an effective listener and willing to be influenced and changed by the views of others
    - understands and considers different perspectives
    - is respectful
    - engages in conflict constructively (i.e., gains alignment to move forward, resolves differences, etc.)
    - understands power dynamics
- Is able to explain and communicate technical and engineering concepts and evidence (e.g., LCA outcomes) to the public and to clients/customers to influence understanding and acceptance of environmental considerations and decision-making$^{\Delta\infty}$
- Is able to apply systematic, disciplined and collaborative project management methodologies in order to effectively manage teams and themselves$^{\Delta}$

Acknowledgement of Collaborators

The EOP initiative began in 2017. Hundreds of conversations, interviews and surveys with subject matter experts from academia (e.g., faculty, students, administrators), professional associations (e.g., ASME, ASEE, ASCE, ACS, ISEE), non-profit organizations, government and industry. The draft Framework, including introduction and background text, was distributed for public comment during September 2019 – November 2019. There were also four online video conversations to collect additional feedback and discuss questions or areas of debate. Over the course of the two-month open commenting period, the Framework was shared with thousands of stakeholders through a variety of methods including: direct email invitations, peer-to-peer sharing, social media networks, online conversations and online surveys. Over 430 direct comments and more than 1,000 peer-to-peer interactions (in the form of responses to one another's comments) were made by stakeholders to revise and refine the Framework. To date, the Framework has been reviewed, commented upon, validated and/or supported by nearly 100 stakeholders, captured in the List of Collaborators (see Appendix B) to create this document.

Thank you to everyone who took the time to contribute. We are deeply grateful for the collaborative energy that has grown throughout this project. Community members are eager to continue advancing this work by further testing and refining the Framework with additional stakeholders and using it in actual courses. Work will also be taking place to pilot the integration of the Framework in curricula in diverse institutions and to create tools for teaching the next generation of engineers the core student outcomes identified in the Framework.

About VentureWell

VentureWell is on a mission to cultivate inventors, innovators and entrepreneurs driven to solve the world's biggest challenges and create lasting impact. Since VentureWell's inception nearly 25 years ago, more than 7,500 science and technology inventors and innovators have been supported and trained, and thousands of their startups have been nurtured to reach millions of people in over 50 countries with groundbreaking technological advancements in fields such as biomedicine and healthcare, energy and materials, and solutions for low-resource settings. To cultivate a pipeline of promising student inventors, VentureWell actively supports faculty in developing programs and initiatives to transform innovation and entrepreneurship (I&E) education through grants, workshops, trainings and conferences. To date,VentureWell has provided over $12MM in grants to faculty at over 1,000 schools that has led to the creation of more than 500 new or improved courses and programs at higher educational institutions across the country, engaging thousands of students.

To learn more about Venturewell's work and resources for early-stage innovators and the faculty that support them, visit venturewell.org.

About The Lemelson Foundation

The Lemelson Foundation uses the power of invention to improve lives. Inspired by the belief that invention can solve many of the biggest social and economic challenges of our time, Lemelson helps the next generation of inventors and invention-based businesses to flourish. The Lemelson Foundation sees its role as a convener and collaborator in cultivating a new generation of inventors and problem solvers who view environmental responsibility as a central tenet to the design, manufacturing, distribution and disposal processes for new products and services. Together with a growing community of individuals and organizations, Lemelson is working to ensure all engineers develop environmental stewardship skills to minimize future harm to the planet and the lives it sustains.

Established in the early 1990s by prolific inventor Jerome Lemelson and his wife Dorothy, The Lemelson Foundation continues to be led by the Lemelson family. To date, grants totaling more than $270 million have been made in support of the mission.

For more information, visit lemelson.org.

Join the EOP Initiative

Everyone interested in this work is encouraged to participate. Sign up for updates or submit your feedback by emailing info@engineeringforoneplanet.org.

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Appendix A: Engineering for One Planet: Core Student Learning Outcomes

Cross-referenced with Engineering Accreditation Requirements and United Nations Sustainable Development Goals

SYSTEMS THINKING

- Interconnectedness to ecological system $^{\Delta}$
- Tradeoffs and impacts within systems $^{\Delta}$
- Designs are systems $^{\Delta\infty}$
- Connection and collaboration with other disciplines $^{\Delta\infty}$
- Planetary system boundaries $^{\infty}$

COMMUNICATION & TEAMWORK

- Communicates through audience-specific written, graphic/visual, oral and interpersonal communication skills $^{\Delta\infty}$
- Prioritizes projects, schedules, and time and manages people equitably $^{\Delta}$
- Leads teams $^{\Delta\infty}$
- Works within and functions well across disciplines $^{\Delta\infty}$
- Interacts with, collaborates on and leads multidisciplinary teams $^{\Delta\infty}$
- Champions ER values and approaches $^{\Delta\infty}$

ENVIRONMENTAL LITERACY

- Environmental literacy
- Basic facts and quantify data about important environmental issues $^{\Delta\infty}$
- Opportunities to solve environmental challenges $^{\Delta\infty}$
- Whole life-cycle and closed-loop systems thinking
- Key global ecosystem services $^{\infty}$

RESPONSIBLE BUSINESS & ECONOMY

- Forecast the near- and long-term costs and value $^{\Delta\infty}$
- Risks and opportunities of changing environments $^{\infty}$
- Alternative business, revenue and entrepreneurship models $^{\infty}$
- Business models can positively or negatively influence environmental/social systems $^{\infty}$
- Opportunities and demand for new business models
- Alternative forms of capital $^{\infty}$

SOCIAL RESPONSIBILITY

- United Nations Sustainable Development Goals (SDGs) $^{\infty}$
- Engineering activities directly and indirectly cause positive and negative social/cultural impacts $^{\Delta\infty}$
- Role of social responsibility $^{\Delta\infty}$
- Cultural implications and influences $^{\Delta\infty}$
- Resilient systems and transdisciplinary stakeholder networks

ENVIRONMENTAL IMPACT MEASUREMENT

- Environmental impact measurement skills
- High-level environmental impact measurements
- Eco-labelling systems and certificates $^{\infty}$
- Assess broader energy, climate, water, wastewater, air pollution and land-use implications $^{\infty}$
- Analyze complex or contradictory information and make decisions among tradeoffs $^{\infty}$

MATERIALS CHOICE

- Design-appropriate materials $^{\Delta\infty}$
- Potential impacts of materials through supply chain $^{\Delta\infty}$
- Environmental/social impacts of others' designs $^{\Delta\infty}$
- Current environmental assessment research $^{\infty}$
- Physical/structural properties and uses of natural materials

DESIGN

- Sets goals to minimize environmental impact $^{\Delta\infty}$
- Design for environment using discipline-specific technical skills $^{\Delta}$
- Creative solutions for environmental problems $^{\Delta\infty}$

CRITICAL THINKING

- Define problems comprehensively $^{\Delta\infty}$
- Make ethical, empathetic and values-based choices $^{\Delta\infty}$
- Self-aware and reflective practitioner $^{\Delta\infty}$
- Understands normative thinking $^{\Delta\infty}$
- Role of environmental responsibility $^{\Delta\infty}$

Legend

Δ Is used to denote when a Framework student learning outcome is directly tied to The Accreditation Board for Engineering and Technology student outcome as described in Criteria 3.

∞ Is used to denote when a Framework student learning outcome is directly tied to the SDG Goal #12 learning outcomes.

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EOP Framework Integration Pilot Grantees and Program Leads

Between 2020-2022, faculty from five universities will be working as a Community of Practice and piloting the integration of the framework into their institution's courses and programs. Each is taking a distinct approach to curricular change on their campus and will be sharing lessons learned and teaching resources developed through the pilot program.

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Engineering for One Planet Advisory Group

The EOP Advisory Group (AG) provides strategic advice on the EOP initiative. The AG includes students and professionals with experience in academia, industry, and public sector who are passionate about advancing environmentally sustainable engineering. As of December 2020, EOP AG members are:

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APPENDIX C: Glossary of Terms

COMPLEX ENGINEERING PROBLEMS (From ABET, 2017)

Complex engineering problems include one or more of the following characteristics: involving wide-ranging or conflicting technical issues, having no obvious solution, addressing problems not encompassed by current standards and codes, involving diverse groups of stakeholders, including many component parts or sub-problems, involving multiple disciplines, or having significant consequences in a range of contexts.

ENGINEERING DESIGN (From ABET, 2017)

Engineering design is a process of devising a system, component, or process to meet desired needs and specifications within constraints. It is an iterative, creative, decision-making process in which the basic sciences, mathematics, and engineering sciences are applied to convert resources into solutions. Engineering design involves identifying opportunities, developing requirements, performing analysis and synthesis, generating multiple solutions, evaluating solutions against requirements, considering risks, and making trade- offs, for the purpose of obtaining a high-quality solution under the given circumstances. For illustrative purposes only, examples of possible constraints include accessibility, aesthetics, codes, constructability, cost, ergonomics, extensibility, functionality, interoperability, legal considerations, maintainability, manufacturability, marketability, policy, regulations, schedule, standards, sustainability, or usability.

RESPONSIBLE BUSINESS AND ECONOMY

Ability to operate as environmentally and socially responsible as possible within the constraints of the current business model.

SOLUTION, WORK or DESIGN

In this document, “solution”, “work” or “design” refers to anything that an engineer creates, codes, builds, implements or invents including, but not limited to, products, designs, projects, technologies, software, materials and solutions services.

STUDENT OUTCOMES (From ABET, 2017)

Student outcomes describe what students are expected to know and be able to do by the time of graduation. These relate to the knowledge, skills and behaviors that students acquire as they progress through the program.

Engineering for One Planet

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