Engineering for One Planet

The Engineering for One Planet Framework

Essential Sustainability-focused Learning Outcomes for Engineering Education (2022)

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

Overview

Welcome to the Engineering for One Planet (EOP) Framework!

The EOP Framework is a platform for curricular change and is one of the key pillars of the EOP initiative. For more information about the Engineering for One Planet initiative, visit **EngineeringforOnePlanet.org**.

The EOP Framework comprises 92 (46 Core and 46 Advanced) essential sustainability-focused learning outcomes that hundreds of academics, engineering professionals, and other key stakeholders have identified as necessary for preparing all graduating engineers — regardless of subdiscipline — with the skills, knowledge, and understanding to protect and improve our planet and our lives.

We use the following definition of sustainability in the EOP Framework:

Designs, practices, innovations, technologies, methodologies, etc., that mitigate negative impacts and/or enable increased positive and regenerative impacts on environmental and social systems.

The EOP Vision

Sustainability is a core tenet of the engineering profession.

The EOP Goal

Transform engineering education to ensure all engineers are equipped with the skills, knowledge, mindsets, and understanding to protect and improve our planet and our lives.

A Tool for Change

Hundreds of faculty are using the EOP Framework for curricular change. The EOP Framework provides a common language to help faculty share teaching tools and learn from each other.

The Lemelson Foundation (2022). *The Engineering for One Planet Framework: Essential Sustainability-focused Learning Outcomes for Engineering Education (2022)*. Cynthia Anderson and Cindy Cooper (Eds).
The Lemelson Foundation, Portland, Oregon, USA. 28 pages.

Commonly Asked Questions

What is the EOP Framework?

- A practical implementation tool — rather than a research framework — to help educators embed sustainability into engineering education
- A curated list of core and advanced sustainability-focused student learning outcomes that all engineering students should acquire that was co-created by a community of hundreds of experts from a range of identities, lived experiences, geographies, and sectors including academia, industry, nonprofit, government, and philanthropy

Why do we need the EOP Framework?

- Engineers are needed to help create a healthy, flourishing world
- Engineering activity has outsized impacts on our world
- Most engineering students are not learning sustainability-focused concepts, tools, and methodologies
- Engineers must be equipped with the mindsets and skills to ensure that the solutions of today do not become the problems of tomorrow, and to restore and regenerate our environment and improve lives for all
- Engineers must understand the history and implications of racist, classist, and patriarchal practices in engineering and social systems, and be prepared to help eliminate these practices
- Engineers must understand the social and cultural impacts of their work, and be prepared to help engender environmental justice (see Glossary of Terms)
- Engineers must receive professional preparation in sustainability because industry demands it

Who is the EOP Framework for?

- Academic engineering faculty, educators, students, and administrators who want to integrate sustainability education into a diverse array of classes, programs, departments, and institutions
- Professional engineering educators who want to equip practicing engineers with contemporary skills in and mindsets of sustainability
- Educators seeking resources for integrating sustainability into other STEM disciplines and K-12 education

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Commonly Asked Questions

When was the EOP Framework developed?

- 2017: Research to develop the EOP initiative began
- 2019: The first EOP Framework draft was shared with thousands of stakeholders for public comment; more than 400 comments were received, synthesized, and used to refine the draft
- 2020: Draft EOP Framework was launched in February
- 2020-2022: The EOP Framework was tested by several academic institutions, including EOP pilot grantees and hundreds of faculty in the US and internationally
- 2022: The EOP Framework was revised based on pilot grantee feedback and additional public comment. Reviewers were asked to prioritize Diversity, Equity, Inclusion, and Justice (DEIJ), environmental justice, and usability; more than 600 comments were received, synthesized, and used to refine the document with these lenses in mind.

How is the EOP Framework Implemented?

- There is no recipe or prescriptive approach — each situation will be different, but a combination of multiple faculty creating “bottom up” change with “top down” support from deans or department heads is ideal
- Users are encouraged to start by integrating the core student learning outcomes as much or little as they are able to into existing, required engineering courses
- To achieve the intent of the EOP Framework, faculty and deans who have used the EOP Framework suggest spreading learning outcomes across each year of a program, integrating a handful into each course
- Users can consult EOP “how to” guides for specific exercises and resources to implement the EOP Framework core learning outcomes in existing engineering courses
- The “how to” guides and diverse case studies on using the EOP Framework in curricular change efforts are available on the EOP website **EngineeringforOnePlanet.org**

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Foundations of the EOP Framework

The Lemelson Foundation, VentureWell, and Alula Consulting have collaborated with hundreds of individuals to steward the co-development of the EOP Framework, building on past curricular change efforts and drawing from a variety of sources. Efforts to infuse sustainability into engineering education have existed for decades, and a growing number of academic institutions, departments, and faculty, as well as social sector organizations and companies, are leading outstanding efforts and outcomes in sustainability. Hundreds of representatives from these groups have been involved in developing the EOP Framework. In addition to their collective knowledge, the EOP Framework draws upon numerous related frameworks, courses, programs, and definitions (e.g., sustainable engineering, green engineering, green chemistry, and circular economy). EOP Framework developers also took care to utilize inclusive approaches in undertaking this effort, including:

- leveraging synchronous and asynchronous commenting methods to enable an open and collaborative approach for co-developing the EOP Framework;
- mobilizing and motivating a large-scale, global community to foster collective impact;
- drafting learning outcomes that could be integrated into existing courses, across diverse engineering disciplines;
- mapping the learning outcomes to the 2010 Bloom's Taxonomy (Armstrong 2010); and
- capturing and sharing learnings and tools via methods that created pathways for replication by other communities beyond engineering disciplines.

The result is a Framework that addresses the seven ABET student outcomes, as outlined in the **ABET Criteria for Accrediting Engineering Programs** (ABET 2021), and aligns with the 17 United Nations (UN) **Sustainable Development Goals** (SDGs; United Nations 2015).

ABET Student Outcomes (ABET 2021)

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*

5. *an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives*
6. *an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions*
7. *an ability to acquire and apply new knowledge as needed, using appropriate learning strategies*

Relevance to Engineering Accreditation

ABET defines accepted attainment standards that prepare graduates to enter the professional practice of engineering. All ABET accredited engineering programs must adhere to and achieve accreditation from the Engineering Accreditation Commission (EAC) and must demonstrate that their programs satisfy all of the General Criteria for Baccalaureate Level Programs (ABET 2021). 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 social and environmental impacts of a product (or structure, software, etc.) nor the impacts of the materials or processes used in creating, distributing, using, and discarding the engineered products, codes, structures, etc. The EOP Framework collaborators recommend — where possible — that engineering programs adopt the core student outcomes identified in the EOP Framework, **thereby not only meeting, but also surpassing ABET's current requirements** to go beyond exposure and support the development of critical thinking, deeper sustainability knowledge and skills, and applied learning in engineering students.

ABET Engineering Technology Accreditation Commission

Relevance to the United Nations Sustainable Development Goals (SDGs)

Engineers and their work contribute both directly and indirectly to all of the 17 SDGs, yet one of the SDGs is most highly relevant and influential to the field of engineering: **Goal #12: Ensure sustainable consumption and production patterns.** Collaborators called for a mapping of the EOP Framework to Goal #12 because each decision for "responsible consumption and production" — as described by Goal #12 — offers the most pertinent framing for engineering (United Nations 2015).

SUSTAINABLE DEVELOPMENT GOALS

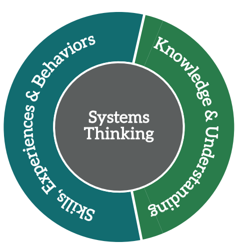
EOP Framework Structure

Student Learning Outcomes

The EOP Framework is a practical tool to facilitate embedding sustainability-focused learning outcomes into engineering education. It focuses on the "what" to teach, and you can find helpful tips and resources about "how" to teach the core learning outcomes and change curricula at the EOP website.

Faculty recommended that the EOP Framework be flexible and adaptable, noting that a prescriptive formula or exhaustive list of outcomes is less likely to be useful and adopted across a diverse range of situations. Still, a framework that lacks sufficient specificity and depth will not adequately advance student knowledge and skills, a key concern that catalyzed the development of the EOP Framework. Faculty also recommended using the educational goal categories of the 2010 Bloom's Taxonomy — Low (remember and understand), Medium (apply and analyze) and High (evaluate and create) — to organize and determine level of proficiency of the EOP Framework's student learning outcomes. The EOP Framework therefore prioritizes the core student outcomes identified as the most critical for integrating into existing curricula and is aligned with the 2010 Bloom's Taxonomy.

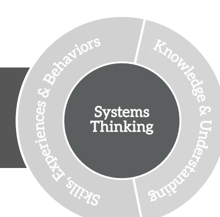
When defining learning outcomes for students, the EOP Framework uses ABET's definition of "Student Outcomes" as follows: "Student outcomes describe what students are expected to know and be able to do by the time of graduation. These relate to the knowledge, skills, and behaviors that students acquire as they progress through the program" (ABET 2021).



Three Categories

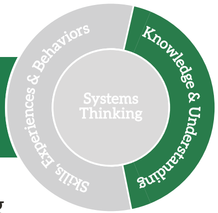
Drawing from and aligning with ABET's definition for student outcomes, the EOP Framework is structured around student learning outcomes under three main categories: "systems thinking," "knowledge and understanding," and "skills, experiences, and behaviors." Although "mindsets" are not explicitly categorized, acquisition of the EOP Framework learning outcomes also cultivates sustainability mindsets.

SYSTEMS THINKING



Systems thinking is central to and interconnected with all the other learning outcomes in the EOP Framework. EOP Framework contributors identified systems thinking from an environmental and social perspective as the most fundamental concept and approach that students must learn. Engineering education must expand the boundary of systems thinking, for example, by considering the ecological and social systems that engineers operate within, and developing more holistic and integrated systems-thinking mindsets. Systems thinking is a critical approach for engineers to understand that engineering solutions and 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

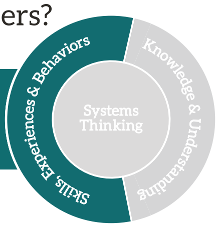


Sustainability-focused theories and concepts that are critically important to cultivating competencies related to environmental and/or social sustainability in engineers are divided into topic areas of **environmental literacy**, **social responsibility**, and **responsible business and economy**.

The learning 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 and socially responsible engineers?

SKILLS, EXPERIENCES, AND BEHAVIORS



A series of interdependent and interconnected skills, experiences, and behaviors are divided into technical skills, including: environmental impact assessment, materials selection, and design; and, leadership skills, including: critical thinking, and communication and teamwork.

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

- What technical and professional skills must all engineers have to become competent in sustainability?
- What values, behaviors, and ethos of responsibility to society and culture do students need to experience in order to practice environmentally sustainable and socially responsible 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; managers and shareholders; procurement and supply-chain managers; regulation and policy makers; key project stakeholders; etc.) to practice environmentally sustainable and socially responsible engineering?

Nine Topics

Including the category of Systems Thinking, which is central to the EOP Framework, there are eight additional topic areas followed by specific student learning outcomes for each. The nine topic areas include: Systems Thinking, Environmental Literacy, Responsible Business and Economy, Social Responsibility, Environmental Impact Assessment, Materials Selection, Design, Critical Thinking, and Communication and Teamwork. Despite being listed under separate topics, the learning outcomes are interdependent and interconnected. In an effort to ensure that the EOP Framework is pragmatically useful and applicable across engineering disciplines, the community developed distinct categories as a practical solution for organizing topics.

Under each of the nine topic areas, there are both **core learning outcomes** and **advanced learning outcomes**. Based on community feedback, core learning outcomes are the most important ones for students to achieve. Advanced learning outcomes may take core learning outcomes to the next level or may reflect additional competencies to be achieved after attainment of core learning outcomes. Core learning outcomes are not repeated in advanced outcomes although there is some overlap in topic areas. The assumption is that core outcomes would be integrated first. Advanced learning outcomes are provided for institutional adoption as resources and interests allow. The community encouraged the adoption of all core and advanced learning outcomes, but recognized that this will not always be possible.

The community considered the following guiding questions to qualify the suggested depth of each learning outcome:

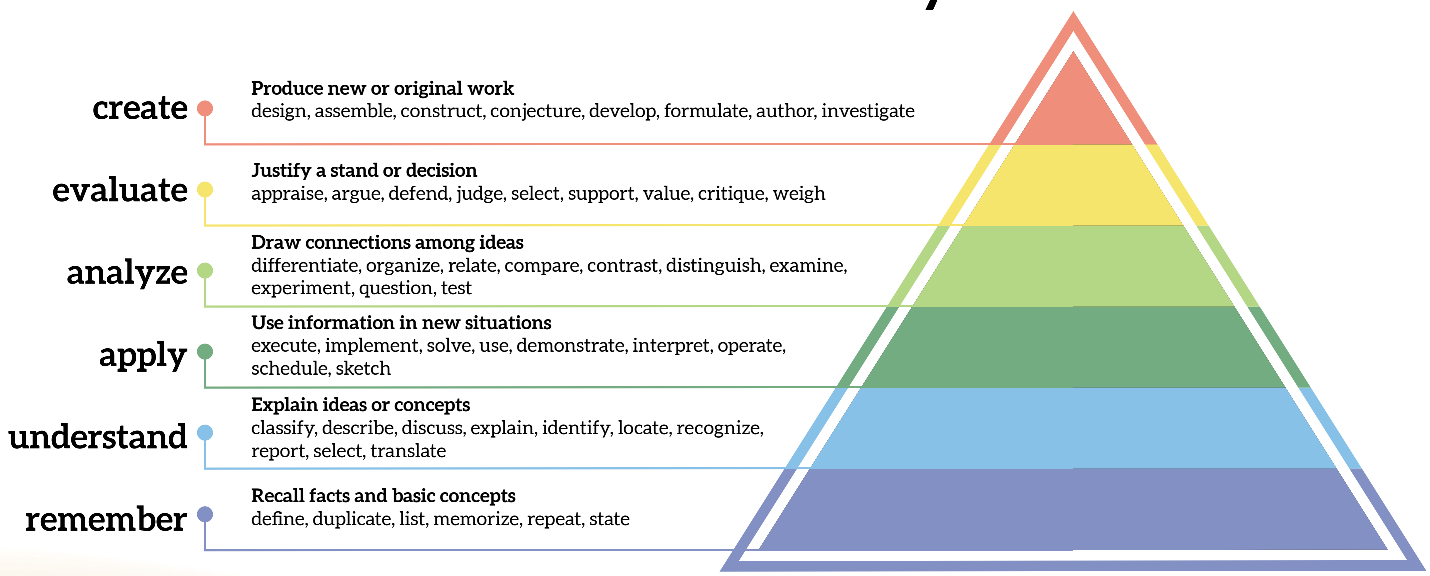
- What level of depth is considered sufficient for a student to demonstrate proficiency in the learning outcome?
- When a student becomes proficient in the collection of learning outcomes under each topic area — to the depth and degree articulated using the Bloom's Taxonomy verbs — is their overarching knowledge of this topic sufficient?
- When a student acquires each of the core learning 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 competencies to be confident and well-equipped to think beyond business as usual?
- Will acquisition of these competencies help students to obtain a better job, be a better employee, become a better manager?

The depth of proficiency of learning outcomes varies widely within topics. Bloom's Taxonomy educational goal categories were used to organize and reflect the level of proficiency of the learning outcomes — Low (remember and understand), Medium (apply and analyze) and High (evaluate and create). Verbs were utilized in the EOP Framework to demonstrate active cognitive processes by which engineering students will encounter and work with knowledge (Armstrong 2010). The community determined which verb to use for each learning outcome based on the most relevant level of attainment for all engineering students to acquire during an undergraduate engineering degree. However, EOP Framework implementers are encouraged to modify the learning outcome to meet their needs. For example, if the learning outcome states "Recognize opportunities to solve environmental challenges," the instructor could scale up the Bloom's Taxonomy level to Medium or High by modifying the verb (i.e., "Critique opportunities to solve environmental challenges".)

Note: Core vs. Advanced learning outcomes do not correlate with Low or High level of attainment of Bloom's Taxonomy. As mentioned above, core learning outcomes denote the most important or essential learning, whereas advanced learning outcomes go beyond what the community deemed to be essential.

For each learning outcome, an instructor should be able to complete the sentence: "After completion of the curriculum, a student should be able to..."

Bloom's Taxonomy



The EOP Framework

All learning outcomes are linked to the UN SDGs. However, throughout the EOP Framework the identifier is used to denote when an EOP Framework learning outcome is directly tied to the SDG Goal #12. The identifier ◯ is used to denote when an EOP Framework learning outcome is directly tied to an ABET student outcome as described in Criteria 3. A full summary graphic of the nine topics of the EOP Framework is located on **Page 26**. *The EOP Framework lists "what" graduating engineers should know and be able to do. For guides on "how" to teach the core outcomes in the EOP Framework, visit the* **EOP website.**

Systems Thinking

CORE

1. Explain interconnectedness (e.g., intersecting, related and/or connected systems; human actions and global environmental and social impacts and consequences; synergies and rebound effects) and how all human-made designs and activities rely upon and are embedded within ecological and social systems ○ (4)

2. Identify dynamic impacts between and among different parts of the system (i.e., social, environmental, and economic considerations) ○ (4)

3. Apply relevant concepts from required disciplines to the study of real-world problems and their solutions with empathic and ethical consideration for communities/societies, environmental justice, and cultural awareness ○ (2,4,7)

4. Create solutions that consider the scale of the activity relative to the planetary system boundaries (i.e., carrying capacities) ○ (2)

5. Create designs that include communities/societies, environmental ecosystems, and the life they sustain while keeping systems dynamics concepts in mind (e.g., feedback loops, complex cause-effect chains, cascading effects, inertia, tipping points, legacy, resilience, adaptation, energy systems and flows, etc.) ○ (2,4)

ADVANCED

1. Identify system archetypes (i.e., the tragedy of the commons), ecosystem services, and key concepts in system dynamics and their impacts on communities/societies

2. Design solutions for real-world problems in partnership with communities using human-centered design and system dynamics, including feedback loops, tipping points, and system resilience ○ (2)

3. Create visual system maps (e.g., causal loop diagramming, system dynamics simulations, etc.)

4. Apply Life-Cycle Assessment (LCA) at various scales of length (local and global effects), time (acute and chronic effects), and impacts (second and third order impacts, time-delayed impacts, etc.) ○ (2)

Environmental Literacy

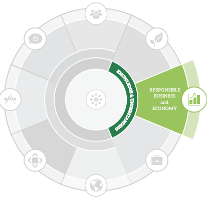
CORE

1. Recognize opportunities (i.e., social, economic, and environmental benefits, etc.) to solve environmental challenges (2,4)
2. Explain 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) (4)
3. Discuss 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 (2,4)
4. Explain the nature and role of energy in the world, our daily lives, and in engineering practices (e.g. is energy literate) (2,4)
5. Examine data about environmental issues (e.g., climate change, energy and water use, scarcity and pollution, air quality, waste management, toxicity, etc.) including consideration for past/current/future and local/regional/global impacts (2,6)

ADVANCED

1. Explain abiotic assets (e.g., fossil fuels, minerals, metals), flows (e.g., wind and solar energy), and biotic natural capital (e.g., ecosystems)
2. Describe key ecosystem services and functions including provisioning services, regulating and maintenance services, cultural services, and supporting services (e.g., material cycles, energy cycles)
3. Apply environmental laws, ethics, and policies at the regional, national, and global levels, and consider ethical, social, environmental justice, and cultural implications beyond current environmental compliance and political boundaries (2, 4)
4. Apply key ecosystem services and functions to their design solutions (2)
5. Weigh energy-use decisions based on an understanding of impacts and consequences (2,4)

Responsible Business and Economy



CORE

1. Recognize opportunities and demand for more inclusive and sustainable business models, such as models that leverage product durability (e.g., renting, upgradeability, repairability, modularity, resale, etc.), protect consumers and their privacy, reflect the interests and needs of diverse users and consumers, and reflect ethical considerations (4)
2. Examine risks and opportunities related to changing social, economic, political, and ecological systems on their work (e.g., extended costs, value, trade-offs, partnerships, regulations, policies, etc.) (2,7)
3. Demonstrate awareness that different revenue and 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.)
4. Demonstrate awareness of 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, circular economy, etc.)
5. Weigh the near- and long-term costs and value of their work to the environment and society through the sustainable use of resources and engagement with stakeholders (2,5)

ADVANCED

1. Explain alternative business, revenue, and entrepreneurship models (e.g., B Corps, product service systems, sharing economy platforms, cooperatives, indigenous practices/sensibilities, etc.)
2. Explain sustainable use and disposal practices to consumers
3. Locate funding sources for public infrastructure
4. Apply International Organization for Standardization (ISO) management systems (e.g., Environmental, Health, and Safety (EHS), Global Reporting Initiative (GRI), etc.) as tools to enable systematic integration of sustainability impact management into business practices (2)
5. Judge supply chain agents, vendors, etc., from environmental, social, and Diversity, Equity, Inclusion, and Justice (DEIJ) perspectives
6. Weigh economic trade-offs in sustainability efforts; these economic trade-offs may happen for a variety of stakeholders within each unique value chain, so students must be able to identify, quantify, and compare the financial trade-offs in sustainable initiatives

Social Responsibility

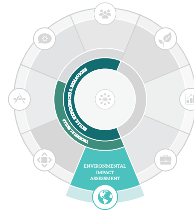
CORE

1. Identify the United Nations Sustainable Development Goals (SDGs) ○ (2)
2. Recognize and be empathetic to ethical implications relative to the social impact of their work ○ (4)
3. Describe 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, society, and non-human life (i.e., resources acquisition, waste production and management, traditional/cultural methodologies, etc.) ○ (2,4)
4. Recognize that some communities (e.g. communities of color, rural communities, etc.) have historically been negatively impacted and/or intentionally marginalized, and continue to be disproportionately negatively impacted by engineering activities ○ (2,4)
5. Explain the role of social responsibility and environmental justice in the engineering profession (i.e., policies, laws, social justice, etc.) ○ (4)
6. Identify cultural, local, and global 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.) ○ (2,4)
7. Create robust, dynamic, and resilient systems and transdisciplinary stakeholder networks ○ (2,3,5)

ADVANCED

1. Recognize the breadth of social and environmental justice issues, indigenous rights, laws, policies, and commitments (e.g., Global Compact (GC)) ○ (4)
2. Recognize social and cultural implications related to local, regional, and global materials and energy use (e.g., land changes, surface and groundwater use and pollution, air pollution, energy production and use, toxins, labor rights, land tenure, etc.) as a global citizen ○ (4)
3. Recognize that impacts are disproportionately borne by low-income and marginalized groups ○ (4)

Environmental Impact Assessment



CORE

1. Explain high-level environmental impact assessments (e.g., basic Life-Cycle Assessments (LCAs) and life-cycle hazards; i.e., how they work, what information they require, how to incorporate their findings into their work) ○ (2)
2. Recognize current eco-labelling systems and certificates (i.e., EPEAT, Energy Star) for sustainable production and consumption
3. Interpret broader energy, climate, water, wastewater, air pollution, and land-use implications of their work by conducting basic environmental impact assessments (e.g., Life-Cycle Assessments, carbon footprints, etc.) ○ (6,7)
4. Question complex or contradictory information to make decisions among trade-offs (i.e., What is the cost of the decision? Who and what will be most impacted by the decision? Are marginalized communities part of the decision?) ○ (2,4)

ADVANCED

1. Discuss relative impact reduction vs. absolute impact reduction (e.g., greenhouse gas (GHG) emissions)
2. Judge Environmental, Health, and Safety (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 ○ (2)

Materials Selection

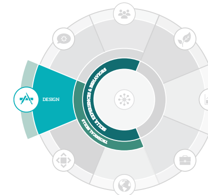
CORE

1. Identify potential impacts of materials (e.g., embodied energy, emissions, toxicity, etc.) 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., especially those who have been intentionally marginalized) (2,4)
2. Recognize current environmental assessment research and gaps in research (6)
3. Critique the environmental and social impacts of designs created by others (6)
4. Compare materials properties (e.g., chemical, physical, and structural properties) and performance aligned with end-use application (2)
5. Design with lower impact, natural materials (e.g., earth, bamboo, agro-waste, etc.) with an aligned degree of knowledge of industrial materials (e.g., iron, steel, aluminum, etc.) (2)
6. Select materials for design alternatives and trade-offs that enable a long functional lifetime, have net zero greenhouse gas emissions impact, either minimal or no environmental and social harm, or are restorative to social, cultural, and environmental ecosystems (2)

ADVANCED

1. Implement tools and resources for identifying potential social and environmental impacts of materials supply chain throughout the entire life-cycle — from raw material extraction through processing, manufacturing, use, reuse/recycling and end of life — with a zero waste and restorative perspective (2)
2. Discuss sustainability reports and data (e.g., Global Compact, Global Reporting Initiative, etc.) to draw upon leading research (7)
3. Explain the implications of the of impacts of material consumption at scale
4. Recognize materials composition and that macro materials include those with structural properties (e.g., concrete, metals, plastics, etc.) and functional properties (e.g., chemicals and solid/liquid/intermediary states), and that substances of concern can be bound up in engineered products and materials (often micro materials, chemicals, and nanoparticles) (2)
5. Identify innovation gaps in existing materials options and how to help spur appropriate research and development
6. Apply systems perspective and calculate embodied energy of materials to make informed decisions (2)
7. Evaluate Environmental, Health, and Safety (EHS) (e.g., ecotoxicity, chemical hazard assessments, etc.) and green chemistry aspects of materials (2)
8. Weigh trade-offs that guide selection of design-appropriate materials (e.g., technical considerations including strength, weight, cost, toxicity, extraction impacts, material compatibility, and thermal properties, among others) (2)

Design



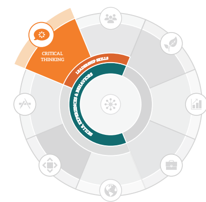
CORE

1. Execute technical analyses to choose strategies that maximize the positive and minimize the negative environmental and social impacts in order to achieve design goals (2,6)
2. Design for the environment and society 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.) (2)
3. Create long-term approaches for tackling environmental problems (e.g. climate mitigation and adaptation) or preventing negative environmental and/or social impacts including creative solutions within supply chains (6)

ADVANCED

1. Recognize local craft traditions, indigenous knowledge systems, and vernacular practices, and innovate inclusive and regenerative solutions and processes
2. Implement stakeholder user experience/participatory studies (e.g., design thinking, human-centered design) and social impact assessments to meet user needs in responsible, novel, improved, ethical, and sustainable ways (2)
3. Design with approaches that incorporate whole life-cycle and systems thinking (2)
4. 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.) by working across disciplines (2,4,5)
5. Design with systems dynamics concepts in mind (e.g., feedback loops, complex cause-effect chains, cascading effects, inertia, tipping points, legacy, resilience, adaptation, etc.) (2)
6. Create solutions for use with alternative business models and emerging economic contexts

Critical Thinking



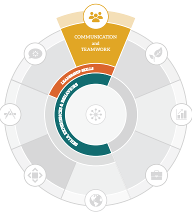
CORE

1. Define problems comprehensively with consideration of consequences, unintended and intended (1,2,4)
2. Report being a self-aware and reflective practitioner with values, empathy, and guardianship of one's environment (4)
3. Report understanding that their values are both shaping, and being shaped, by the designs, technologies, innovations, etc., they create and scale (4)
4. Recognize that every person has a role in sustainability, and has the right and need to be informed about the environmental/social/economic impacts of the products they purchase, consume, and discard (4)
5. Examine norms, biases, and values that underlie one's behaviors (i.e., normative thinking and cognitive dissonance) (4)
6. Critique complex ethical and values-based choices, employing empathy when evaluating conflicts of interest, trade-offs, and uncertain knowledge and contradictions within problem constraints (4)

ADVANCED

1. Discuss varying standpoints with empathy for different perspectives, opinions, views, etc. (i.e., normative thinking) (3)
2. Identify issues and actions of environmental and social priority (1,2,5)
3. Implement relevant qualitative and quantitative research into decision-making processes (6,7)
4. Distinguish the consequences of one's actions and how to deal with risks and changes (i.e., apply the precautionary principle) (4)
5. Compare the pros, cons, and tradeoffs of incremental vs. radical innovations
6. Prioritize appropriate solutions based on the context of the problem, in collaboration with other stakeholders and experts (3)
7. Evaluate possible, probable, and desirable futures for diverse people, societies, and cultures, to create their own visions for the future (i.e., futures literacy)

Communication and Teamwork



CORE

1. Communicate through audience-specific written, graphic/visual, oral, and interpersonal communication skills (3,5)
   - Demonstrate ability to sell, pitch, and explain ideas and advance learning
   - Demonstrate ability to work well with others, across organizations, disciplines, and cultures
   - Advocate for underrepresented and intentionally marginalized or excluded groups
   - Support organizational and societal change
   - Develop team effectiveness
2. Develop leadership potential and capability (5)
   - Recognize team member strengths/weaknesses
   - Demonstrate contributions to group problem-solving and effectiveness
   - Evaluate team effectiveness
   - Support followership
   - Support team member performance, growth, and wellness
3. Demonstrate ability to work within and function well on teams and across disciplines (5)
   - Demonstrate ability to effectively communicate on teams
   - Demonstrate active participation
   - Demonstrate initiative and proactive problem-solving
   - Demonstrate ability to participate in group decision-making
   - Demonstrate ability to share workload
4. Demonstrate self-awareness and understanding of unconscious bias (5)
5. Prioritize projects, schedules, and time, and manage people equitably and inclusively (5)
6. Champion sustainability-focused values and approaches (e.g., to management, procurement, marketing, etc.) to maintain the integrity of design criteria across environmental and human dimensions (5)

Communication and Teamwork

ADVANCED

1. Explain technical and engineering concepts, assumptions, and evidence (e.g., Life-Cycle Assessment (LCA) outcomes) to the public and to clients/customers to influence understanding and acceptance of environmental, social and cultural considerations, impacts, and decision-making (3)

2. Develop and maintain relationships through interpersonal skills (3)
   - Cultivate emotional intelligence
   - Identify and relate to different perspectives
   - Demonstrate ability to engage in conflict constructively (i.e., gains alignment to move forward, resolves differences, etc.)
   - Demonstrate understanding of power dynamics and the systemic oppression that supports them
   - Value effective listening, and be willing to be influenced and changed by the views of others

3. Investigate solutions to individual, institutional, and systemic bias (4)

4. Apply systematic, disciplined, and collaborative project management methodologies in order to effectively manage teams and themselves (5)

5. Demonstrate ability to interact with, collaborate on, and lead multidisciplinary teams, effectively representing an engineering perspective in a comprehensible manner through project-based work (3)

Conclusion

The EOP Framework was designed to be a practical tool to make the systemic changes needed to embed sustainability into all engineering education. The EOP Framework's curated list of core and advanced sustainability-focused student learning outcomes was co-created by a community of hundreds of experts from a range of identities, lived experiences, geographies, and sectors including academia, industry, nonprofit, government, and philanthropic sectors with the goal of hearing and acting on a diverse array of voices and perspectives. The contributors to the EOP initiative have collectively sought to transform engineering education to ensure all engineers are equipped with the skills, knowledge, mindsets, and understanding to protect and improve our planet and lives. We have come a long way together - and the journey will continue. We encourage you to join the efforts to transform engineering education by integrating the EOP Framework outcomes into your courses, programs, departments, and institutions. And if you do, we want to hear from you! Please contact us at **info@engineeringforoneplanet.org**.

Join the EOP Initiative

Everyone interested in this work is encouraged to participate. Visit **EngineeringforOnePlanet.org** for teaching tools, information about grants, curricular change examples, and to sign up for the EOP Newsletter.

Acknowledgement of Collaborators

The research for the EOP initiative began in 2017. Since then, the EOP Framework has been developed and revised through hundreds of conversations, research interviews and surveys, and over a thousand comments received through public comment, from stakeholders and subject matter experts from academia (e.g., faculty, students, administrators), professional associations (e.g., ABET, ASME, ASEE, ASCE, ACS, ECL-CA, ECL-USA, GEDC, IFEES, ISEE, IEEE, etc.), non-profit organizations, government, and industry. Visit **www.EngineeringforOnePlanet.org** to see the List of Collaborators who helped to create the EOP Framework.

Thank you to everyone who took the time to contribute. We are deeply grateful for the collaborative energy that has grown throughout this project.

We also thank the National Science Foundation (NSF) for generously supporting the revision of the EOP Framework in 2022. *The opinions, findings, and conclusions, or recommendations expressed in this work are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.*

About VentureWell

VentureWell supports the creation of an emerging generation of science and technology inventors and the innovation and entrepreneurship ecosystems that are critical to their success. Since its founding in 1995, we have funded or trained over 14,400 science and technology inventors and innovators resulting in the emergence of nearly 3,000 startups with ground-breaking technological advancements in fields such as biomedicine and healthcare, sustainable energy and materials, and solutions for low-resource settings. These startups have raised subsequent funds totaling over $2.9B and are reaching millions of people in over 90 countries. 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 $12M in grants to faculty at over 1,000 schools that have 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, the Foundation 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, the Foundation 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 $300 million have been made in support of the mission.

For more information, visit **lemelson.org**.

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APPENDIX A: EOP Core Student Learning Outcomes One-Pager

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

CRITICAL THINKING

- Define problems comprehensively with consideration of consequences, unintended and intended ○ (1,2,4) ◌
- Report being a self-aware and reflective practitioner with values, empathy, and guardianship of one's environment ○ (4) ◌
- Report understanding that their values are both shaping, and being shaped, by the designs, technologies, innovations, etc., they create and scale ○ (4)
- Recognize that every person has a role in sustainability, and has the right and need to be informed about the environmental/social/economic impacts of the products they purchase, consume, and discard ○ (4) ◌
- Examine norms, biases, and values that underlie one's behaviors (i.e., normative thinking and cognitive dissonance) ○ (4) ◌
- Critique complex ethical and values-based choices, employing empathy when evaluating conflicts of interest, trade-offs, and uncertain knowledge and contradictions within problem constraints ○ (4) ◌

COMMUNICATION and TEAMWORK

- Communicate through audience-specific written, graphic/visual, oral, and interpersonal communication skills ○ (3,5) ◌
- Develop leadership potential and capability ○ (5) ◌
- Demonstrate ability to work within and function well on teams and across disciplines ○ (5) ◌
- Demonstrate self-awareness and understanding of unconscious bias ○ (5)
- Prioritize projects, schedules, and time, and manage people equitably and inclusively ○ (5)
- Champion sustainability-focused values and approaches to maintain the integrity of design criteria across environmental and human dimensions ○ (5) ◌

ENVIRONMENTAL LITERACY

- Recognize opportunities to solve environmental challenges ○ (2,4) ◌
- Explain whole life-cycle and closed-loop systems thinking as related to the impact of their work ○ (4)
- Discuss key global ecosystem services and how they are interconnected ○ (2,4) ◌
- Explain the nature and role of energy in the world, our daily lives, and in engineering practices ○ (2,4)
- Examine data about environmental issues including consideration for past/current/future and local/regional/global impacts ○ (2,6) ◌

SYSTEMS THINKING

- Explain interconnectedness and how all human-made designs and activities rely upon and are embedded within ecological and social systems ○ (4)
- Identify dynamic impacts between and among different parts of the system ○ (4)
- Apply relevant concepts from required disciplines to the study of real-world problems and their solutions with empathic and ethical consideration for communities/societies, environmental justice, and cultural awareness ○ (2,4,7) ◌
- Create solutions that consider the scale of the activity relative to the planetary system boundaries ○ (2) ◌
- Create designs that include communities/societies, environmental ecosystems, and the life they sustain while keeping systems dynamics concepts in mind ○ (2,4) ◌

DESIGN

- Execute technical analyses to choose strategies that maximize the positive and minimize the negative environmental and social impacts in order to achieve design goals ○ (2,6) ◌
- Design for the environment and society based on discipline-specific technical skills ○ (2)
- Create long-term approaches for tackling environmental problems or preventing negative environmental and/or social impacts including creative solutions within supply chains ○ (6) ◌

RESPONSIBLE BUSINESS and ECONOMY

- Recognize opportunities and demand for more inclusive and sustainable business models ○ (4)
- Examine risks and opportunities related to changing social, economic, political, and ecological systems on their work ○ (2,7) ◌
- Demonstrate awareness that different revenue and business models can positively or negatively influence environmental and social systems as a result ◌
- Demonstrate awareness of alternative forms of capital beyond financial resources and awareness of emerging economic systems ◌
- Weigh the near- and long-term costs and value of their work to the environment and society ○ (2,5) ◌

MATERIALS SELECTION

- Identify potential impacts of 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 ○ (2,4) ◌
- Recognize current environmental assessment research and gaps in research ○ (6) ◌
- Critique the environmental and social impacts of designs created by others ○ (6) ◌
- Compare materials properties and performance aligned with end-use application ○ (2)
- Design with lower impact, natural materials with an aligned degree of knowledge of industrial materials ○ (2)
- Select materials for design alternatives and trade-offs that enable a long functional lifetime, have net zero greenhouse gas emissions impact, either minimal or no environmental and social harm, or are restorative to social, cultural, and environmental ecosystems ○ (2) ◌

ENVIRONMENTAL IMPACT ASSESSMENT

- Explain high-level environmental impact assessments ○ (2)
- Recognize current eco-labelling systems and certificates for sustainable production and consumption ◌
- Interpret broader energy, climate, water, wastewater, air pollution, and land-use implications of their work by conducting basic environmental impact assessments ○ (6,7) ◌
- Question complex or contradictory information to make decisions among trade-offs ○ (2,4) ◌

SOCIAL RESPONSIBILITY

- Identify the United Nations Sustainable Development Goals (SDGs) ○ (2) ◌
- Recognize and be empathetic to ethical implications relative to the social impact of their work ○ (4)
- Describe how engineering activities directly and indirectly cause positive and negative social/cultural impacts throughout the design life-cycle, both to workers producing the products and to communities, society, and non-human life ○ (2,4) ◌
- Recognize that some communities have historically been negatively impacted and/or intentionally marginalized, and continue to be disproportionately negatively impacted by engineering activities ○ (2,4) ◌
- Explain the role of social responsibility and environmental justice in the engineering profession ○ (4) ◌
- Identify cultural, local, and global implications and influences in the context of their work ○ (2,4) ◌
- Create robust, dynamic, and resilient systems and transdisciplinary stakeholder networks ○ (2,3,5)

Legend

○ *Is used to denote when a Framework student learning outcome is directly tied to an ABET 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.*

The Lemelson Foundation (2022). *The Engineering for One Planet Framework: Essential Sustainability-focused Learning Outcomes for Engineering Education (2022)*. Cynthia Anderson and Cindy Cooper (Eds). The Lemelson Foundation, Portland, Oregon, USA. 28 pages.

APPENDIX B: Glossary of Terms

COMPLEX ENGINEERING PROBLEMS (ABET 2021)
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.

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

ENGINEERING DESIGN (ABET 2021)
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.

ENVIRONMENTAL JUSTICE (EPA 2022)
Environmental justice is the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income, with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies. This goal will be achieved when everyone enjoys the same degree of protection from environmental and health hazards, and equal access to the decision-making process to have a healthy environment in which to live, learn, and work.

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.

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 (ABET 2021)
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.

SUSTAINABILITY
Designs, practices, innovations, methodologies, etc. that mitigate negative impacts and/or enable increased positive and regenerative impacts on environmental and social systems.

Engineering for One Planet

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