Addressing Engineering Reductionism by Reimagining ABET Outcomes

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Introduction

Engineering students often identify being effective "problem solvers" as core to their identity as engineers [1], which engineering educators amplify by placing "problem solving" as a core component of students' professional identity formation [2, 3]. However, "problems" come in many forms, and engineers do not grapple—and not least "solve"—many of those forms [4]. In fact, the types of problems solved in most engineering undergraduate courses are highly simplified versions of their real-world referents. However effective it may be pedagogically in teaching engineering analysis, this reductionist approach to engineering problem solving has been widely identified as a barrier to students' engagement with real-world entanglements and the development of professional skills needed for practice in all but the most constrained engineering problem-solving spaces. One prevalent response to reductionist problem solving is to teach students to engage with the solution-generation process further upstream, to precede solution generation with *problem definition.* Problem definition is where real-world problems are translated into "engineering" problems, which is to say, problems amenable to engineering analysis. Often referred to as "problem definition and solution," or PDS, this approach helps students recognize the wide range of contextual factors that influence the reduction of real-world design spaces into a neatly bounded engineering problem [5].

This paper builds upon and expands the PDS approach by positing "problem framing" as a coequal dimension of engineering education alongside "problem solving." By problem framing we mean to engage students not only in translating real-world problems into engineering problems (i.e., "problem definition") but also to grapple with the wide-ranging conditions that lead to accepted and acceptable engineering problem statements. A focus on problem framing demands consideration of the professional judgment needed to contextualize engineering solutions and place them alongside other approaches to responding to human problems. Attention to problem framing also highlights the reductionist conception of "solutions" in much of engineering education, where the end-goal of many assignments is to demonstrate mastery of a discrete analytic tool without necessarily understanding its appropriate domain of application, or its limited boundaries of usefulness. In this sense, solutions can often be a single, discrete number or optimized model. Real-world engineering problems rarely have such tidy formulations, so to conflate this type of solution generation with a core identity as expert "problem solver" is analytically clumsy if not presumptuous. It also radically collapses engineers' imagination for the breadth and complexity of most problems worth solving and the contextual sophistication needed to effectively navigate most real-world problems.

To explore how engineering education can engage more holistic and complex problems by elevating problem framing as a precursor skillset to problem solving, we review a variety of provocations based on our experience in program and curriculum building through sociotechnical integration in multiple academic initiatives within the Engineering, Design, and Society Department (EDS) at the Colorado School of Mines. We discuss interventions that take place across the curriculum, including our first-year introduction to engineering design course, integrating design throughout an engineering curriculum via a design spine, and how we consider problem framing as a core component of our ABET accreditation performance indicators. Rather than attempting to provide a series of "problem-framing best practices," we seek instead to promote a deeper conversation on how engineering educators perceive and frame engineering problem solving, the assessment of student learning of sociotechnical integration, and engineering judgment post-graduation.

Background

EDS offers a range of academic programs emphasizing design and sociotechnical integration, including service courses for the core curriculum, service courses serving other engineering programs, an interdepartmental graduate program, and departmental minors and an undergraduate major. In this paper, we focus attention on program development considerations surrounding our undergraduate BS in Design Engineering program. This program is built upon a "general engineering" framework with two significant exceptions. First, the program systematically situates "design" expertise at the program's core, both in terms of students' expert identity and in terms of the curricular structure. Second, the program offers wide-ranging "focus areas" as an alternative to disciplinary depth. The curricular logic is that students develop domain depth in *the design process* that structures engineering problem solving, and they then *apply that design expertise* to a thematic (versus disciplinary) focus area of their choice. Focus areas span energy and water, robotics and music, community development and corporate sustainability. A plurality of our students chose to pursue individualized focus areas that allow them to assemble courses from across campus to suit their particular interests.

The aspects of our Design Engineering curriculum that overlap with general engineering include basic math and science requirements alongside breadth requirements in humanities and social sciences and student wellness—together these requirements are built into Mines' core curriculum. The general engineering foundation also includes mid-level engineering fundamentals, upper-level engineering electives, as well as some upper-level focus area electives. Our focus area electives can but need not include engineering courses, depending on the focus area.

Our program's design spine includes EDS's "bookend design experiences," including a first-year introductory course covering engineering design, open-ended problem solving, and stakeholder engagement—called Cornerstone Design—and a senior-year inter-departmental, two-semester Capstone Design experience. Between these bookends, we have created a sequence of "integrated design studios" (IDSs) for each of the remaining five semesters. The IDSs seek to integrate disciplinary perspectives from engineering, design, and the social sciences (with the latter focusing in particular on science and technology studies or STS). We often articulate the IDSs as bridging engineering's "technical, creative, and social dimensions." Because our social science faculty are largely trained in STS, "sociotechnical integration" is a departmental hallmark, so a tagline for Design Engineering is "sociotechnical integration through design." This approach to educating engineers has been challenged by—but also advanced because of—ABET accreditation requirements and our efforts to navigate the accreditation planning and review.

EDS offers, and therefore (mostly) controls the content of, the design spine courses (in addition to some of the focus area courses) within the overall curriculum. Because the various focus area courses are not degree requirements, the program development team has decided to restrict all ABET accreditation program assessment to the design spine courses: The campus-wide Cornerstone Design course, the IDS 5-course sequence, and the 2-course Capstone Design sequence. Because EDS offers the bookend design experiences to the campus community, we do not have full independent control over those courses within the design spine, but we have sufficient control to specify ABET assessments and associated student learning outcomes.

Innovating with ABET

Engineering program builders typically have much to say about ABET program accreditation, and wide-ranging scholarship provides guidance, critique, and reflections in response to ABET accreditation requirements and practices [6]. In our experience in the field of engineering education program building and reform, we see that ABET accreditation is often met with guardedness and inadvertently produces a conservatizing force on engineering. This guardedness is not exclusively the result of ABET requirements but extends to include how program builders anticipate the expectations of ABET program evaluators (PEVs). In our own program design, our development team deliberated extensively on how we could simultaneously streamline our investment in accreditation planning while remaining ambitious with regard to deploying ABET accreditation as a lever for change in engineering, particularly in the assessment of student competencies in engineering problem solving.

Our take-away is that accreditation can serve both as a comprehensive audit of program performance and as an opportunity to facilitate program growth, pedagogical innovation, and even engineering reform. Deciding what matters and what to measure can have long lasting impacts on how programs grow through assessment cycles. As we prepare for first-time ABET accreditation for our design engineering major, we are apprehensive regarding PEV-expectations, especially surrounding traditional formulations of engineering “rigor” and its commensurability with the kinds of educational innovations we seek to produce [7]. We have begun the intensive process of preparing for accreditation through discussions with ABET departmental coordinators, review of numerous self-study reports, and the drafting of our program’s program educational objectives and performance indicators aligned with student outcomes. This process led our highly interdisciplinary development team to reflect deeply on the accreditation process and how we can ensure its standardized and arguably normalized process supports the development of our unique, deeply interdisciplinary engineering program.

The normalization of engineering program assessment provides coherent and widely accepted educational models for ABET-accredited programs. We learn from the comprehensive learning targets associated with the standardized program assessment process, allowing for graduates of these programs to successfully demonstrate their competencies across diverse work environments seeking a particular skillset. But programmatic normalization can also hinder development, innovation, and growth. The question is the extent to which ABET’s standardized process demands engineering normalization and whether it can reliably foster innovative programs in practice. While the mission of ABET is to enhance program delivery and ensure continuous improvement, engineering norms surrounding technical competency and boundaries around engineering expertise raise legitimate concerns over how far “engineering” programs can innovate while still being considered engineering. The tension between a streamlined, assured accreditation outcome and realizing our aspirations surrounding program innovation is the site of our reflection.

Our goal is to navigate ABET accreditation in a way that avoids this conservatizing pressure toward the norm. In our accreditation planning deliberations, we identified the need for a theoretical framework that deconstructs engineering problem solving—and perhaps goes further than engineering problem definition and solution (PDS)—that could encourage our unique program features while protecting the likelihood of successful accreditation. As suggested above, continuous improvement is core to ABET's accreditation approach. Continuous improvement requires both a starting point and a goal. We recognize we are at an important early stage of accreditation and must establish clear goals for our program so that the continuous improvement process moves us closer to our aspiration rather than pulling us back toward educational assessment norms. Our team will be better prepared for continuous improvement if we have clarity in our learning goals as they align with accreditation requirements. We seek to achieve our program outcomes in innovative ways, but we also seek to innovate how we think about those outcomes—how we define key terms within the outcomes to incorporate a much broader notion of engineering expertise than is usually aspired to or assessed.

Constructing Performance Indicators

ABET accreditation best practices recommend the establishment of performance indicators; programmatic learning targets associated with each student outcome. The breadth of student outcomes provides an opening to craft more focused learning targets through performance indicators. For example, we have devised performance indicators to expanded ABET EAC Student outcome 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" [8]. These performance indicators are:

- Recognize mutual impact between engineering designs and global, environmental, and societal contexts
- Anticipate the likelihood of engineered solutions impact on global, economic, environmental, or social settings
- Acknowledge variations of ethics
- Redefine ethical solution requirements in relation to variable contexts (user empathy, professional responsibility, pattern recognition)

Unlike the example given below where the performance indicator was narrowly described as the application of a specific model, the performance indicators here leave room for innovative approaches in ethics instruction as well as engagement with complex, open-ended socio-technical issues. This contrasts with more straightforward but arguably less robust assessments, such as applying a professional code of ethics to a given ethical challenge. In this way, we deploy ABET to ensure our program engages with the complexities of engineering for ethical outcomes rather than the application of a single, specific ethical approach.

Performance indicators provide detailed assessment metrics which are context and program-specific. ABET encourages the use of performance indicators to highlight the learning required to achieve the overall program mission. Yet, in practice, as we have discovered, performance indicators typically conform to engineering competency norms and do not expand or otherwise challenge what engineers ought to know or do. This conformance to engineering competency norms bolsters the argument that ABET tends to conservatize engineering program development and generates conformist postures toward student outcomes.

We provide a concrete example of the tension between conformism and program innovative as we moved to specify our program's performance indicators. As a starting point, we referenced an existing mechanical engineering program's performance indicator evaluating students' ability to solve a complex free-body-diagram problem as evidence of their attainment of ABET EAC Student Outcome 1 (SO1): "an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics." We deliberated over the extent to which a free-body-diagram problem requiring a singular correct answer could fairly be called "complex" in the spirit of real-world engineering problems. This opened wide-ranging consideration by the development team of the core competencies conveyed by SO1. What exactly is meant by "identifying a complex engineering problem" and how would that translate to educational activities and performance indicators? Where should a competent engineer initiate this process of problem identification? If we move problem identification further upstream, how does that impact demonstration of competency in specifying solutions? One must move very deeply into any identified human problem to result in a "solution" whose answer is the outcome of a free-body-diagram calculation. As practitioners of PDS in our integrative design studios, early-stage problem definition and framing are central to our coursework and, from our perspective, represent an important innovation in thinking about engineering competencies, not to mention "rigor."

As an engineering design program, a primary focus is on the engineering design process, and performance indicators offer an opportunity to discretely assess different parts of this process within a given student outcome. Using the example of SO1 above, we break down identification, formulation, and application of engineering and scientific principles by assessing four performance indicators:

- Determine boundary conditions to support problem definition
- Identify appropriate engineering, science, and math principles to solve problem
- Calculate solution using suitable steps
- Assess alternative solutions

SO1 is assessed throughout our design curriculum, but in a way that focuses on the students' overall problem-solving process rather than their ability to apply a single, specific tool (e.g., a free-body diagram) to get a discrete result. We use SO1 as an opportunity to clearly define what matters to us in terms of identifying and formulating problems and solutions in a manner that invites consideration of the problem's broader context. How students determine boundary conditions is left open to allow flexibility in responding to the unique social and cultural conditions that influence the problem of focus. Similarly, students' ability to identify the appropriate principles for their analysis and determine which alternative solutions are worth assessing matter more to us than their ability to apply a given engineering principle in an unrealistically constrained context.

Tensions between our desire for streamlined accreditation and our goal of fundamentally innovative programming manifest as well in our treatment of *engineering judgment*. Here we deliberated on the bounds of Student Outcome 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" [7]. Clearly, much is at play in this catch-all outcome, including recognition of ethical quandaries and identifying a potentially infinite set of possible impacts, neither of which could ever reasonably be reduced to identification of the correct equation or calculating the correct solution. In our benchmarking activities, we noticed that other programs tended to translate this outcome into performance indicators that touched superficially on ethics (e.g., familiarity with professional codes of ethics) or invited students to identify discrete potential impacts of a given design solution, occasionally requiring the crafting of engineering proposals to ameliorate negative impacts. Rarely did we see indicators seeking to operationalize engineering judgment as an arbiter between technical and social or contextual dimensions of engineering decision making. Again, our accreditation planning deliberations returned to the question of which "problem"—or, more expansively, which problem *domain*—engineering students are being asked to "solve" or even to consider.

The Problem with "Problems"

The usual emphasis on engineering problem solving in ABET accreditation corresponds to a focus on narrowly defined skills, which in turn corresponds to simple, discrete (usually quantitative) solutions to engineering problems. Narrow analytic skills and discrete solutions crowd out more complex, arguably more genuine framings of both problems and their solutions. In response to this concern, anthropologist and engineering studies scholar Gary Downey calls for something different: an improved engineer who focuses equally on problem definition and solution (PDS) [5]. While narrowly defined engineering skills lend themselves well to streamlined assessment, as with the free-body diagram example above, they also detract from a focus on the more complex problem framing aspects of engineering. A focus on PDS would consider the translation of the problem-in-the-world to a free-body diagram simplification. It might ask: How were the boundaries of the free body diagram chosen? In what social context might a student find this physical setup? What alternative arrangements or applications of force might matter for a given user or situation? And, most ambitiously, whether the conceptual tool of a free-body diagram is the best or most appropriate tool to apply to make sense of the underlying physical problem in the world? These questions explore the problem-framing process.

Engineering educators who are frustrated by the near-exclusive technical focus of engineering "problem solving" identity formation often point to the complexities of real-world engineering practice and the need to better prepare our graduates to succeed when addressing problems without tidy demarcations. We note the confluence of engineers' identity as problem solvers with a deeply superficial understanding of the mechanisms by which engineering education problems tend to be artificially constrained. This confluence leads to engineers who often have trouble recognizing when expertise beyond their own is needed to solve a real-world problem or even when, in a real-world situation, it is appropriate or useful to apply a given learned conceptual tool. Further, this can lead to frustration when the (reductive) problem-solving methods they have honed fail to respond adequately to untidy real-world problems.

To overcome some of these challenges, PDS is predicated on the assumption that engineers and the overall solution both benefit by engineers' earlier participation in the "problem solving" process. PDS engineers expect to be asked to engage early, ready to help define problems from the onset [5, p. 446]. However, engineers need not enjoy exclusive dominion over problem definition; PDS engineers collaborate with other participants, including those who define problems differently, such as potential users. In this way, PDS engineers are prepared to assess alternatives with and through stakeholder perspectives, thereby serving as technical mediators [5, p. 446-449]. We have deployed PDS, and its four defining practices, to expand how we approach the sociotechnical features of engineering education programming. As with PDS, we believe it is possible to educate engineers in a way that overcomes a narrow technical focus, is responsive to diverse contexts, and yet nevertheless provides robust technical engineering expertise.

However, through our pilot course offerings and especially our journey planning for ABET review, we have come to wonder if framing engineers as problem definers and solvers is, on one hand, expansive enough and, on the other hand perhaps too optimistic. Our team, and the programs that reside within our academic department, respond to this challenge of narrowly technical engineers with a range of design education offerings. At the same time, we integrate the socially constructed nature of engineering design to question its limits; engineering design builds upon a foundation of militaristic, labor-capitalist, and hegemonic processes of oppression and suppression of engineering practice [9, 10, 11]. Despite these challenges, engineering design provides an environment in which to contextualize and critique engineering problem defining. The contextualization of engineering design is where we aim to build upon PDS in generative ways. We work with our students to understand engineering labor as uniquely and structurally constrained to answer particular problems posed to engineers by particular interests. In turn, we ask ourselves, how can we identify program outcomes and establish assessment standards that eschew complacency with regards to problem setting in design education?

It is the situatedness of engineering labor that guides what engineers define as problems and what they are given in terms of resources to "solve" these problems. The very ability of engineers to so immodestly call themselves "problem solvers" is part of this problem. While we encourage our students to feel empowered—to leverage their design expertise to engage with complex problems and contentious spaces—we also expect a degree of humility in assessing their preparedness, capability, and resource-basis for addressing any actual problem of even modest complexity, including in their professional work. To suggest engineers (and engineering students) are "solving problems" radically constrains what we set as problems. The problem with engineering problems is that we conflate the process of responding to the simple arithmetic problems that are common across engineering education with "problem solving" most generally. We aspire for our students to engage this very distinction, that between the skills and practice of solving problems within typical engineering coursework and the identity of being a "problem solver" independent of one's perspective, skills, and experience base.

De-centering engineering expertise as the sole site of solution making leads to both challenges and opportunities within an ABET accreditation framework. What we assess in turn guides what we give importance to in an educational program. To decentralize the view of the engineer as the universal problem solver, we include multiple performance indicators which require the student to engage in activities, thought experiments, and experiences that focus on the idea of engineering as only part of any sociotechnical solution. For example, Student Outcome 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" [7] points to candidate performance indicators that might require students to "identify contextual constraints – global, cultural, social, and economic." These performance indicators can then be used to assess the process students engage in of discovering where engineering knowledge and problem framing/solving methodologies are effective and where the solution requires additional expertise beyond that which is available within their experience or within their engineering team's experience. By assessing the limitations of engineering problem solving scope and emphasizing, in other PIs, the importance of stakeholder engagement and intertwined complex systems level interactions we can focus our education on innovative engineering practices while providing clear sites for assessment and continuous improvement.

De-centering traditionally conceived engineering expertise also weaves in and out of the very core of our program. Within our integrated studio design spine, students explore design as a means of communication, design as a means of physical creation, engineering as part of solving problems in complex sociotechnical and global contexts, as well as designing one's own engineering pathway and designing for real-world clients as required in our Capstone Design sequence. For assessing and growing this programmatic spine, we have carefully integrated the assessable performance indicators into our course delivery to expand what it means to be a design engineer in a socially, and technologically, complex world.

Problem Solving Five Years Out

As we develop our students for their post-graduate careers, we consider not only the mission and values of our department, but projections for student development and growth five years after their learning experience in our courses. Program educational objectives (PEOs) help us to frame student success as related to their skillsets, career trajectories, and penchant for continuous learning. Created by our development team, our design engineering program educational objectives are:

- Apply their creative interpretation of complex problems and propose novel solution concepts within unique social, technical, ethical and environmental constraints.
- Serve as innovators, bridging the gap between social, technical and creative design disciplinary teams, all while incorporating a high level of ethical standards, social consciousness, and technical expertise.
- Seek to contribute to interdisciplinary endeavors and establish positions of leadership in their careers and through service activities within their profession or community.
- Actively engage in lifelong learning, demonstrating continuous professional growth.

Our PEOs align with ABET student outcomes, as outlined in Table 1 below, and provide another lens on our approach to innovating student experience to create more holistic engineering graduates.

Table 1. Program educational objectives mapped to ABET student outcomes 1-7

Program Educational Objective	**Student Outcomes**						
The objectives of the Engineering, Design, & Society Bachelor of Science in Design Engineering program are to produce graduates who, within five years of graduation, will:	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Apply their creative interpretation of complex problems and propose novel solution concepts within unique social, technical, ethical and environmental constraints.	X	X		X		X	
Serve as innovators, bridging the gap between social, technical and creative design disciplinary teams, all while incorporating a high level of ethical standards, social consciousness and technical expertise.	X	X	X	X	X		
Seek to contribute to interdisciplinary endeavors and establish positions of leadership in their careers and through service activities within their profession or community.			X		X		X
Actively engage in lifelong learning, demonstrating continuous professional growth.		X			X		X

Our PEOs have been reviewed and confirmed by our various constituent bodies: department faculty, our student advisory panel, our program alumni group, and our industry panel. During PEO review discussions, the constituent groups tended to focus on words or phrases they felt best captured strengths of our program. Occasionally, however, they also expressed differences of opinion. Results of our conversations with student and faculty representatives are summarized in Table 2.

Table 2. Remarks and Actions Regarding PEO Constituent Review

Constituent Board	PEO	Issue/Remark/Recommendation	Dept'l Action/Consideration
Faculty	PEO 1	Emphasize sociotechnical integration, **problem definition**, and engineering judgment. Apply **design thinking** methodologies.	
Student	PEO 1	**Ethics** is an intrinsic part of the educational journey; how do you measure students' ethics?	Incorporate opportunities for students to have wider-ranging discussions to **inform their** ethical perspectives. Develop ethical frameworks as social context throughout coursework.
Faculty	PEO 2	Serve as **interdisciplinary** technical experts with empathy and humanity to solve complex problems.	
Student	PEO 2	Mixed feelings about framing our expertise as '**bridging the gap**'; demotes expertise. Fear of DE students being categorized as mere translators. DE provides experience 'bridging' the design process and communication avenues.	Boost student confidence in technical content by incorporating engineering fundamentals into IDSs. Enhance identity development via career panels or other professional development opportunities.
Student/ Faculty	PEO 3	Service can satisfy personal AND professional fulfillment. Positions of leadership can equate to **unofficial mentorship.**	Formalize opportunities for student mentorship and leadership experience.
Student	PEO 4	Would appreciate the inclusion of **personal growth.** DE provides opportunities for constant evolution and growth.	Discuss with other constituent bodies the addition of 'personal growth' in the PEO.

Initial discussions of our PEOs with our two core constituent groups provided evidence that our students and faculty agree with these core program objectives. More importantly, these discussions suggest we can leverage ABET outcome alignment and successive program assessment to advance the unique strengths of our programming. We hope that findings from our initial cycle of program data collection will further justify our program's emphasis on problem framing, while highlighting areas for clarification and growth.

Conclusion

In preparing for ABET accreditation, our team has struggled with, embraced, remixed, and come to terms with the accreditation process as a site for innovating within engineering education. We have committed to moving beyond casting it as a barrier to deep educational innovation or a mere bureaucratic requirement on the path to delivering quality engineering education. Throughout this process, we have found ourselves reconceptualizing engineers, moving from "engineers as solution creators" to "engineers as problem framers and solution partners." This was not merely an intellectual exercise, but has become core to our program's accreditation framework, in terms of assessment through our performance indicators and ensuring deliberately formulated student outcomes.

Even as we have provided (what we hope is) a solid platform for the initial accreditation of our program, we also leave the door open for radical reorientation of our accreditation planning as part of our quest for continuous improvement. Not negotiable is our commitment to innovating engineering education according to our signature approach: sociotechnical integration through design. As we further explore PDS, and perhaps the limits and opportunities for further growth that it affords, we will consider its impacts on how we assess our program as well as its impact on our students. Ultimately, we strive to focus on students' mindset development and the full suite of professional workplace practices they will need in addition to problem solving or PDS. To do so, we cannot rely on the limited set of easily quantifiable categories that follow normalized engineering assessment.

As we commence our journey toward ABET accreditation of an atypical, and unusually interdisciplinary, engineering program, we look forward to further discussion in the engineering education community on the nuances of program accreditation and how accreditation itself might be a site for critical analysis, inspiration, and conceptual (and literal) frustration. Despite its significant influence on the world, engineering remains a young discipline with a wide range of societal interpretations: Engineers are everything from (expansive) problem solvers to (mere) technicians, from humanitarian to colonizer, from socially situated changemakers to normatively agnostic ("neutral") tools of their employers. As educators, we can help to frame both the definitions and outcomes of engineers in society by using assessment and accreditation to reflect and project our visions of the profession.

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