Paper ID #44325

Sociotechnical Integration as Programmatic Foundation in Engineering: Curriculum Design and ABET Assessment Protocols

Dr. Chelsea Salinas, Colorado School of Mines

Chelsea Salinas is a Teaching Professor at the Colorado School of Mines where she focuses on program development in the design engineering space, teaching design thinking strategies, user experience and systems modeling.

Dr. Dean Nieusma, Colorado School of Mines

Dean Nieusma is Associate Professor and Department Head of Engineering, Design, & Society at Colorado School of Mines.

Sociotechnical Integration as Programmatic Foundation in Engineering: Curriculum Design and ABET Assessment Protocols

Abstract

Engineering education has faced enduring criticism for being overly focused on the narrowly technical dimensions of engineering practice, ill preparing engineering graduates for their future work. "Sociotechnical" approaches to engineering education have arisen as one category of responses to this perceived narrowness. This paper reviews our efforts to situate sociotechnical integration as the foundation of our new undergraduate design engineering undergraduate degree program, focusing on how we have cast this foundation in both our program's curriculum and through our ABET assessment protocol design and implementation. The paper first reviews some of the scholarship on sociotechnical integration, including justifications for expanding engineering education's focus beyond technical competencies and identification of a framework for thinking about different conceptions of the relationships between social and technical dimensions of engineering practice. It then provides an overview and justification of our Design Engineering program's curricular structure, built around a "design spine." Next, the paper considers the design of our program's ABET assessment infrastructure and how we have used ABET requirements to ensure we hold ourselves accountable to a high-bar of sociotechnical integration throughout our program, with a particular focus on how we operationalize ABET student outcomes via our program's targeted performance indicators.

Introduction

Engineering education has faced enduring criticism for being overly focused on the narrowly technical dimensions of engineering practice, ill preparing engineering graduates for their future work. "Sociotechnical" approaches to engineering education have arisen as one category of responses to this perceived narrowness. Advocates claim sociotechnical approaches: provide students a more robust framework for engaging professional engineering practice, enhance learning through increased engagement, and result in more satisfying overall educational experiences. Faculty members in the Department of Engineering, Design & Society at the Colorado School of Mines have been leaders in advancing sociotechnical frameworks in engineering education, including pedagogical experimentation and implementation in a variety of engineering and non-engineering courses. This paper reviews our efforts to situate sociotechnical integration as the foundation of our new undergraduate design engineering undergraduate degree program, focusing on how we have cast this foundation in both our program's curriculum and through our ABET assessment protocol design and implementation.

Our bachelor's of science in Design Engineering program is carefully devised to integrate key content from engineering disciplines and the social sciences, particularly science and technology studies, in a manner that both technical and social dimensions of engineering problems solving are perceived as directly relevant to students' design process. While this combination of approaches may be straightforward conceptually, getting the balance right—and the identifying the right type of content to integrate—is tricky in practice. Further, ABET requirements allow, and in some ways implicitly encourage—but do not necessitate—programs to separate out technical, social, and professional skills development and their assessment. In our program development efforts, and in particular our preparations for first-time ABET accreditation review, we have set for ourselves the goal of using our program's ABET assessment protocol to ensure we achieve sociotechnical integration consistently and robustly across our targeted coursework, namely our program's design spine. While many facets of our programming and assessment strategy are unique to our goals and institution, our expectation is that other programs seeking to advance sociotechnical integration in their own curricula or assessment practices may find insights or approaches to integration applicable to their contexts as well.

To highlight how we have sought to cement sociotechnical integration in our program's foundation, the paper first reviews some of the scholarship on sociotechnical integration, including justifications for expanding engineering education's focus beyond technical competencies and identification of a framework for thinking about different conceptions of the relationships between social and technical dimensions of engineering practice. This framework helps to clarify how "sociotechnical integration" is in fact a high bar for engineering design practice (or, for that matter, any formalized inquiry practice). The following section provides an overview and justification of our Design Engineering program's curricular structure, built as it is around a "design spine"—that is, open-ended project-based design every semester—alongside more traditional engineering curricular requirements. After reviewing our curriculum, we turn attention to the design of our program's ABET assessment infrastructure and how we have used ABET requirements to ensure we hold ourselves accountable to a high-bar of sociotechnical integration across our design spine. Before concluding the paper, we offer some reflections on limitations of our analysis based on our positionality.

Sociotechnical Integration Literature

Engineering students are routinely exposed to framings of engineering that privilege the technical aspects of their work while presenting social issues as less important or ignoring them altogether [1], [2], [3], [4]. Sociologist Erin Cech has famously shown how engineering education's privileging of technical content and bounding of students' aspirations surrounding social impact produces a "culture of disengagement" among engineering students [5]. Other critics have explored various sociopolitical forces shaping engineering education—even as the role of those forces has been stripped from most observers' imagination—such as the close alignment with contemporary configurations of capital and militarism [6], [7], [8]. Responding to such criticisms, sociotechnical integration has been prominently featured as a promising approach to engineering education reform that can enhance student engagement by contextualizing engineering knowledge systems and students' personal values. Sociotechnical integration has been touted as means: to fulfill ABET criteria related to global context [9], [10]; to enhance student engagement in the classroom [11], [12], [13]; and to support students' awareness of stakeholder diversity and ability to work on open-ended, ambiguous problems [14], [15]. Others have argued for more ambitious outcomes resulting from robust approaches to sociotechnical integration in engineering education, suggesting it could help students attend to the full complexity of sociotechnical systems and thereby become better engineers [14], [16], [17]. Despite being poorly supported by traditional engineering education, sociotechnical perspectives are demanded by professional practice, and there is evidence that practicing engineers do gain sociotechnical perspectives over time [1], [2], [18], [19], [20], even if these are hard-won.

Design and project-based courses are frequently identified as promising sites for sociotechnical integration in engineering [21], [22], [23], [24], [25], [26]. Human-centered design perspectives typically strive to incorporate social, political, environmental, and economic dimensions of the design context alongside the technical dimensions, leading to more meaningful solutions [27]. Design and project-based learning also offer opportunities for students to engage more fully with their education, bringing more of their capacities and personal values to their coursework. Offering coursework that leverages students "funds of knowledge" has been shown to engage a greater diversity of students [28] and supports career preparation beyond what most engineering programs offer [29], [30]. Such coursework can also foster student belongingness in engineering [31], [32], particularly important for women and minoritized students [36], and positive peer relationships [33], [34].

Given the diversity of approaches to sociotechnical integration, Smith et al. [35] sought to provide a framework to help disambiguate underlying conceptual models for exploring the relationship between social and technical dimensions of engineering competencies. Figure 1 provides an illustration of this framework, highlighting increasing degrees of conceptual integration between social and technical dimensions. This model is elaborated by Kleine et al. [36] as follows:

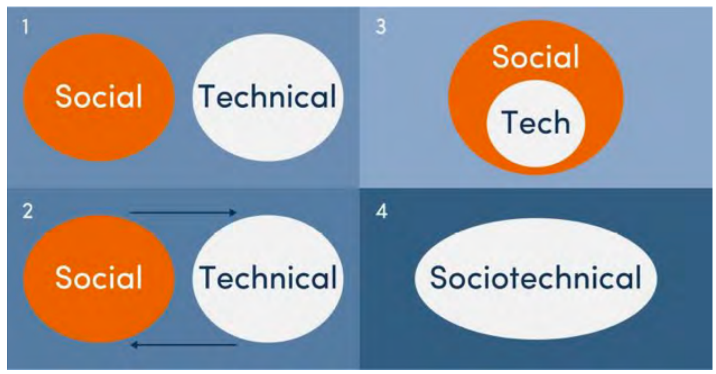

Figure 1. From Social + Technical to Integrated Sociotechnical

1. **Independence**: The social and technical dimensions of the phenomenon are each important but distinct. They can be treated separately or together in parallel, but there is no necessary correspondence.
2. **Mutual shaping**: Social and technical dimensions of a phenomenon are conceptually distinct but impact one another in an endless cycle of influence. One can isolate a given social or technical dimension at a given point in time, but must recognize the particular configuration has been shaped by both social and technical antecedents.
3. **Pervasive social context**: Technical dimensions of a given phenomenon and technical knowledge itself are always situated within the pervasive social context of human activity, human infrastructures, and human understanding.
4. **Sociotechnical integration**: Social and technical dimensions of a given phenomenon are not only mutually shaped, but are fully mutually constituted: One cannot exist without the other, conceptually or materially. Independent constructs of social and technical are misleading simplifications, since each is necessarily and inexorably intertwined with the other.

Regardless of the terminological clarifications provided here, many scholars who use the language of sociotechnical integration span categories 2 through 4 above, often moving among those categories. We also move among these categories as we describe different dimensions of our program development activities, but we believe the framework to be important because it is category 4 that sets the bar for our program's design studios, described in detail below. That goal notwithstanding, all categories in this framework inform our assessment practices and we accept that category 1 is prevalent across our students' educational experience outside of our department.

Design Engineering Program Development and Curricular Structure

Institutional Context

The Department of Engineering, Design, and Society (EDS) was created at the Colorado School of Mines (Mines) in 2017. EDS was created to provide campus-wide support for design education as well as to offer our own undergraduate design-based engineering major and to administer Mines' existing Humanitarian Engineering minors. Our bachelor's of science (BS) degree program, originally a BS in Engineering (often referred to as "general engineering"), was approved by our university's board of trustees in 2018. One of the goals for the program was to provide an alternative pathway to graduation for undergraduate students seeking more creative problem solving and educational foci outside of traditional engineering disciplines, including in interdisciplinary areas such as robotics and energy studies as well as in thematic areas that otherwise could only be covered via electives such as community development, corporate sustainability, and STEM teaching. A "focus area" component of the curriculum was included as a mechanism for achieving these diverse goals.

Our program's first incoming cohort arrived Fall 2019, so those students suffered the disruptions of the Covid-19 pandemic in the midst of their second college semester. Nevertheless, 17 students graduated in May 2023—our first full cohort of program graduates. Despite the pandemic disruptions, we continued to iterate and improve our program delivery, diversify our instructional base, and refine the program's common ground in the face of divergent student identities resulting from their distinct focus areas. Most importantly, we have incrementally emphasized "design" as core to our degree program, both in terms of the design spine that defines our curricular distinction and in terms of fleshing out a "designer identity" for our students that leverages our unique approach to design through sociotechnical integration. To better reflect this identity as well as our faculty's domain expertise in integrative design education, we renamed the program in January 2023 to be a BS in Design Engineering. This new name better conveys what our students (and faculty) have in common—expertise in sociotechnical integration within the engineering design process—with a broad systems approach to design as the primary mode for problem solving, informed by (but not predominantly organized around) technical engineering problem solving as covered by students' traditional engineering coursework.

Design Engineering Program Requirements

With our first cohort of Design Engineering (DE) students having graduated in May 2023, our program is in the process of seeking ABET accreditation under the Engineering Accreditation Commission for the 2024 assessment cycle. Our program's curricular structure satisfies ABET requirements listed as 30+ credit hours of basic math and science coursework in addition to 45+ credit hours of engineering topics along with the Criterion 3 Student Outcomes requirement (elaborated below). As a strong STEM-focused institution, Mines has a long history of maintaining high standards surrounding technical engineering coursework, which all DE students must satisfy along with students in traditional disciplinary engineering programs. Alongside the traditional technical engineering coursework offered by the disciplinary engineering programs, the Design Engineering program weaves our design-spine, providing an avenue for exploring the context of engineering design applications, with a strong focus on user experience and social, ethical, and environmental responsibility. Our program has evolved to a place where the design coursework brings about critical transformations through a deep commitment to sociotechnical integration.

The Design Engineering program includes 132 total credit hours (CH) broken into six distinct categories: our unique design spine (27 CH); math and science (33 CH); engineering fundamentals (15 CH); engineering electives (15 CH); focus-area electives (18 CH); and general education requirements (27 CH). Figure 2 provides a simplified visualization of these requirements as students satisfy them over time; in practice, there is more interweaving of requirements than represented here.

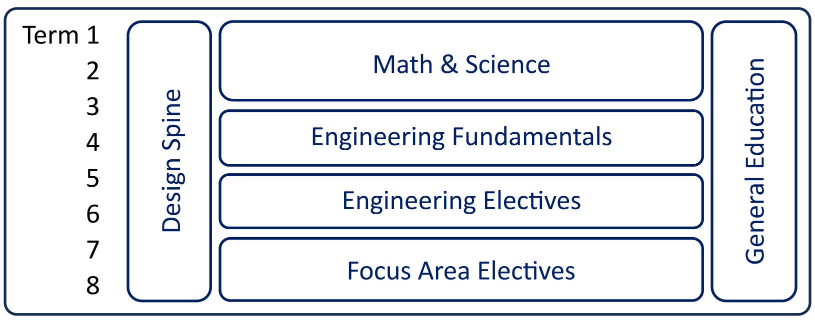

Figure 2. Design Engineering Simplified Requirements Map

Each of the curriculum categories in Figure 2 is briefly described below:

Design Spine – Open-ended, interdisciplinary engineering design projects every semester, including our signature "integrative design studios" (IDSs). IDSs are founded on sociotechnical integration over five semesters and are situated between our first-year Cornerstone Design campus-wide requirement and our senior-year Capstone Design I & II requirements. All these design courses are crafted to expose students to complex, open-ended, real-world problem-solving with hands-on and team-based components. Sociotechnical integration is prioritized in the IDSs, where students repeatedly reflect on the complexity of their design challenges and solution proposals as compared to the type of problem solving typical in their math, science, and engineering courses. All of the design-spine courses are offed by EDS, with the full list of design-spine courses below:

1. **Cornerstone Design:** An introduction to engineering design serving the entire campus community, including DE students.
2. **Introduction to Design Engineering**: An introduction to integrative design with a focus on user-experience design at the intersection of engineering design, design communication and visualization, and social sciences perspectives; an IDS serving DE students only.
3. **Design Unleashed**: An open-ended design courses that permits students to identify and pursue individualized design learning, structured via an iterative prototyping and testing process; an IDS serving DE students only.

4. **Design for a Globalized World**: A systems thinking and design course exploring global interdependencies surrounding social and environmental systems as they intersect with engineered solutions; an IDS serving DE students only.
5. **Design and Modeling of Integrated Systems**: A systems modeling course that enables students to characterize and formalize component relationships to inform design in response to complex sociotechnical systems; an IDS serving DE students only.
6. **Design Engineering Applications**: A career-focused distillation of DE-student competencies and identities; an IDS serving DE students only.

7-8. **Capstone Design I & II**: An interdepartmental collaboration offering client-sponsored projects serving majors in civil, electrical, environmental, mechanical, and design engineering.

Math & Science – Calculus, chemistry, physics, differential equations, computer science. These serve in different configurations as prerequisites to many of the engineering fundamentals courses. These courses are offered exclusively by other departments.

Engineering Fundamentals – Statics, circuits, materials, thermodynamics, fluids. These courses are structured to satisfy the Fundamentals of Engineering General Exam that is administered by the National Council of Examiners for Engineering and Surveying (NCEES). Courses fulfilling the engineering fundamentals requirement are offered exclusively by other departments.

Engineering Electives – Upper-level engineering, design, or computer science courses. These courses are carefully chosen between students and their faculty advisor to best prepare students for their chosen focus areas. Many of the focus-area electives have engineering course prerequisites, often with cascading prerequisites, which the engineering electives requirement must be structured to satisfy. In focus areas without such prerequisite structures, students still select engineering electives that advance their career preparation. For example, design engineering students with an interest in community development may select engineering electives related to civil engineering infrastructure or environmental engineering water reclamation. These courses often provide technical expertise in a topical field that enhances the student's ability to communicate across the technical and social dimensions of community development projects. Courses fulfilling the engineering electives requirement are offered predominantly by other departments; however, students can also select from among the few project-based design courses offered by EDS that are not part of the design spine above.

Focus-area Electives – Coherently selected course sets to suit students' individualized career goals. All DE students currently select a focus area from among the following options, listed in order of popularity (Spring 2024 data):

- Individualized Option (44%)
- Robotics and Automation (19%)
- Community Development (12%)
- Music, Audio Engineering, and Recording Arts (12%)
- Corporate Sustainability (7%)
- Energy Studies (4%)
- K-12 STEM Teaching (1%)
- Water Security (0%)

Many of these focus areas are modeled after existing minors available to students across campus, and the focus-area requirement of 18 credit hours aligns with our university's requirement for minors. As a result, any campus minor can be used "plug and play" as an individualized focus area. As implied by the list of focus area topics, coursework can consist of a greater degree of technical content (e.g., robotics), social sciences content (e.g., community development, corporate sustainability), or a mixture of both fields (e.g., energy studies, water security).

The individualized focus area attracts the greatest number of students, since many of our students desire the flexibility to choose courses about which they are passionate and in areas they see themselves pursuing in their careers. Product design and project management are two areas that many students pursue with their individualized course plans, and while there may be overlap between students' course choices for a product-design-oriented individualized focus, we tend to see customized curricula for each student. This customization demands close coordination between students and their faculty advisors to ensure student success and protect against meandering by students with ever-evolving interests.

General Education – A requirements set including a mix of required courses and restricted and unrestricted electives across three areas:

1. **Culture and society** (formerly humanities and social sciences) to provide a modicum of educational breadth in non-STEM areas
2. **Wellbeing** courses offered by our Student Life unit to promote student wellbeing
3. **Unrestricted "free" electives** to provide a baseline of curricular flexibility

The culture-and-society requirement incorporates creative thinking and ethical decision making, written communication, and attention to introductory business and economics principles. These courses often provide students with a broader understanding of social, environmental, and/or ethical implications of engineering decisions, yet the courses remain peripheral for most students as they tend to be completely independent of students' STEM learning activities and identities. Further, these "non-engineering" requirements fade in the face of the much larger number of credit hours dedicated to math, science, and engineering content.

Assessment Practices for Sociotechnical Integration

Upon institutional approval of the then-named BS in Engineering program, Mines' leadership determined the program would seek ABET accreditation in line with all the other engineering programs offered across campus. Given the DE program's goals as articulated above, including our focus on sociotechnical integration and design-across-the-curriculum, it should not be surprising that our approach to accreditation would vary from traditional programs' assessment efforts. Specifically, we have chosen an assessment strategy that relies exclusively on our design-spine coursework, thereby excluding all traditional engineering course requirements from our accreditation protocol, even though it is in these courses that students most readily demonstrate their competencies in traditional technical engineering problem solving. While we could have used student performance in these mandatory classes to demonstrate achievement of ABET requirements, we chose a different strategy for two main reasons: Control over course content and holding ourselves accountable for achieving a high-bar of sociotechnical integration.

Currently, all of the traditional engineering courses required by our program are taught outside of our department, making it more challenging to identify and then enforce recommended course improvements based on our assessment findings. This challenge is magnified by the fact that these courses tend to serve a far greater number of disciplinary engineering students with more traditional technical learning goals as well as student and faculty expectations regarding the nature of the coursework. By limiting our assessment protocol to courses fully under EDS-department control, namely our design spine courses, our DE program team determined we would be better positioned to implement our continuous improvement goals. Therefore, our ABET assessment protocol is limited to collecting data, demonstrating student performance, and continuously improving our program across only eight distinct courses.

The second, and more intellectually ambitious, justification for limiting our assessment protocol to our design spine courses is to hold ourselves accountable for demonstrating engineering problem solving and judgment in our open-ended design courses. Of course, the use of design courses within ABET assessment protocols is not at all unusual, and most engineering programs—including traditional disciplinary programs—tend to rely heavily on design courses for student-outcomes assessment purposes. At Mines, the traditional disciplinary engineering programs that participate in our interdepartmental Capstone Design course sequence, use that course to assess a majority of Criterion 3 outcomes (see Table 1), specifically SO2, SO3, SO4, SO5, and SO7. In DE program assessment planning, we too determined that it would be straightforward to demonstrate these student outcomes via our design courses. In contrast, we also worried that assessment of SO1 and SO6 could be more challenging in our design courses depending on how program evaluators operationalized "solv[ing] complex engineering problems by applying principles of engineering, science, and mathematics" and "us[ing] engineering judgment." Despite this worry, we committed ourselves to maintaining our agreed plan to assess all student outcomes exclusively through our design courses. Further, we committed ourselves to using the entire assessment planning and implementation process to confirm and demonstrate our programmatic commitment to sociotechnical integration. Instead of planning for ABET review defensively—instead of playing it safe—we decided to operationalize ABET assessment in line with our non-traditional programmatic commitments.

Table 1. ABET Criterion 3 Student Outcomes

Student Outcome	**ABET Definition**
SO1	an ability to identify, formulate, and solve **complex engineering problems** by applying principles of engineering, science, and mathematics
SO2	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
SO3	an ability to **communicate effectively** with a range of audiences
SO4	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
SO5	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
SO6	an ability to develop and conduct appropriate experimentation, analyze and interpret data, and **use engineering judgment** to draw conclusions
SO7	an **ability to acquire and apply new knowledge** as needed, using appropriate learning strategies

Evaluating the Flexibility of ABET Student Outcomes

ABET requires that accredited programs or those seeking accreditation adopt or recommend specific student outcomes—the explicitly identified skills students should possess at their time of graduation. These outcomes, listed in Table 1 above, are intentionally broad to allow programs to interpret them according to their unique character or goals. Even though ABET does not require programs to accept outcomes 1 – 7 as provided, like most programs, we decided to accept them with no modifications or additional outcomes. Our assessment planning team first identified the student-outcomes keywords, identified in boldface text in Table 1, which we believed most closely aligned with our program goals.

As briefly suggested above, our committee quickly determined that our program's structure consistently and unambiguously addressed five of the seven student outcomes. Our design coursework provides opportunities for students to hone their skills in engineering design based on needs, communicating effectively, consideration of impact of engineering solutions, effective team functioning, and acquiring new knowledge. Our program strives to produce students who are critical thinkers, consider broadly the potential impacts of their designs, value the diversity in ideas from a team, foster effective communication among teammates and stakeholders, including via constructive feedback, and continue to seek additional information to deepen their understanding of design opportunities.

Through our accreditation planning discussions, we came to recognize that, at face value, ABET places disproportionate emphasis on skills more typically developed in a team-based educational environment focused on critical-thinking, and relatively less attention to solving narrowly defined technical engineering problems. This recognition provided the impetus for our committee to explore the degree of latitude existing across ABET's assessment criteria, including SO1 and SO6, which we determined to be most closely tied to problem-solving techniques addressed across the majority of traditional engineering coursework.

Traditional implementation of the above SO1, for example, has often been presented through the lens of narrow right-or-wrong problem solving, assessed straightforwardly according to the fraction of students that correctly solved the problem. Our committee struggled with the premise that students solving narrowly defined problems could effectively encompass the skillset of "identifying, formulating and solving *complex* problems." How could problems be considered complex, we wondered, if they failed to incorporate the expansive facets of real-world engineering problems, including their messy social or economic dimensions? This line of questioning, coupled with our unique pedagogical practices, spurred us to reframe key engineering-problem-solving terminology to ensure our ABET accreditation activities advanced our program's goals.

Establishing Program-Specific Performance Indicators

ABET evaluation best practices recommend the use of performance indicators to create more accessible points of assessment for each of the seven student outcomes. While we adopted ABET student outcomes 1 – 7 as provided, our performance indicators were uniquely tailored to our program, since it is the prerogative of the program to generate performance indicators that establish and target key measures of overall student-outcome attainment. This flexibility in specifying how each student outcome is operationalized within the program is a mechanism to facilitate alignment of program mission with assessment practices. Our team carefully evaluated each student outcome, investigated more traditional programs' performance indicators, and then identified our priorities for student skills to be developed. With that preparation, we began to craft language around our instructional and scholarly goals, allowing us to draw connections and translations between ABET outcomes and our approach to sociotechnical integration though design. Developing performance indicators that wove together the ABET assessment language and our overall programmatic mission proved to be a pivotal moment in the structuring of our assessment planning and our approach to program development.

By embedding our educational goals around sociotechnical integration into our assessment infrastructure via our performance indicators, our program development team turned ABET planning into a deeply reflective intellectual exercise. Figure 3 provides a visualization of our ABET assessment planning process, where our program educational objectives guide how we incorporate student outcomes and performance indicators into our evaluation cycle. Through course-level assessment, program assessment, and a process of continuous improvement, we seek to ensure that ABET helps us drive our programmatic and scholarly commitments to sociotechnical integration.

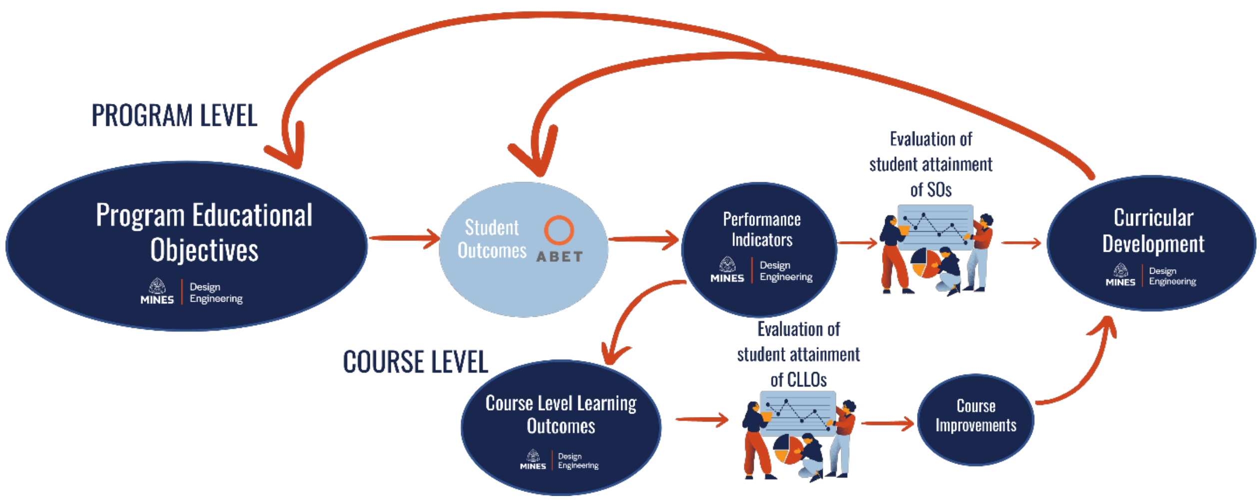

Figure 3. Our Team's ABET Assessment Planning Process

In creating unique performance indicators, we chose to work backward from course outcomes as shown in the figure above. We collected all design-spine course-level learning outcomes (CLLOs), referenced ABET student outcomes (SOs) and compared those against our PEOs, which are the key skillsets our graduates should embody five years after graduation. Analyzing the outcomes across courses and how they related to our PEOs created space for a refinement of language at the course level. Once course-level outcomes were aligned with overarching goals of the program, we sought to begin the process of mapping ABET SOs assessment to our curriculum. Each course and the embedded learning outcomes were directly mapped against the ABET SO to best identify where assessment of each SO would be most effective. As ABET SOs are program assessment metrics, our mapping exercise identified multiple courses in which each SO could be assessed, creating an array of course-level learning outcomes to inform the development of more program-specific performance indicators.

The newly refined course outcome language provided a list of key skills taught within a course that could serve as a potential spot for student outcome assessment, yet more refinement was needed. All course learning outcomes that mapped to a student outcome were initially listed for review. Those deemed to be inconsistent with the goals of the student outcome in question were removed from the list, leaving course-level learning outcomes that mapped to both the student outcome in question and our program educational objectives. Distilling the CLLOs into higher-level performance indicators required attention to ABET-specific SO key phrases and program-specific language surrounding the value of sociotechnical integration. Performance indicators were written for our program and further iterated upon second and third rounds of review. Each performance indicator was then formalized through the establishment of assessment rubrics. ABET student outcomes 1 – 7 were further broken down into four performance indicators per outcome. Each performance indicator was then extended to cover appropriate attainment for certain levels: unsatisfactory, developing, meets expectations, exceeds expectations. Upon establishing rubrics for each performance indicator, our team clarified language and realized the benefits of program-guided assessment goals.

Using Performance Indicators to Prioritize Integration

The process outlined above led our team to reflect upon course learning and programmatic goals with a commitment to prioritizing sociotechnical integration at every level. To achieve this vision, our team strove to look beyond traditional assessment methods. For example, we return to ABET Student Outcome 2:

> SO2: 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

Oftentimes, a student's or team's engineering design solution is the metric that is assessed through this outcome. Did students produce an acceptable, viable, demonstrated, or optimal design solution? Some programs might also require students to evaluate the costs of their solution or its environmental impact, safety, or perhaps even overall social benefit. We seek to re-define what it means to evaluate a design solution by encouraging deep, critical thinking from the initial phases of the design process and not rewarding surface-level consideration of contextual dimensions as an afterthought once the engineered solution already has been devised. Hence, rather than focusing on post-design analysis and reflection, we crafted our performance indicators to ensure student attention to context early in the design process, to encourage accountability across diverse dimensions of context, and to critically evaluate the integration of sociotechnical assessment into each phase of students' design work. To achieve that, the performance indicators for SO2 were written as such:

a. Participate in the design process through needs identification, problem formation, research, and alternative solution exploration
b. Examine how social and technical design decisions are synthesized through the design process
c. Compare alternative design solutions and their respective impacts on the social “good” (public health, safety, and welfare)
d. Validate design solutions considering global, cultural, societal, environmental, and economic factors

At each stage of the design process, from problem identification through final validation, our students are assessed on their ability to engage in the problem and solution spaces through an integrated sociotechnical lens.

Similarly, ethical evaluation of engineering solutions is equally at risk of superficial, post-hoc coverage, sometimes distilled into a single lecture about how ethics ought to be incorporated into engineering design without serious assessment of the context of engineering decision making. In contrast, we interpret this as another area appropriate for constructive integration of problem framing and solution justification. ABET SO 4 is restated below along with our associated performance indicators:

SO4: 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

a. Recognize mutual impact between engineering designs and global, economic, environmental, or social contexts
b. Anticipate the likelihood of engineered solutions impact on global, economic, environmental or social settings
c. Acknowledge how ethics expectations vary across contexts
d. Redefine ethical solution requirements in relation to variable contexts (user empathy, professional responsibility, pattern recognition)

These performance indicators provide a variety of alignments between SO4 and our thoroughgoing approach to integration. First is a fundamental insight from STS about the nature of the relationship between technology and society, namely that these are “mutually constituted.” It is not merely that technology impacts society but also that society impacts technology in an ongoing cycle of influence. This is the “mutual shaping” approach to sociotechnical integration as provided in the framework summarized in Figure 1. Next, we expect our students to anticipate social impacts early in their thinking about technological solutions rather than after the fact. Third, we treat ethics themselves as influenced by context and not a black-and-white matter of “doing right” in as abstracted and simplified manner. Finally, we expect students’ reflections on what is right in a given context to impact students’ design output—and to be able to articulate that relationship as part of their design solution justification.

For SO2 and SO4, our goals are to embed attention to the broad context of design work into the design process alongside traditional technical dimensions of design. This plays to our strengths as interdisciplinary engineering design educators. As mentioned above, however, a more demanding goal in the space of early-stage, open-ended design (and problem framing) is attending to SO1: to ensure students are “applying principles of engineering, science, and mathematics” to “solve complex engineering problems.” Arguably, this outcome is more straightforward to assess in traditional STEM coursework, where students repeatedly apply advanced math and science concepts, engineering theory, and (technically) complex problem solving. In fact, engineering education's focus on "fundamentals first" pedagogy [37], is explicit and systematic in scaffolding math, science, and engineering science tools through a highly specified prerequisite structure. The approach allows for continually increasing complexity of problem solving within traditionally bounded engineering problem spaces, allowing SO1 assessment to be seamlessly integrated into almost any of these courses.

Design Engineering students all complete at least 45 credit hours of traditional mid- and upper-level engineering coursework, in addition to 33 credit hours of math and science, suggesting that we could confidently assess their SO1 competencies in those courses as do most other programs. For the reasons stated above, we chose instead to interpret SO1 competencies in line with our programmatic commitment to sociotechnical integration. DE students experience higher-order complexity in their engineering problem solving. because they are forced to confront both social and technical dimensions of the design process simultaneously. Traditional engineering problem sets are ignored; however, students are challenged to integrate knowledge from their traditional engineering coursework with the broader complexity of the real-world problems they seek to address. For our program assessment planning committee, we saw an opportunity in rethinking the key terms of competency in SO1 as we established our associated performance criteria.

In specifying our SO1 performance indicators, our underlying challenge was clear: To effectively demonstrate "engineering" problem solving, and integrate application of "principles of engineering, science, and mathematics," without falling back on traditional engineering problem solutions or downplaying the centrality of sociotechnical *integration* as the core expertise our students demonstrate. While we chose to include more traditional components of engineering problem solving—formulating the technical problem, identifying appropriate equations, solving the narrowly-framed problem, and then assessing where simplifications or errors may exist—we were sure to carefully align these steps within a comprehensive design process. In establishing our performance criteria, show below, our team recognized, for example, that boundary conditions may constrain or narrow a materials problem through definition of temperature, material type, size of the material, etc. Similarly, a properly designed systems model must also adhere to certain boundary conditions in the form of key identified elements, elements both within and outside a bounded system, and explicated connections among elements. While the establishment of boundary conditions may require different approaches to solving the problems in each of these examples, the methods for bounding a complex problem remain an essential component. Recognition of these parallels between narrow and broad engineering design decision making gave us some confidence in establishing these performance indicators in the context of sociotechnical integration.

SO1: an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics

a. Determine boundary conditions to support problem definition
b. Identify appropriate engineering, science, and math principles to solve problem
c. Calculate the solution using suitable steps
d. Assess alternative solution approaches

In order to meet our goals around sociotechnical integration, our students are expected to approach engineering problem solving with immediate attention to contextual complexities and the mutual impact between the technical and social dimensions of their problems. Real-world engineering design problems do not exist in a frictionless, ambient-temperature, isolated environment as they may be described in abstracted, narrowly defined textbook problems. But neither do real-world engineering problems exist in a social or contextual vacuum, as they tend to be considered in traditional engineering courses. Instead, social and technical complexities pervade engineering problems, where technical needs are defined through social constructs and values, and where user needs can frustrate or contradict those projected onto the problem space by engineers.

Limitations

We have attempted to document the messy, iterative, and multiparticipant process of program design and development in a coherent manner, yet we acknowledge both the partiality of our perspective and the sheer complexity and unboundedness of sociotechnical integration in engineering [1]. As co-authors, we occupy different positions along the spectrum of disciplinary education representing our department's faculty, from exclusive traditional engineering to exclusive traditional social sciences, with one of us falling toward the engineering side and the other toward the social sciences side. Additionally, one of us is a teaching faculty member with aspirations to participate more in educational research while the other is a tenured faculty member with aspirations to devote more systematic attention to course design, delivery, and assessment. While this paper seeks to document our challenges in attempting to instantiate and formalize our commitment to sociotechnical engineering, it is based predominantly on our interpretations, and not sanctioned by the larger Design Engineering planning group or even other department faculty, who operate as educators and scholars in intersecting spaces.

Another obvious limitation is our focus on curricular intent in this paper. Future work could assess the how our programmatic intentions are experienced by students in the program, including but extending beyond the extent to which they achieve our ABET learning outcomes as operationalized through our performance indicators. Our program planning committee recognizes the central role of student feedback in assessing program goals independently of formalized assessment activities. Our program's student advisory board has reviewed and made recommendations in response to our Program Educational Objectives in addition to our program's mission and vision statements. These students serve the program in an advisory capacity, often providing constructive feedback on course-level learning outcomes, which are then discussed in program planning committee to ensure continuous improvement in students' experiences.

Conclusions

The paper has sought to document and provide detailed justification for one approach to operationalizing sociotechnical integration in an engineering program's foundations. Our approach combines a key pedagogical component, a key curricular component, and a thoroughgoing commitment to deploying ABET accreditation planning in a way that ensures that our continuous improvement practices align with our program's unique educational innovation.

The key pedagogical component is our approach to sociotechnical integration via design as practiced in our "integrative design studios." Our unique department configuration—with program faculty expertise spanning traditional engineering, design, and social sciences—allows us to achieve significant levels sociotechnical integration in the classroom without extensive reliance on co-teaching staffing models, where different individuals carry the technical and social content expertise. The key curricular component is our program's design spine—sociotechnical integration every semester alongside what is otherwise a very traditional combination of math, science, and engineering course content with general education requirements. We see an increasing number of engineering programs introducing "design across the curriculum" approaches to student engagement; our programming extends this logic to include design coursework as a strategic location for comprehensive sociotechnical integration for engineering students. Finally, the key assessment component—and the thrust of our argument—is that ABET assessment practices can and should be crafted to advance programmatic innovations and differentiation rather than constraining them. Since we are not yet accredited, this may be a risk, but it is a risk worth taking and one that we believe is well aligned with ABET's stated goals surrounding assessment best practices.

Ultimately, our key achievement at this stage of program development is to have created ABET performance indicators that consistently advance our programmatic commitment to sociotechnical integration as a differentiating factor. Sociotechnical integration is woven throughout our program from course design and delivery to curricular structure to the way in which we pursue assessment. How we approach sociotechnical integration is evolving, but as committed educators, we have attempted to create our program's infrastructure in a way that challenges the boundaries between technical content and all other dimensions of engineering problem solving—boundaries we see as persistent in engineering education. Our faculty and students are progressively moving toward enhanced integration, but we also recognize areas of growth needed to achieve better-balanced integration in our teaching methods, student projects, assessment techniques, and applications of design. Through targeted data collection and reflection on our programming and student outcome attainment, we aim to continuously refine our approach and delivery, creating a unique and robust undergraduate design engineering program founded on sociotechnical integration.

Acknowledgements

The authors would like to acknowledge the active engagement in program development conversations among many faculty members in the Department of Engineering, Design, and Society, especially the other participants in our programmatic ABET planning: Marie Stettler Kleine and Aubrey Wigner. We also acknowledge the efforts of Elizabeth Reddy and Marie Stettler Kleine in helping us map the literature on sociotechnical integration in engineering.

References

[1] E.A. Cech, "The (mis)framing of social justice: Why ideologies of depoliticization and meritocracy hinder engineers' ability to think about social injustices," in *Engineering Education for Social Justice: Critical Explorations and Opportunities,* J. C. Lucena, Ed. Springer, 2013, pp. 67–84.

[2] R. Stevens, A. Johri, and K. O'Connor, "Professional engineering work," in *Cambridge Handbook of Engineering Education Research*, A. Johri and B.M. Olds, Eds. Cambridge: Cambridge University Press, 2014, pp. 119–199.

[3] G.L. Downey, “Are engineers losing control of technology?: From ‘problem solving’ to ‘problem definition and solution’ in engineering education,” *Chemical Engineering Research and Design*, vol. 83, no. 6, 2005, pp. 583–595.
[4] L. Kamp, “Engineering education in sustainable development at Delft University of Technology,” *Journal of Cleaner Production*, vol. 14, 2006, pp. 928–931.
[5] E.A. Cech, “Culture of disengagement in engineering education?” *Science, Technology & Human Values*, vol. 39, no. 1, 2014, pp. 42–72.
[6] E. Blue, M. Levine, and D. Nieusma, *Engineering and war: Militarism, ethics, institutions, alternatives*. Williston, VT: Morgan and Claypool, 2013.
[7] J. C. Lucena, *Defending the nation: US policymaking to create scientists and engineers from Sputnik to the “War Against Terrorism.”* Lanham, MD: University Press of America, 2005.
[8] D. Noble, *America by design: Science, technology, and the rise of corporate capitalism*. Oxford, UK: Oxford University Press, 1979.
[9] G.L. Downey, J.C. Lucena, B.M. Moskal, R. Parkhurst, T. Bigley, C. Hays, B.K. Jesiek, B.K. Kelly, L. Miller, J. S. Ruff, J. L. Lehr, and A. Nichols-Belo, “The globally competent engineer: Working effectively with people who define problems differently.” *Journal of Engineering Education*, vol. 95 no. 2, 2006, pp. 107–122.
[10] B.K. Jesiek, Q. Zhu, S. Woo, J. Thompson, and A. Mazzurco, “Global engineering competency in context: Situations and behaviors.” *Online Journal for Global Engineering Education*, vol. 8 no. 1, 2014, pp. 1–14.
[11] K. Johnson, J. A. Leydens, J. Erickson, A. M. Boll, S. Claussen, & B. M. Moskal. “Sociotechnical habits of mind: Initial survey results and their formative impact on sociotechnical teaching and learning.” *Proceedings of the 2019 ASEE Annual Conference & Exposition*. ASEE, 2019.
[12] G. D. Hoople and A. Choi-Fitzpatrick, *Drones for good: How to bring sociotechnical thinking into the classroom*. Synthesis Lectures on Engineers, Technology, and Society, Morgan and Claypool Publishers, 2020.
[13] J. Blacklock, . Johnson, R. Cook, N. A. Plata, and S Claussen. “Faculty interpretations of sociotechnical thinking in their classrooms: Techniques for integration.” *Proceedings of the 2021 ASEE Virtual Annual Conference & Exposition*. ASEE, 2021.
[14] N. Andrade and D. Tomblin, “What are they talking about? Depth of engineering student sociotechnical thinking in a technical engineering course” *Proceedings of the 2019 ASEE Annual Conference & Exposition*. ASEE, 2019.
[15] N. Andrade and D. Tomblin, “Engineering and sustainability: The challenge of integrating social and ethical issues into a technical course.” *Proceedings of the 2018 ASEE Annual Conference & Exposition*. ASEE, 2018.
[16] J. A. Leydens and J. C. Lucena, *Engineering justice: Transforming engineering education and practice*. Hoboken, NJ: John Wiley & Sons, 2017.
[17] D. Riley, *Engineering thermodynamics and 21st Century energy problems: A textbook companion for student engagement*. Synthesis Lectures on Engineers, Technology, and Society, Morgan and Claypool Publishers, 2011.
[18] W. Faulkner, “Dualisms, hierarchies and gender in engineering.” *Social studies of science*, vol. 30 no. 5, 2000, pp 759–792.
[19] W. Faulkner, “‘Nuts and bolts and people’: Gender-troubled engineering identities.” *Social studies of science*, vol. 37 no. 3, 2007, pp 331–356.
[20] J. P. Trevelyan, *The making of an expert engineer: How to have a wonderful career creating a better world and spending lots of money belonging to other people*. CRC Press, 2014.
[21] D. Nieusma, “Alternative design scholarship: Working toward appropriate design.” *Design issues* vol.20, no. 3, 2004, pp 13–24.

[22] G. D. Hoople, A. Choi-Fitzpatrick, and E. Reddy, “Drones for good: Interdisciplinary project based learning between engineering and peace studies.” *International journal of engineering education*. Vol.35, no. 5, 2019, pp. 1378–1391.

[23] J. S. Krajcik amd P. C. Blumenfeld, “Project-based learning,” in *The Cambridge Handbook of the Learning Sciences*, Cambridge University Press, 2006.

[24] J. E. Mills, D. F. Treagust, “Engineering education: Is problem-based or project-based learning the answer?” *Australasian journal of engineering education*, vol. 3, no. 2, 2003, pp. 2–16.

[25] P. C. Blumenfeld, E. Soloway, R. W. Marx, J. S. Krajcik, M. Guzdial, and A. Palincsar, “Motivating project-based learning: Sustaining the doing, supporting the learning,” *Educational Psychology*, vol. 26, no. 3–4, 1991, pp. 369–398.

[26] J. R. Savery, “Overview of problem-based learning: Definitions and distinctions,” *Essential readings in problem-based learning: Exploring and extending the legacy of Howard S. Barrows,* vol. 9, no. 2, 2015, pp. 5–15.

[27] D. Nieusma and D. Riley. “Designs on development: Engineering, globalization, and social justice,” *Engineering Studies*, vol 2, no 1, 2010, pp 29–59.

[28] M. Llopart and M. Esteban-Guitart, “Funds of knowledge in 21st Century societies: Inclusive educational practices for under-represented students. A literature review,” *Journal of Curriculum Studies*, vol. 50, no. 2, 2018, pp. 145–161.

[29] K. Litchfield, A. Javernick-Will, and A. Maul, “Technical and professional skills of engineers involved and not involved in engineering service,” *Journal of Engineering Education*, vol 105, no. 1, 2016, pp. 70–92.

[30] D. R. Fisher, A. Bagiati, and S. Sarma, “Developing professional skills in undergraduate engineering students through cocurricular involvement,” *Journal of Student Affairs Research and Practice*, vol. 54, no. 3, 2017, pp. 286–302.

[31] P. O’Keeffe, “A sense of belonging: Improving student retention,” *College student journal*, vol. 47, no. 4, 2013, pp. 605–613.

[32] T. L. Strayhorn, *College students’ sense of belonging*, 1st edition. New York, London: Routledge, 2012.

[33] C. E. Foor, S. E. Walden, and D. A. Trytten, “‘I wish that I belonged more in this whole engineering group:’ Achieving individual diversity.” *Journal of Engineering Education*., vol. 96, no. 2, 2007, pp. 103–115.

[34] L. Berhan, R. Kumar, M. A. Goodloe, J. K. Jones, and A. L. Adams, “Comparative study of the intersection of engineering identity and Black identity of African-American engineering students at a PWI and an HBCU,” *Proceedings of the 2018 ASEE Annual Conference & Exposition*, ASEE, 2018.

[35] J. M. Smith, J. C. Lucena, A. Rivera, T. Phelan, and K. Smits. “Developing global sociotechnical competency through humanitarian engineering: A comparison of in-person and virtual international project experiences.” *Journal of International Engineering Education,* vol. 3, no. 1, 2021.

[36] E. A. Reddy, M. S. Kleine, M. Parsons, and D. Nieusma. “Sociotechnical integration: What is it? Why do we need it? How do we do it?” *Proceedings of the 2023 ASEE Annual Conference & Exposition*, ASEE, 2023.

[37] D. Nieusma. "Analyzing context by design: Engineering education reform via social-technical integration." *International perspectives on engineering education: Engineering education and practice in context, Volume 1*. Eds. S.H. Christensen, C. Didier, A. Jamison, M. Meganck, M. Mitcham, and B. Newberry, 2015, pp. 415–434.