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Metallurgical Engineering Design at South Dakota School of Mines and Technology

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Initiated in 2013, the metallurgical engineering design sequence at the South Dakota School of Mines and Technology (SD Mines) has experienced a significant rebirth. During this time, key areas for continuous improvement were identified, including teamwork, technical communications, project management, and improving quality and industrial relevance of design projects. Although students engaged many aspects of engineering design, projects lacked practical constraints and inadequately prepared students for engineering practice.

The primary goals of the reconstituted design program appear in Table 1 and are mapped to the 2019–2020 ABET Criterion 3 Student Outcomes (1–7). These goals were implemented via the activities highlighted in this article.

Design Program Goals	Student Outcomes
Students will:	
Goal 1: Learn the engineering design process.	**2, 4, 5, 7**
Goal 2: Improve technical communication skills.	**3**
Goal 3: Students will develop/improve teamwork and leadership skills.	**5**
Goal 4: Apply technical knowledge gained in the undergraduate curriculum to a practical engineering design problem.	**1, 6**

Table 1: SD Mines metallurgical engineering design program goals mapped to 2019–2020 ABET Criterion 3 Student Outcomes.

Learning Design While "Doing" Design

Goals 1 and 4 of the design program often present a pedagogical dichotomy. We are interested in students not only learning the design process, but also challenging themselves technically. In many ways, a truly challenging technical problem is not the best environment to "learn design". As such, we implemented a junior-senior design sequence in which students initially learn the design process in a one-semester junior course followed by a two-semester senior course. The junior course involves the highly-integrated series of design process lectures presented in Table 2.

As students learn the design process, they concurrently engage in a highly constrained, metallurgical engineering mini-design project. For instance, this past semester students were asked to identify a customer with a specific need and subsequently designed a solution to this problem, while being constrained to using aluminum alloy casting. Students were required to identify several feasible solutions, select a specific alloy, identify an appropriate casting method, and ultimately evaluate their design versus specified requirements. The advantage of such highly constrained projects is that students are able to learn the design process within a simplified environment.

Industry-Inspired Design Projects

Senior-level design has a significant emphasis on industry involvement. ABET

Criterion 5[1] defines engineering design as "*...a process of devising a system, component, or process to meet desired needs and specifications within constraints*." The definition continues by highlighting that design involves "*...identifying opportunities, developing requirements,... evaluating solutions against requirements, considering risks, and making trade-offs, for the purpose of obtaining a high-quality solution under the given circumstances*."

This definition clearly articulates the need to provide students with design projects that simulate "real world" problems with clear constraints and the potential to define meaningful requirements. The ultimate goal of the engineering design experience is to prepare students for their profession. We believe that the best way to offer relevant design projects is to partner with industry. In this regard, selected companies are invited to suggest engineering design problems, forming the basis for student design projects. This process ensures that students work in concert with industry members, develop requirements, identify constraints, and generate possible design solutions. Industry partners contribute by providing a company lead who meets regularly with the student team to review reports and presentations. The approach also provides students a diverse team environment that incorporates varied experience and disciplinary background. Industry partners often provide samples, manufacture parts, and may even support student travel to their facility.

Since 2013, 18 companies have supported 34 industry design projects to enrich the student design experience at SD Mines, improve our relationship with industry partners, and facilitate student placement. A significant increase in student internship and full-time opportunities have resulted from new industry relationships developed through the design sequence.

A critical element of the industry-inspired design program is defining a problem that can be solved using metallurgical engineering principles. This process is further complicated by the stigma that design equates to making a "widget", which generally aligns well with other disciplines. Conversely, our senior design projects are focused on designing new processes, material treatments, and analytical capabilities. Given the nature of the SD Mines program, projects tend to have great breadth, including extractive metallurgy, mineral processing, primary/secondary metal manufacturing, and fabricated metal products manufacturing. This model requires a continuous expansion of industrial partners to ensure the necessary diversity mentioned previously.

As an example, a recent design project involved the development of a rapid flux composition analysis method for an aluminum recycling process. Students established the project constraints and design requirements and generated multiple alternative measurement solutions. Ultimately, they developed an analysis technique, based on differential thermal analysis and coupled with a thermodynamic-based composition calculator with user-friendly interface, capable of estimating the flux composition within ±0.5 wt% in under 30 minutes. This design was adopted by the company and is in use today.

Teamwork and Engineering Design

Teaching teamwork in an academic setting is a challenge because student team dynamics are complicated by the lack of common priorities and clear organizational framework. An often-cited challenge with student teams is *social loafing*—some students do not contribute fairly to the team.[2] This corrodes the team dynamic, resulting in lack of trust, resentfulness, and ultimately pushes other students away from developing their teamwork skills. This diminishes student learning and overall achievement.[3-4]

Smith[5] define the five characteristics of effective teams as follows: (1) promotive interaction (2) positive interdependence, (3) individual and group accountability, (4) teamwork skills, and (5) group processing. These characteristics clearly highlight the importance of interdependence and individual accountability. To promote these characteristics, we have incorporated several key elements within the SD Mines program. Each student is required to define and execute an individual technical assignment in support of the design project. Student accountability has been shown to improve when students are asked to evaluate themselves and their teammates. Teamwork skill development has also been facilitated by the implementation of monthly self-, peer-,

Design Process – Overview
Problem Statement, Requirements, Constraints
Teamwork and Engineering Design
Project Management/Planning
Information Gathering
Concept Generation and Evaluation
Trade Studies and Decision Making
Embodiment Design
Global, Economic, Environmental, Societal Context
Ethics and Intellectual Property

Table 2: Junior Design Course Lectures (Partial List)

team-, and faculty evaluations (adapted from Kelley[3]) in which students and their advisors rate individual team members and the team as a whole in the areas of quality, timeliness, participation, and teamwork.

While evaluations are held confidential by the advisor, they are an important instrument for advisors to "coach" effective teaming and to identify conflicts. New lectures have also been developed on the topic of "teamwork skills" and "highly functioning teams" and delivered early in the design sequence to promote appropriate teaming behavior from the onset of the project.

Project Management in Engineering Design

ABET Student Outcome 5 highlights the need for students to "*establish goals, plan tasks, and meet objectives*[1]." Project management is a critical element in engineering design, and, the SD Mines program has placed a significant emphasis in developing these skills by preparing formal lectures focused on project management/planning. In addition, these elements are reinforced throughout the program by requiring students to develop and maintain a project plan. Each student is also coached on conducting effective meetings, documenting meeting minutes and action items, and continuously identifying project risks and possible mitigation plans.

Technical Communication in Engineering Design

Technical communication is a critical element of the SD Mines program. Students deliver monthly written assignments (e.g. project plan, design proposal or final report) and oral design updates. The latter is delivered to all program faculty and students. The written assignments are designed to be additive, as opposed to independent documents, ultimately combining to comprise the final design report. The most important aspect of this process is providing students with rapid and high-quality feedback. We prioritize a one-to-one design advising strategy where each faculty advisor is dedicated to a single design team. In addition, all oral presentations are evaluated (in terms of presentation quality, technical content, and design methodology) by all program faculty. The student design team also holds bi-weekly teleconferences with its industrial partner. Finally, a campus-wide design fair audience (i.e. students, faculty, and community members) and final presentation audience (i.e. students, faculty, and industry representatives) provide students with an opportunity to develop skills in communicating engineering information to an interdisciplinary and diverse group.

Lessons Learned

As a consequence of the program outlined in this article, we have witnessed a significant improvement in ABET evaluation instruments targeting (1) design process understanding and execution, (2) technical communication skill development, and (3) teaming skills development.

While this success is noteworthy, there have been a number of lessons learned through the process. Key among these is that a good industry project must have a "true industry champion" to lead the project. This individual(s) must be in a position to make decisions on behalf of the company and must have sufficient time available to provide guidance, especially during the early project stage. Without this resource, problems associated with poor communication, delayed materials or information, and changing project scope are encountered. Another important takeaway is that the problems must be real problems that are meaningful to the company. If the problems are hypothetical in nature, then constraints and requirements are often vague and lead to an inadequate design experience.

End Notes

1. ABET, "Criteria for Accrediting Engineering Programs, 2018–2019: IV. Proposed Changes to the Program" (ABET, 2018), www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2018-2019/#proposed. Accessed 11 May 2018.
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5. K.A. Smith, *Teamwork and Project Management*, 4th ed. (New York, NY: McGraw-Hill, 2014).

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