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Incorporating Design into the Senior Thesis Capstone at Penn State University

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The Pennsylvania State University (Penn State) Department of Materials Science and Engineering (MATSE) began as the Metals Science and Engineering department in 1907. Since its inception, the department has required students to write a senior thesis in order to graduate. Over the years, it has had many discussions with ABET program evaluators about design in a senior thesis.

In 2012, MATSE launched a new curriculum with a two-course sequence that constitutes the senior design capstone experience. The first design course, taken during the second semester of the junior year, provides students with an overview of engineering design by taking a student-generated idea and developing a research proposal that addresses an engineering challenge. This gateway course is required for students to complete the senior year capstone experience, which is now offered as either an individual research thesis or an industry-sponsored team research thesis. Rubrics for student performance and the thesis document ensure consistency between these two pathways.

Providing Context: ABET Student Outcomes

The most recent changes in ABET student outcomes, approved by the Engineering Area Delegation in October of 2017 (to be implemented 2019–2020), took the well-known a–k student outcomes and condensed them into student outcomes 1–7. In particular, student outcome 2 addresses the concept of engineering design as follows: "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."

In addition to this student outcome, a definition for engineering design was specified: "*Engineering design* is a process of devising a system, component, or process to meet desired needs and specifications within constraints. It is an iterative, creative, decision-making process in which the basic sciences, mathematics, and engineering sciences are applied to convert resources into solutions. Engineering design involves identifying opportunities, developing requirements, performing analysis and synthesis, generating multiple solutions, evaluating solutions against requirements, considering risks, and making trade-offs, for the purpose of obtaining a high-quality solution under the given circumstances."

This definition has its roots in the previous definitions from Criterion 3 (student outcome, c) and 5 (definition of engineering design), but expounds significantly on those references.

Preparation Through Competition

In order to provide students with an overview of the concept of engineering design, we created a competitive course, focused on clear, persuasive communication that requires students to propose materials solutions to engineering challenges and design a research plan to develop their ideas into marketable products. The course, MATSE 492W, is a writing and speaking intensive course that leverages the time and expertise of alumni in industry to provide students with focused, critical feedback on their ideas and research design. This external board of alumni, playing the role of potential investors, judge the projects, with winning teams receiving a monetary prize.

The course begins with students developing an elevator pitch to sell their materials solution that addresses one of the National Academy of Engineering's Grand Challenges or United Nations Sustainable

Development Goals (UN-SDG). These pitches are delivered orally by the students to their peers in the class, a panel of the previous year's team leaders, and faculty. The top quartile become team leaders and the rest of the class is dispersed into four- or five-person teams under the team leaders.

The teams then begin the process of writing a one-page white paper that details their design plan and preparing a poster for presentation to the external board of alumni. The white paper includes an executive summary, as well as descriptions of technological need, technical goals and approach, resources, and deliverables. In addition, the white paper contains several appendices that explain the importance of the product to the related Grand Challenge or UN-SDG, elucidate the social, scientific, and economic impact of the product, estimate the costs and potential return-on-investment, and articulate risk mitigation strategies for the product's critical components.

A poster based on the white paper is presented via a five-minute pitch during a session in which each poster is judged four times by different board members. Each time the poster is judged, the student giving the pitch must rotate to a new team member. These pitches are followed by three minutes of questions and discussion in which a second team member may assist. The top quartile of teams after the white paper and poster competitions remain in contention for the monetary prizes conferred at the end of the semester.

All teams move forward to produce a five-page full proposal. Following the subsequent in-class competition, one to three teams are invited back for a chance to compete for the monetary prize. The full proposal is presented to both the external board and class, with all team members expected to participate. The full proposal contains all of the sections of the white paper and its appendices, along with two additional appendices that contain a detailed project timeline and budget. In the end, the winning team receives a $1000 prize.

Beyond the competition, the MATSE 492W course contains lectures and practices on subjects related to design and development in industry. Topics include, but are not limited to, team management and leadership, project time management, return on investment and the net present value of money, intellectual property, technology readiness level, effective presentations and posters, and valuing diversity in the workplace.

As a course, MATSE 492W directly addresses the ABET definition of engineering design, in particular by requiring the students to design a product to meet a specific need within precise constraints as well as applying basic sciences, mathematics, and engineering sciences, and evaluating requirements and assessing risk associated with a product. The virtual research and product design project in this course prepares the student for the actual production of a senior design capstone.

Capstone Experience

During their senior year, students must complete the senior design capstone experience by either selecting to execute an individual research thesis or an industry-sponsored team project. The two choices count for the same number of academic credits, but the individual research thesis is conducted over two semesters, while the industry-sponsored team project is accomplished over one semester. The use of rubrics for evaluating the performance of the individual or team on their physical work and for evaluating the final thesis report ensure consistency over the different paths.

Students choosing the individual research thesis must fill out an application form, which is an abstract of their intended research. This application determines how the academic credits will be assigned and evaluated and must be signed by the thesis advisor and mentoring graduate student, as applicable. The first semester of the individual research thesis concludes with a personal evaluation of the student's performance by the thesis advisor. The final product is the thesis and a poster that is presented in the spring semester department poster competition. The rubric used to evaluate student performance in the laboratory requires assessment of student ownership in the design and problem solving of experiments, as well as assessment of the student's critical thinking in evaluating data, experimental design, and general knowledge of the literature.

Students who chose the industry-sponsored team project join the Penn State Learning Factory. The Penn State Learning Factory is a center that solicits projects from industry and then forms multi-disciplinary teams of senior engineering students on campus per the request of the sponsoring industry. These projects tend to be ambitious drawing boards to prototype experiences. The same rubrics used for the individual research thesis students are used for the teams as well. Each project has a faculty mentor who is responsible for the evaluation of team performance. The final deliverables are a thesis report and a poster that are presented during the Learning Factory Design Showcase.

Outcomes

Over the years, we have had many discussions with ABET program evaluators about the question of engineering design in individual senior thesis projects and if such projects meet the definition of design. The MATSE 492W course directly addresses the ABET student outcome on engineering design and the definition of engineering design as defined by ABET. The course also minimizes those past discussions by removing the need for the senior thesis to completely cover the engineering design student outcome. The two-course sequence also provides us with the opportunity to critically assess students, both formatively and summatively, in engaging in the practice of engineering design and applying engineering design concepts.

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