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Senior Design: The Swiss Army Knife of the Curriculum

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Abstract

Over the years, senior design courses in engineering curricula have been subject to numerous internal and external driving forces. Widespread adoption of senior design capstone experiences was dictated by the then Accreditation Board for Engineering and Technology (ABET) in the mid-1980's. At that time, ABET began to specify a "culminating design experience" for all accredited engineering curricula.

For many schools, the shift of accreditation criteria to assessment and evaluation processes has impacted senior design courses. Student outcomes are often assessed in the senior design course(s). Integration of student outcome assessment in design course(s) has met with varying degrees of success.

Senior design has presented an opportunity to increase interaction with external constituents that have an interest in projects and in hiring graduates. While these interactions often strengthen overall student experience, in some cases they present unanticipated challenges within a structured design course.

Shifting budget priorities within engineering departments has meant that a wide range of instructors teach senior design. Often, fewer full-time, tenure-track faculty members are teaching design. The gap is filled in a number of different ways: graduate student-teachers, adjunct faculty (particularly from industry), and professors of practice.

With these drivers, it can be challenging to create and deliver a coherent design experience that meets all of these objectives. This paper will present the configuration, tools, and methodologies of a senior design course sequence that addresses its large menu of objectives in a rational, structured fashion.

Introduction

Throughout the Bachelor of Science in Electrical Engineering (EE) program at the Milwaukee School of Engineering (MSOE), design is strongly integrated into many courses[1]. These projects are generally short-term in the context of an eleven-week term, and involve individual or two-student teams. The projects lead to the major capstone design experience, Senior Design, which is a three-term course sequence: EE-407/8/9. Each term consists of an eleven week term, so three terms is one academic year. While all EE students are required to take this course sequence, interdisciplinary projects may be undertaken, and the teams can include other engineering students: computer, mechanical, software, etc. Over the 26 years of the existence of this course, it has evolved due to changes in employer needs, student traits, technology, and the faculty members' understanding of the needs of the graduates. [2]

An extensive, detailed, and highly structured packet lays out the entire course sequence and sets expectations (e.g., assignments, grading rubrics, etc). [3] The packet was assembled after receiving student feedback that greater structure was desired in the courses since there was no textbook. The instructors re-designed the sequence with this student feedback at the forefront.

Senior Design – The MSOE Electrical Engineering Approach

Quarter 1 – EE407. This is the first course in the three-course EE senior design sequence. Students form four-person (typical) design teams and define a design problem. In this first course in the sequence, teams will (1) formulate, analyze, and evaluate design solutions to determine the most feasible solution(s); (2) build, test and demonstrate a subsystem; (3) maintain an engineering design log; and (4) present a formal design review. Topics discussed include team building, conceptual thinking and problem definition, solution feasibility, composing technical specifications, design aids and research techniques, industry standards, prototype development and testing, and verbal and written communications. Each student is required to keep a design log in a bound engineering logbook. Substantial, continuous individual and team progress is expected.

Projects arise in three ways: 1) industry partners pose ideas, 2) students bring projects back from internships, and 3) students generate ideas. The course structure must accommodate all three modes. Weekly meetings between advisors and student teams (and rarely a large group, classroom setting) allows content to be tailored to individual teams. Industry sponsorship of the projects is allowed, provided that the academic goal of successfully completing Senior Design takes precedence over competing business desires. Such sponsorship is fairly common.

The process is modeled after industry-standard design practices.[4] Students and alumni have commented that the process mirrors their intern and job experiences. Project design is treated as a process, in which teams must achieve various milestones: define a valid problem, research the problem, use ideation methods to generate a list of possible solutions, reduce the list to the best solutions, and determine feasibility of the solutions. They identify competing products, and discuss the problem with potential customers. They must determine a preliminary set of specifications and a list of solution requirements. The solution requirements identify stakeholders and their needs. Potential solutions are laid out as system diagrams.

Each team is required to build a working prototype of their entire system solution that is due near the end of the third term. Our experience and student feedback led us to impose a premature hardware demonstration of one major subsystem in the first term. The purposes of this demonstration are: to give students experience at writing and executing a test plan, to prove conceptual feasibility of one major subsystem, and to provide the students with experience at construction in an open-ended design problem. This last objective is critical for the students prior to their committing a detailed technical design to paper in the second term.

Each student composes a proposed Personal Growth Plan near the end of the term. In this plan, the student identifies one skill area they are targeting for improved performance over the remainder of the project. Skill areas include personal abilities such as performing analysis, solving problems, and designing to meet needs. They describe their present state, describe their desired state with measurable goals, and list specific steps to be taken toward the desired state.

Finally, the teams conduct a formal design review at the end of the term. Their goal is to convince the supervisor(s) and their peers that the project: is technically feasible, is economically viable, will satisfy the customer, will meet specifications, and will be completed by the Compliance Test (in the third term).

The sequence of submittals in the first term is:

Week in term	**Submittal**
2	Project Selection Criteria
3	Problem Statement
5	Solution Requirements and Specifications
6	System Diagrams
7	Subsystem Test Plan
8	Team Charter and Project Plan
9	Subsystem Test Results
10	Personal Growth Plan
11	Formal design review

Term 2 – EE-408. In the second course in the three-course EE senior design sequence each team completes the Final Design of their system solution, on paper. Upon reflection, each student assesses their team processes and defines ways to use team processes more effectively in support of team productivity. Following that, all major subsystems are built and tested. The second term ends with an oral Final Design Review. Throughout the quarter there are weekly meetings with the advisor. Substantial, continuous individual and team progress is expected.

For the project work, there is a special large laboratory set aside solely for EE Senior Design, containing four workstations, each with modern, networked test equipment. For the most part, the students use it as a work and meeting room. To some extent it is a social gathering place, but that also serves a very useful purpose in forming, developing, and sustaining teams.

The sequence of submittals in the second term is:

Week in term	Submittal
3	Final Design Report
6	Team Process Evaluation
7	All Subsystems Test Plans
9	All subsystems demonstration and Test Report
10	Formal design review

Term 3 – EE-409. In the third course in the EE senior design sequence, the complete system solution will be integrated, assembled and tested. The project prototype will be complete, functional, and fully-tested in accordance with the Compliance Test Plan. Each student assesses their own professional practices and also reports back on the progress of toward their personal growth plan (written in the first term). A project poster is created for display at the Senior Design Show and in the department. Instead of a formal design review, a Senior Design Show takes place on the last day of final exam week. Industry representatives, family, friends, professors, and other students attend this “trade show” display of the projects.

The sequence of submittals in the third term is:

Week in term	Submittal
4	Professional Practices Report
6	Annotated Bibliography
7	Personal Growth Evaluations
9	Compliance test plan
10	Compliance test demonstration and report
10	Project poster
11	Final engineering report
11	Senior design trade show

Outcomes and Assessment

The learning outcomes of the three course sequence are closely aligned with eight of the eleven ABET (a) through (k) student outcomes. More details about the integration of senior design assessment into program assessment may be found in [5].

Course Outcome	ABET Student Outcome
• Prepare a test plan and conduct a subsystem hardware test.	(b) an ability to design and conduct experiments, as well as to analyze and interpret data
• Approach engineering design problems with an open and creative mind, and use various ideation techniques to explore a variety of alternative solutions. • Develop detailed design specifications. • Design to match a set of detailed specifications.	(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
• Form a team to define and solve an open ended engineering problem. • Define their team roles and evaluate their performance on a team.	(d) an ability to function on multidisciplinary teams
• Evaluate behavior on a design team in the context of professional and ethical responsibility	(f) an understanding of professional and ethical responsibility
• Give oral status reports on the design. • Make a formal oral presentation on the project. • Prepare a formal design report	(g) an ability to communicate effectively
• Understand the impact of engineering solutions in a global, economic, environmental, and societal context	(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
• Keep a bound engineering logbook of all design activities.	(i) a recognition of the need for, and an ability to engage in life-long learning

Industry Sponsorship

The primary intent of the senior design course is to teach students how to apply their math, science, and engineering knowledge to solve open-ended problems in response to the needs of a customer. Projects derived based on the needs of industry partners often make for the most rewarding student experiences. Such projects can provide a variety of challenges within the context of a highly structured course sequence. Therefore, careful coordination and shared expectations between industry sponsors, student teams, and the course instructors are essential.

Students are expected to have necessary technical knowledge from their coursework, or be able to acquire it with reasonable effort. Students starting the senior design sequence have just completed their junior classes and most have little or no professional industrial experience, although some may have had summer internships. Students are expected to work 10 to 15 hours per week, which includes time spent in design, build, and test phases of the project, as well as generating reports, preparing for design reviews, and other course assignments.

Sponsors of senior design projects should have a well-defined product in mind with well-defined requirements, specifications, and constraints. The scope of the project should be suitable for teams of 3-5 students working steadily for approximately 8 months. Sponsors are expected to provide all parts and/or financial support for material consumed in the completing the project, technical support services (e.g., surface mount board assembly, system calibration and/or test, standards certifications, etc.), and any required off-campus travel. Sponsors should also provide regular guidance to the team so that important design issues can be resolved satisfactorily.

Instructional and support staff makes every effort to ensure a return on investment that meets the expectations of sponsoring organizations. However, advising faculty and course instructors do not micro-manage projects. Student teams maintain ownership of project outcomes.

Good industry sponsored projects exhibit the following characteristics:

1. Projects have realistic electrical, mechanical, and/or computer-based solutions involving proven technologies.
2. Projects maintain multiple components, allowing concurrent design and subsequent integration.
3. Projects have multiple solutions that are acceptable to the customer. Building a pre-existing design does not make for a good project.
4. Project scope and complexity should be comparable to those given to an entry-level engineer.
5. Project milestones and deliverables are amenable to the structured design process outlined in the course sequence.
6. Projects do not require development tools or instrumentation that the institution does not possess and that the sponsor is unable to provide to the team.
7. Projects do not involve excessive proprietary material.
8. Projects should not be in the critical path of the sponsor's business plan.

This information is published as part of the course packet, as it is relevant to students as well. This is particularly helpful for students who discuss sponsorship opportunities directly with potential sponsors, say, during a summer internship.

Instructors and Course Delivery

After years of revising, refining, and vetting the contents of the course packet, it has evolved into the primary resource for senior design instructors within the program. The maturity and stability of the packet provides numerous advantages.

Perhaps of primary importance, the highly structured course packet of 50-60 pages helps ensure a level of consistency in delivery of the design experience. All instructors (typically between 2 and 4 instructors each academic year) use the same set of course assignments, grading rubrics, and generally adhere to the same schedule for project milestones and deliverables. This commonality maintains course integrity and helps ensure a satisfactory student design experience. Student achievement is improved by having common requirements and expectations across multiple sections taught by different instructors. The use of a common course structure is similar to a design firm imposing a particular design methodology across varied development teams.

Since assessment tools are integrated into the course packet, all instructors use the same instrument for assessing achievement of student outcomes. Further, in part because the tools are common, experience has shown that instructors are more likely to discuss their evaluations of student performance, which leads to greater consistency among instructor evaluations, and may lead to higher confidence in the assessment results.

Historically, senior design courses in the program were taught by senior faculty who had significant industry experience. Faculty retirements; an evolving profile for newly hired faculty; and shifting budget priorities have all led to changes in the staffing of senior design. The structured fashion of the course sequence and supporting packet has paid dividends in easing the learning curve for first-time instructors, particularly for junior faculty and adjunct instructors. Each time the course is taught, a course improvement form is completed by the instructor. The accumulation of these forms indicates that faculty appreciate the structure of the course.

Experience has shown that the structured approach allows a greater degree of responsibility to be shifted to the student teams earlier in the project. After navigating the highly-structured process for two terms, the majority of student teams are largely self-sufficient in the third course. Students take significant strides towards become more organized, more proficient at team-dynamics (e.g., communication and delegation of tasks), and better at anticipating upcoming challenges (whether technical or non-technical), all of which are important steps for the maturation of students into professionals.

Conclusion

Although senior design has many constraints including design process instruction, program accreditation, program assessment, industrial relevancy, and broad instructor backgrounds, a mature course structure has been described. Faculty assessment, alumni feedback, and employer feedback confirm that the course sequence is meeting its objectives in all of the described areas.

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