Enhancing the quality of senior design projects: The introduction of a coordinated sequence of design courses to prepare students for the capstone experience in electrical engineering

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Abstract

General dissatisfaction with the quality of capstone projects led the Undergraduate Curriculum Committee (UCC) in the Electrical Engineering Department at The Pennsylvania State University to adopt a coordinated sequence of design courses that will prepare students to make better use of the capstone semester. The goal for this re-definition was to revitalize the capstone program by offering broader opportunities for students to find ambitious projects aligned with their professional interests. In addition, there was a desire to breach the wall between graduate and undergraduate programs and to increase professionalism training.

An assessment plan was developed at the same time as the curriculum. Assessment measures, embedded throughout the sequence, will validate the effectiveness of the curriculum changes, encourage the continued evolution of the program, encourage coordination among the constituent courses and thus provide coherence to the sequence. The assessment plan includes surveys, an e-portfolio, focus groups and a final evaluation of the capstone project itself. Some preliminary data from pilot semesters are included here.

The design sequence

The senior capstone design program has played an important role in the core electrical engineering curriculum at the Pennsylvania State University since 1992. In the original vision, the capstone project was a chance for students to demonstrate their abilities at the conclusion of their undergraduate career. In the wake of ABET 2000, it came to play an exaggerated role in fulfilling the program outcomes of Criterion 3. Of the eleven outcomes, seven are covered in this one course, four of them are covered here exclusively.

By 2009, when the Undergraduate Curriculum Committee (UCC) reviewed the senior capstone design course, it was felt that the students were not making the best use of this opportunity. It was viewed by students as simply another lab-based course. The demands of teaching professionalism topics, project management *and* the design process meant that there was seldom time in a single semester for students to complete an extended project that had meaning for their professional development. Furthermore, it was observed that student members of the several project-based clubs and programs in the department (as well as students performing honors research) were taking time away from their projects to complete a less rigorous capstone project. Dissatisfaction with this state of affairs led to a year-long discussion of the place of capstone and, more generally, of the teaching of design in the core curriculum.

The objectives for the new capstone program included:

- Greater flexibility and a wider variety of opportunities for students to fulfill the capstone requirement;
- Higher quality senior projects;
- Continued compliance with ABET Criterion 3 program outcomes;

- Providing a path for undergraduate students to become involved in graduate research labs.

Since a multiple-semester senior design course was logistically unworkable, the UCC has turned to a series of design courses to prepare seniors for a higher standard of capstone project. These preparatory courses will include skills practice and tools that students can use in summer jobs and internships. We compared our program to peer institutions and sought input from other engineering departments at our institution before settling on a plan for a sequence of four design courses, extending across the undergraduate years, that would lead to the capstone semester.

- 100-level course – Provided by the College of Engineering, this “Introduction to Engineering Design” is required of all pre-engineering students. Since we have no influence over its content, it was not part of our planning and we will not consider it further in this paper.
- 200-level course – In the “Design Tools” course, students are introduced to LabView and data-flow programming, cplds, circuit simulation with printed circuit board layout and embedded microcontrollers. It is hoped that these skills will be useful for students immediately and will help them to pursue opportunities for hands-on experience. Details of the course content for this course have been previously published.¹
- 300-level course – The “Introduction to the Design Process” covers the phases of a project lifecycle, project management skills (including teaming), as well as professionalism topics including leadership, conflict resolution, lifelong learning and engineering ethics. Technical communication skills are also a focus of this course. During the final weeks, students begin to organize their capstone projects.
- 400-level course – “Senior Capstone Design” will be offered in three different forms: Corporate-sponsored projects, Projects with faculty and Special Topics sections.

This sequence of design courses was approved by the Electrical Engineering Department faculty in 2010 and by the University Faculty Senate in early 2012. The 200-level course was required of all students beginning in the fall semester of 2012.

This sequence unquestionably represents an expanded commitment to design education by the department. Yet, although it will require increased T/A support, it will not increase the teaching load for research faculty. By decreasing the number of required electives, care was taken not to increase the number of credits to graduation.

For the design sequence to be effective in preparing students for their senior projects, there should be close coordination among the constituent courses. Concepts that are introduced in the 200-level course will be further developed in the 300-level course. We would expect to see those skills appear in the senior capstone projects that the students undertake. Conversely, skills that students struggle with in their capstone projects can be further emphasized in the 200- and 300-level course. It is unknown what effect a gap semester in the sequence will have on student readiness for the senior capstone project.

Having completed the 300-level course, the students should be ready to undertake an ambitious senior design project in their area of professional interest. Capstone projects will be offered in three forms:

- The Department of Electrical Engineering participates in a college-wide program for corporate-sponsored projects. In these projects, students work with engineers from industry to solve a problem put forward by a “client”.

- In the Projects with Faculty section, individuals and teams of students work on projects in the research labs. Oversight of the students' work (including grading) is shared between a Course Coordinator (CC) and a research faculty Technical Mentor (TM).
- Special Sections provide a focus for students that share a professional interest. The content of the class is left to the discretion of the instructor and will change from semester to semester. For instance, the class might be organized around a public competition. Or it might provide fundamentals of a particular area of expertise, such as acoustics, microcontrollers or microwave engineering.

Assessment and evaluation methodology

A formal assessment plan for the sequence has been developed in parallel with the course content. The assessment has the following objectives:

- To collect evidence for the effectiveness of the sequence in meeting the UCC objectives;
- To improve the individual component courses in relation to subsequent courses in the sequence;
- To collect evidence to support compliance with ABET Criterion 3 program outcomes.

Lamancusa and Pauley² cite an increase in confidence as one of the outcomes of adding a junior design class to the curriculum. The assessment plan will help us determine if a similar outcome is present in our case and when in the sequence this occurs. In addition, we will look for increases in self-efficacy and identity with the electrical engineering major. We will not be able to make a case for causation (the sample size is small and there are many factors that cannot be controlled, such as previous experience and stage of cognitive development). However, we would consider increases as a sign that the sequence is effective in meeting the UCC objectives.

Because of the many constituents involved (students, faculty, and the department curriculum committee), a comprehensive assessment plan was developed. The plan calls for pre- and post-test surveys of student perceptions of each course in the sequence, a mid-semester evaluation of teaching effectiveness survey, a student portfolio of artifacts from each course (under development and ongoing) and analysis of the students' final project reports at the end of the senior capstone course. The instruments have been developed and tested with the assistance of an assessment expert and measurement expert from the teaching and learning center in the College of Engineering. The development of the assessment plan began with a pilot of the 200-level course in the Fall 2011 semester and will continue through the 2013-2014 academic year. After that, the assessments will be incorporated routinely into the course activities.

The comprehensive assessment plan includes several pre-post surveys that target confidence, professional identity, self-efficacy, and also gather demographic information and provide information for formative improvement of the sequence. Close observation of the process of learning will help the instructors understand how students are learning and identify best teaching practices.³ A set of core questions (CQ) (see Appendix A) are asked identically in each course in the sequence. Semester-specific questions (SSQ) target pre-existing knowledge and the depth of gained knowledge gained in each course.

The assessment tools for the pilot courses included:

- Fall 2011, 200-level voluntary pilot course pre- and post-test surveys.
- Spring 2012, 300-level pilot course, mid-semester evaluation and end of semester focus group (see Appendix B for focus group protocol).
- Fall 2012, 200-level sequence required course, pre-survey and beginning of student e-portfolios.
- Spring 2013, 300-level course (to be assessed), pre- survey and focus groups, student e-portfolios, mid-semester course evaluations.
- Fall 2013, 400-level senior design projects (to be assessed), student e-portfolios.

The pre- and post-test surveys consisted of Likert scale questions, short answer and open-ended questions. On a 1-5 scale of strongly disagree to strongly agree students were asked questions related to self-efficacy, identity with the major and with electrical engineering as a profession. Using this scale, students were asked about their confidence in using electrical engineering tools, using software and lab equipment and teaming skills. Data for the Fall 2012 semester showed a positive reaction to the 200-level course. The pre-survey was administered online and was open during the first third of the semester. Eighty six students out of 96 enrolled in the course responded (75 male students and 11 female students). Their GPAs ranged from 4.0 to 2.25. 73% of respondents indicated that they intended to seek employment after graduation with 15% interested in attending graduate school and 8% undecided. 50% of the students stated that they had held a summer internship in a technical position.

Regarding self-efficacy and confidence with being an electrical engineering major, approximately 89% of the students “strongly agreed” that they had chosen the correct major. Since the scores were clustered at the high end of the scale for the identity questions, the research team decided to re-word the questions to track “identity” in future surveys. The charts below are the results from two scales in the pre-survey for the 200-level course.^{4,5} The students were previously enrolled in the pre-requisite course, Circuits and Devices.

Table 1 – responses to the self-efficacy items of 86 out of 96 students enrolled (Fall 2012) in the 200 level course of the design sequence.

On a scale of 0 being the least to 10 being the most, I believe I am capable of performing the following...

N=86 Self-efficacy Scale	Mean	Standard Deviation
Analyzing DC circuits containing dependent and independent sources using node or mesh analysis, source transformations, and superposition.	9.17	1.51
Using computer software (Multisim) to simulate analog circuits.	9.01	2.09
Designing, building, and testing analog circuits.	8.65	1.81
Using Karnaugh maps to minimize the number of gates in combinational logic design.	8.49	2.42
Analyzing basic diode and operational amplifier circuits.	8.08	1.98
Designing combinational logic circuits'	7.84	2.26
Writing and debugging a simple C program	7.75	2.94

Developing a C program that uses the constructs IF-THEN -ELSE and SWITCH	7.67	2.89
Developing a C program that repeatedly executes a sequence of steps using FOR, WHILE, and DO-WHILE loops	7.61	2.90
Analyzing the transient response of RL, RC, and RLC circuits.	7.5	1.86
Implementing a finite state machine using a sequential logic circuit	7.5	2.21
Designing, building, and testing digital circuits	7.49	2.06
Analyzing AC circuits using phasor concepts.	7.48	1.85
Developing a C program that uses one or more array structures to store information.	6.73	3.04
Developing subprogram control structures (functions) in C, including parameter passing and the scope of identifiers	6.42	3.00
Using a programmable logic device (PLD) to implement a sequential circuit entirely on a single integrated circuit	6.15	2.44

Table 1 – responses to the self-identity items of 85 out of 96 students enrolled (Fall 2012) in the 200 level course of the design sequence.

On a scale of 0 being the least to 10 being the most, I believe I can:

N=85 Self-identity Scale	Mean	Standard Deviation
Uphold the engineer's ethical responsibility. N=85	9.86	1.50
Work well on a team project. N=85	9.81	1.33
Receive and act upon feedback on my technical work. N=85	9.53	1.39
Resolve conflict within a small team. N=85	9.25	1.46
Solve technical problems. N=84	9.18	1.43
Give feedback to a peer. N=85	9.16	1.40
Perform effectively on a multicultural team. N=85	9.14	1.90
Give oral presentations. N=84	9.00	1.72
Lead a project team. N=85	8.92	1.72
Work with engineers from other countries. N=85	8.81	2.12
Write technical reports. N=85	8.74	1.57
Manage my time effectively. N=85	8.40	2.22
Place engineering solutions in a cultural context. N=85	8.12	1.97
Conduct research with the intent to publish in a journal. N=85	6.99	2.39

Also, initiated during the 200-level course were student e-portfolios. The student portfolio will provide a longitudinal record of student progress, using actual artifacts that students collect throughout the courses of the sequence. This will be used to determine student success in assignments and to showcase students' best work. "The Assessment Portfolio is intended to document student learning and progress, as well as allow students to identify their own goals and accomplishments."⁶

In the 300-level course, an end of the semester survey will be distributed to the students to obtain feedback on the sequence experience. This survey will include CQs and SSQs to determine if the sequence has continued to meet objectives, whether the students are prepared for the next course, formative assessment of the previous courses in the sequence and whether the students are able to implement skills from the previous course. Focus groups will be held

at the end of the 300-level course. The focus group protocol has been developed and facilitated by an assessment expert and students will volunteer to participate. Focus groups will be used because they allow a confidential, interactive discussion on a particular topic or issue. The facilitator can utilize probing questions in a group interview format.⁷

Conclusions

Although we have only begun to introduce the design sequence, some preliminary conclusions can be drawn from our experience from seven pilot semesters (five trials of the new capstone course and one each of 200 and 300W) before the courses were officially offered. We are excited by the potential that we see in this extended sequence of courses. The breadth of project areas and the degree to which the students have dedicated themselves to their work encourages us to be optimistic that this new approach will revitalize the senior capstone design program. We note that there will be an increased burden of organization. In order for the students to have already identified team members and a viable project before the semester begins, a method for offering projects, for student teams to bid on them and for assigning projects to appropriate teams will have to be developed. The CC/TM partnership seems to be effective. The CC helps the student to organize a project of a realistic scope and to attend to course requirements, enabling the TM relationship to be strictly technical. If necessary, the CC can be an advocate for the student. The TM serves as a technical resource for the student, providing support and training as needed. In the case of honors students, the capstone project, instead of being a distraction from thesis work, now functions as a timely exercise in project management. For many honors students, preliminary design or testing during the fall term forms the basis of a capstone project, preparing them for the thesis research in the spring. In this way, the capstone project encourages them to get started on their research earlier. Finally, the assessment plan has been effective in providing formative data for the improvement of the sequence. Developed alongside the sequence, it has provided an important link for tying the individual courses into a coordinated whole.

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Appendix A

Welcome to the EE Design Sequence pre -survey. The purpose of this survey is to gather information before you begin the course sequence. The statements will address your personal attitudes, traits and beliefs about the upcoming course sequence. This survey is confidential. The information will be shared in summary form only. Your name will not be included in the summary.

What is your name? Your name is needed to match post-survey data to the pre-survey. Your instructor will not know who participated in the survey.

What is your gender?

- ☐ Male
- ☐ Female

Did you attend at a Commonwealth Campus before coming to University Park?

- ☐ Yes
- ☐ No

What is your current GPA?

- ☐ 3.76 to 4.00
- ☐ 3.51 to 3.75
- ☐ 3.26 to 3.50
- ☐ 3.01 to 3.25
- ☐ 2.76 to 3.00
- ☐ 2.51 to 2.75
- ☐ 2.26 to 2.50
- ☐ 2.01 to 2.25
- ☐ 2.0 and below

Are you a Schreyer Honor's college student?

- ☐ Yes
- ☐ No

Please describe any professional engineering experiences you may have had such as internships, research experience or others.

What do you plan to do after you graduate?

- ☐ Seek employment
- ☐ Attend graduate school
- ☐ Other _____
- ☐ Undecided or not sure

Please indicate whether you agree or disagree with the following statements.

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
I believe that I have chosen the correct major for me.	☐	☐	☐	☐	☐
I chose a major based on my interest in the subject material.	☐	☐	☐	☐	☐
I am proud that I am going to be an electrical engineer.	☐	☐	☐	☐	☐
I sometimes wonder if I have the skills to be a successful electrical engineer.	☐	☐	☐	☐	☐
I doubt that I can develop novel solutions to electrical engineering problems.	☐	☐	☐	☐	☐
Being an electrical engineer is an important part of my self-image.	☐	☐	☐	☐	☐
I enjoy solving electrical engineering problems.	☐	☐	☐	☐	☐
I believe I am making progress towards obtaining the knowledge and skills required to be successful in my chosen major.	☐	☐	☐	☐	☐
I prefer working in teams on engineering projects.	☐	☐	☐	☐	☐
I am looking forward to pursuing a career in electrical engineering.	☐	☐	☐	☐	☐
I consider myself to be an electrical engineer.	☐	☐	☐	☐	☐

On a scale of 0 being the least capable to 10 being the most capable, I believe I can:

	Cannot do at all 0	1	2	3	4	Moderately certain can do 5	6	7	8	9	Highly certain can do 10
Work well on a project team	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Solve technical problems	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Lead a project team	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Give oral presentations	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Write technical reports	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Give feedback to a peer	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Receive and act upon feedback on my technical work	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Manage my time effectively	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Resolve conflict within a small team environment	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Conduct research with the intent to publish in a journal	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Perform effectively on a multi-cultural team	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Work with engineers from other countries	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Place engineering solutions in a cultural context	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Uphold the engineer's ethical responsibility	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Appendix B

Focus Group Protocol

Perceptions of Student Learning in EE 300W

Hello, I am _____, the facilitator for our discussion today. We are working with your instructor to get your suggestions and feedback on your learning experience in EE 300W this semester.

The purpose of this focus group is to get feedback from students that will help us improve the EE Design sequence for future semesters.

1. To start off this conversation, please tell me your name. This will only be used for my coding purposes. This conversation is voluntary and confidential. Your instructor will not know if you are participating. A summary of the focus group will be shared with the instructor after the semester is over and will not contain any identifying information. This focus group will be audio recorded. Only the facilitator will have access to the recording.
 - a. State name
 - b. What is your career plan after graduation?
2. What about the course was most helpful to your learning?
3. How have the topics addressed in the course helped you to be better prepared for your intended career?
4. How did the course help most in the development of your technical skills?
5. How did the course help most in the development of your professional skills, for example teamwork, oral and written communication, time management, giving and receiving feedback, any others?
6. What parts of the course were most valuable in helping you learn?
7. As a follow up to #7 if the labs do not come up.
How have the lab activities been valuable in helping you learn?
8. As a follow up question to #7, if it does not come up.
How has the experience in EE 200 and EE 3300W reinforced your decision that electrical engineering is a good career choice for you?
9. What parts of EE 300W helped you to be most confident in your ability to perform electrical engineering tasks?
10. How could the course have been changed to improve your learning?
11. How has the experience in 300W reinforced what you learned in EE 200?
12. As a follow up to #11, how can the EE faculty better prepare you for EE 800W?
13. So, you're 2/3 of the way through the course sequence. Has there generally been a flow or a clear continuum from EE200 to 300W? Or does it seem like EE 200 and 300W were two disconnected courses? Would you please explain your answer?

Regarding preparation for the capstone project.

1. What do you think the senior design project will be like?
2. How has EE 300W prepared you for the senior design project?
3. What steps have you taken in EE 300W so far towards starting your senior design project?
4. In the final weeks of this semester you will be preparing for the senior design project, how do you think this will help you be ready for EE 403W?
5. What concerns do you have about the upcoming senior design project?
6. What do you think will be the value of the senior design project relative to your career goals as an engineer?
7. Would you please comment on whether your professional interests and objectives may be different than they were a year ago?
8. How did your experience in EE200 and EE 300W helped you to think about your professional interests?

Are there any additional comments that you would like to share with the group? Thank you for your time.