AC 2012-5141: A FOUR-YEAR VERTICALLY INTEGRATED DESIGN SEQUENCE IN ELECTRICAL ENGINEERING

Dr. Jeffrey L. Schiano, Pennsylvania State University, University Park

Jeffrey L. Schiano is an Associate Professor electrical engineering at the Pennsylvania State University. He earned a bachelor's of science degree in electrical and biomedical engineering (with university honors) from Carnegie Mellon University in 1983, and the master's of science and doctorate of philosophy degrees from the University of Illinois, Urbana-Champaign (UIUC), in 1985 and 1991, respectively. His expertise is in the areas of feedback control systems and magnetic resonance engineering.

A Four-Year Vertically Integrated Design Sequence in Electrical Engineering

Abstract

This paper describes the creation of a four-year vertically integrated design sequence in the Department of Electrical Engineering at the University Park campus of The Pennsylvania State University. We describe the motivation behind the curriculum revisions, the integration of material among the four design courses, and the strategy for obtaining the approval and support of the Electrical Engineering faculty for implementing the new design sequence.

Introduction

Presently, the Department of Electrical Engineering has forty-one faculty members who hold tenured, tenure track, or multi-year fixed-term positions. Undergraduate engineering students declare a major during the fifth semester. Enrollment for the 2011-12 academic year includes 439 students as juniors and seniors pursuing the BSEE Degree, and an additional 72 M.S. and 135 Ph.D. students in the Electrical Engineering Graduate Program.

The concept of design is of central importance to all engineering disciplines and a required component in every accredited engineering program. In comparison to other core areas within electrical engineering, such as circuit analysis, electromagnetics, semiconductor devices, or linear systems, the development and maintenance of a design course is a more challenging process for several reasons. First, it is easier to identify and instruct the required concepts in the core areas. For example, a review of the first electronic circuits courses among a collection of universities and colleges reveals a similar course outline. Second, there are many texts available for specific areas such as linear systems or electromagnetics. Third, it is easier to recruit faculty for instructing courses in their specific area. In contrast, these three conditions seldom hold for courses that focus exclusively on design. As a result, the design course is likely to receive less faculty attention regarding its content, and not surprisingly, is more difficult to staff.

Before revising the design component of our curriculum, we required our students to complete a freshman engineering design course and a senior capstone design course. The freshman course introduces students to the process skills associated with engineering design. Emphasis is on team work, communications skills, and computer-aided analytical tools. Activities include prototype building and testing with industrial collaboration. As students complete this course before choosing a major in the College of Engineering, the technical content is general and does not focus on a particular engineering discipline. In contrast, the senior capstone design course requires students to apply the tools acquired in both required courses and technical electives within our department. By blending professional engineering topics and project activity, the existing capstone design course dilutes both these components. Moreover, as the professional engineering topics are required for graduation, students cannot replace the capstone design course with other opportunities closer to their professional interests, for example, completing a project in the Student Space Programs Laboratory.

Following a critical review and discussion of the design component of our curriculum, the undergraduate committee identified three areas for improvement: (1) coupling the undergraduate and graduate programs by engaging undergraduates in faculty research projects, (2) diversifying the spectrum and depth of capstone design projects, and (3) increasing the number of credit hours for engineering design tools and professional topics. The committee aims to meet these objectives by introducing a vertically integrated design sequence. The sequence consists of the existing first year design course, a new sophomore-level design tools course, a new junior-level design processes course, and a revised senior capstone design course. The development of the architecture of the four-year design sequence took place over a three year period. This process did not occur overnight; meeting twice a month for an hour, the undergraduate committee required several semesters to develop the architecture for improving the design curriculum. The new design sequence is a requirement for all electrical engineering students starting with the class of 2016.

Design Sequence Architecture

As a starting point for achieving the three objectives stated earlier, the undergraduate committee began by reviewing the design component of the curriculum at peer Electrical Engineering Departments with similar size and ranking. Our senior capstone design course was organized along the same lines as many other departments, and reflects ABET criteria. In addition to general lectures concerning professional engineering topics, there are weekly laboratory sections. In self-defined project sections, students first complete predefined laboratory assignments during the first half of the semester before beginning a self-defined project approved by their instructor. In other sections, student teams select a major design project provided by either a faculty member or an industrial sponsor. For all sections, about one third of the course develops technical communication skills. Students must develop good laboratory documentation techniques and prepare a detailed project proposal. Upon the completion of each assigned task, students submit a summary report to either the faculty or corporate sponsor. Preliminary and critical design reviews require oral presentations. Students must submit a final written report summarizing their work. For the student-chosen projects, each team makes a final oral presentation, while students working with industrial sponsors present their work in poster format at an end-of-semester product showcase.

While this format satisfies accreditation requirements, it presents several challenges. The amount of time a student team spends on the technical aspects of the project is limited, as students divide their time between professional engineering topics and their project work. Second, students cannot substitute other project work, for example, participating in a faculty research project or honors thesis research, as it lacks coverage of professional engineering topics. Furthermore, the requirement that a significant component of the lectures focus on professional topics often discourages faculty from sponsoring a senior deign section that focusses on their research area.

A review of the design curriculum within other departments at our university revealed that the Mechanical Engineering Department introduced a junior-level design course that transferred the professionalism topics from the senior capstone design course to a required junior level course. This approach allows students to focus almost exclusively on the technical component of their senior capstone design course, as well as providing for additional time for professional topics. This course served as catalyst for discussion within our committee.

While there was unanimous agreement that increasing the project time and technical content in the senior design course was a worthwhile goal, concerns arose over the implications of adding a junior-level course to the curriculum, in particular, increasing the faculty workload and need for laboratory resources. Furthermore, proponents of the junior-level course were adamant that it should focus on professional skills such as working in teams and the development of proficiency in design skills and methodologies, rather than the instruction of design tools. While many required classes such as circuits and linear systems naturally introduce some design tools, other desirable design tools do not appear in the curriculum. In particular, members of the undergraduate curriculum committee agreed that our students should not only understand the theory, but also be able to use design tools to realize hardware designs. These tools include computer aided design (CAD) software for designing printed circuit boards and software for automated testing and instrument control.

The thought of introducing a third design course was not appealing, yet a need exists for a vehicle to cover additional design tools. We forged a compromise by moving a required junior-level course covering embedded microprocessors to the sophomore year, and making several modifications to the course content. The modifications include eliminating content appearing in technical electives on computer architecture, and adding material on CAD tools for hardware realization. A benefit of placing this course in the second year is to provide our students with marketable skills that will increase their chance of securing a summer internship. Specific outcomes for the sophomore-level design tools course include:

- Automate tests and measurements using NI LabVIEW
    - Write a requirement specification document
    - Follow coding standards to complete a NI LabVIEW project
- Design hardware and software for embedded microcontroller systems
    - Write and download C-code to the embedded microprocessor
    - Interface the microprocessor with analog and digital circuits
- Implement a digital system using a field programmable device
    - Realize a specific design in HDL
    - Implement the design by programming the device
    - Interface the device with analog and digital circuits
- Realize a mixed signal circuit using a printed circuit board
    - Simulate mixed signal circuits using NI Multisim
    - Layout a printed circuit board using NI Ultiboard
    - Generate Gerber files for printed circuit board fabrication

In the junior year students complete a course focused on the design process. In addition to professional topics, this course also includes an introduction to systems engineering, a topic not previously covered in required courses. Students develop proficiency in the design tools covered in the sophomore course by completing three mini-projects in the junior-level course. In addition to demonstrating project planning and management tools, these projects also provide opportunities for developing team skills. Towards the end of the semester, students in the junior-level design course prepare for the senior design project by identifying a project and forming a team. Specific topics for the junior-level design process course include:

- Project planning and management tools
  - Project definition, engineering requirements, idea generation, resource allocation, budgets, decision matrices and timelines
- Systems engineering principles
  - The systems engineering mindset, functional decomposition, verification testing and integration
- Teaming skills
  - Temperament, characteristics of effective teams and conflict resolution
- Ethics in the engineering environment
  - Recognizing and handling ethically ambiguous situations in the heat of the moment, professional responsibility and the impact of the engineer on society
- Aspects of evolving professional practice
  - TQI/CQI, global engineering, life-long learning, cultural sensitivity and diversity
- Preparation for the senior design project
  - Student resume, team formation and project identification
- Life as an engineer
  - A series of lectures by outside speakers on topics such as building a career, what to look for in a (small, mid-sized, large) corporate position, topics of current concern, the future of the profession, and professional responsibility

In the senior design course, students demonstrate proficiency in a technical discipline area and an understanding of the engineering design process by completing a project of fifteen week duration. The course offers opportunities for undergraduate students to benefit from the varied research and project activities that exist within our university, as well as with corporate sponsors. Our intent is to steadily reduce the enrollment of the self-defined project sections by migrating students to faculty and corporate sponsored projects.

Faculty Acceptance

In the developing the new design curriculum, a central goal of the undergraduate committee was to make a fundamental change in the culture of our department. Rather than allowing the majority of seniors to complete a self-defined project, our intent was to have them complete their senior design project by teaming with graduate students and faculty members in ongoing research projects. To achieve this goal, we are first obliged to have the faculty accept the new design sequence as part of the curriculum, and secondly, we needed to convince our colleagues that accepting students into their research program to complete a senior design project was mutually beneficial. To this end, we provided updates of the revision process at each faculty meeting faculty. Although the undergraduate committee could have approved the new curriculum without taking a vote from the whole department, we decided that such a vote was essential to determine whether or not we would be successful in recruiting faculty to sponsor senior design projects in their laboratory. Realizing the potential for increasing the faculty workload by adding a new course to curriculum would be of central concern, we identified faculty who volunteered to teach the new junior and sophomore level courses. We also redistributed the teaching assistant allocation so that no new teaching assistant slots would be required to implement the new design sequence. Furthermore, we identified several faculty who enthusiastically championed the idea of having senior students participate in the research projects. As a result of these efforts, the vote for adopting the new design sequence was nearly unanimous.

Implementation

Following a vote to adopt the new design sequence in March 2010, faculty designed courses for the new curriculum over a two semester period. During the fall 2011 semester, a small fraction of class completed the sophomore design tools course. This same group of students is now completing the junior-level design process course during the spring 2012 semester. Starting in the fall 2012 semester, all students entering the department must complete the new design sequence.

Procedures for assessing the design sequence include surveys completed by students and faculty before and after each of the three design courses offered by the Electrical Engineering Department. Industrial sponsors who interact with students also complete a survey. The Engineering Assessment and Instructional Support staff of The Leonhard Center in the College of Engineering provided assistance in developing the survey questions. As approximately two hundred students will complete the surveys each semester, the analysis of student feedback includes statistical analysis of quantitative data to gauge teaching effectiveness of specific learning activities. We expect the surveys to evolve along with the design sequence, and will publish assessment results no sooner than 2016, after the first class completes the sequence.