AC 2008-1201: DESIGN OF A FABRICATION OF ELECTRICAL SYSTEMS COURSE FOR A MULTI-DISCIPLINARY ENGINEERING PROGRAM

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1 Introduction

This paper describes the design of a three credit-hour course, "Fabrication of Electrical Systems," in the context of the Electrical Engineering Systems emphasis area in the multi-disciplinary engineering program offered in the Department of Engineering at the Polytechnic campus of Arizona State University.

The Electrical Engineering emphasis area envisions a setting such as automation, robotics, aviation, or automotive, where electrical technology plays important roles in system integration. In these settings, electrical technologies are combined with other technologies inside one overall system. We believe that an essential component of the electrical emphasis area in this setting is an understanding of how the electrical portions of mixed systems are designed and fabricated as well as how system level design issues affect and are affected by electrical system implementation.

To this end, we have designed and are implementing a three credit-hour course to help students develop an appreciation for how one chooses between various solution implementations in a real-world setting. The initial course offering is taking place in the Spring 2008 Semester. The course emphasizes issues such as design cycle time, fabrication and manufacturing costs, quality, reliability, product life cycle and various forms of testing. In addition, the course will develop fabrication technology expertise such as technology selection (e.g. software solutions vs. FPGA).

We believe that our course offers a unique combination of topics. Indeed, the authors are unaware of any other undergraduate courses within an engineering department with a similar breadth of coverage of issues relating to electrical systems implementation. Many courses and degree programs provide expertise in micro-systems fabrication (see, for example [1]). While these cover some of the topics proposed for this course, they typically focus on the fabrication and packaging of chip-level micro electro-mechanical systems and not on the broader issues associated with design and fabrication of electrical systems. These courses are also typically offered at a gradual level. Mechatronics courses also cover material that overlaps in part with our course (see, for example [2]); mechatronics courses typically stress integration of electrical and mechanical systems (through sensors and actuators) and control of systems using programmable devices (e.g. microcontrollers). The University of Limerick offers an electronics systems degree [3] that covers most of the topics in our course, but in much greater depth, devoting several courses to several of the individual topics.

2 Multi-Disciplinary Context

Our multi-disciplinary engineering program at ASU is built around core values of engaged learning, agility and a focus on the individual. The main spine of the program is eight semesters of project work conducted inside an engineering studio. The freshman and sophomore years of the program are multi-disciplinary, with all students sharing a common set of projects and courses. At the upper division, a student will individually select two focus areas: a primary engineering emphasis area and a secondary emphasis area, which may or may not be in engineering.

We expect our graduates from the Electrical Engineering emphasis area to play roles that a traditional EE program does not emphasize; therefore, we have adopted the following outcome for this emphasis area: “the graduate will provide electrical expertise on a multi-disciplinary team”. Simply covering one of the traditional sub-disciplines of electrical engineering would not properly prepare our graduates for this role.

What is the electrical expertise needed in such settings? We have identified four main areas for such expertise: systems theory, signal distribution, implementation technology, and power. The systems theory expertise traces information flows between sensors and actuators at one end and the immediate digital side of the digital/analog interface at the other end. The signal distribution expertise involves selecting signal propagation methods (e.g. wireless vs. tethered), signal and system isolation (e.g. electromagnetic compatibility) and system coupling. The implementation technology expertise involves technology selection (e.g. software solutions vs. FPGA), safety, reliability, and manufacturing test. The power expertise focuses on power distribution, management and dissipation within a system such as an automobile (not a utility-scale system). Note that in this perspective, the emphasis within electrical technology is not that found in a traditional EE program. Also, none of the standard subdivisions of electrical engineering cover this mixed technology agenda.

This paper deals specifically with the area of implementation technology. This is not a focus on integrated circuit fabrication but rather a focus on how one actually implements the electrical part of a mixed technology system such as a robot or vehicle. To address implementation technology, we have created two courses. One course is a one-credit module in which we introduce students to the facilities and capabilities that are available within our department to design and fabricate circuit board assemblies; we wish to avoid having students get well into a project and then discover that we cannot achieve the project goals with our facilities. The other course is the subject of this paper. It is a three-credit course that covers a larger set of contemporary technologies than the one-credit module. It should develop an appreciation for how one chooses between various solution implementations in a real-world setting.

3 Course Implementation

In order to address the needs to be met by this course, we have identified the course student learning objectives outlined in Table 1. These objectives are met in the context of the topics outlined in Table 2.

Students are familiar with the characteristics of the different technologies used in fabricating electrical systems.
Students can select appropriate fabrication technologies for electrical systems by applying criteria and constraints that include design cycle time, fabrication and manufacturing costs, quality, reliability, product life cycle and various forms of testing.
Students understand circuit board design, fabrication, and population processes.

Table 1: Objectives for Electrical Systems Fabrication Course

1. Design cycle
2. Fabrication and manufacturing costs
3. Quality
4. Product life cycle
5. Electrical testing strategies
6. Design for test
7. Physical and electrical properties of circuit boards
8. Computer-aided tools for circuit board design
9. Component mounting approaches
10. Programmable verses hard-wired implementation

Table 2: Topics to be covered in the Electrical Systems Fabrication Course

Student achievement of the course outcomes is assessed using a competency-based grading system; this grading system is a version of mastery-based grading [4]. 33 competencies have been identified; most competencies are derived directly from the course outcomes and topic areas. Additional competencies reflect desired student outcomes at a program level. These competencies are listed in the appendix. A student's grade is determined by the number of competencies that they have mastered by the end of the semester. Students have multiple opportunities to demonstrate mastery. Competencies require at least three demonstrations of mastery: one in an individual effort, one in a group effort, and one individual or group effort. The requirement that the competency is demonstrated three times is a form of triangulation that should help students apply the knowledge they gain in real-life settings. Assignments, quizzes, and tests are not weighted or worth a certain percent of the student's grade; they are opportunities to demonstrate competencies.

This grading approach has been piloted in other courses in previous semesters, and students have expressed strong support for its use. According to their feedback, they feel that competencies help make clear what they are to learn and what is needed for success in a course. They feel that competencies directly relate activities to topics and organize the material. They appreciate multiple opportunities to demonstrate competencies and feel that this gives them good feedback about how they are doing. They feel that competencies positively motivate them (or, in the worst case, that competencies are much less demotivational than traditional grading systems).

The learning activities in the course are structured around three case studies. Each case study poses a topic of relevance to the course material, and students work on a case study for approximately five weeks. Students work on each case study in teams of three. For each case study, the following sequence is repeated:

- Teams are introduced to the case study and the issues it raises.
- Each team is assigned to research a course competency related to the case and to create a short summary of their research on a Wiki web page dedicated to the course.
- Teams critique and edit each other's summaries using the Wiki.
- Each team presents their research to the class.
- The case study topic is explored in more detail using the cumulative research of the class as background information to address issues identified in the case study.
- Students summarize their understanding of case study and its related course competencies in a written report.

4 Developing Appropriate Course Materials

Because this course is significantly different than courses found in a traditional electrical engineering curriculum, the development of this course includes a particular challenge: we have been unable to find a suitable text. We have taken this as an opportunity to emulate a novel experiment, in which students wrote the text for their class [5]. In our class, the student summaries developed for the case studies will be available on a Wiki page for the entire class. At the end of the semester, the summaries will be compiled into a book that will be available from a print-on-demand printer. Students will each retain copyright to their contributions. All students who contribute to a chapter will be identified as co-authors of the chapter. These materials will be made available under a Creative Commons license and could conceivably form the nucleus of an open-source textbook for the material.

5 First Case Study: Implementation and Preliminary Assessment

The first case study used in the Spring 2008 Semester course is the invention and subsequent commercialization of the implantable heart pacemaker. This topic provided examples of the interplay between technology and social factors in the product life cycle of the pacemaker. Issues of quality and reliability run through the topic. This case study was chosen to address the following course competencies generally related to the product design process:

- Quality concepts
- Designing quality in
- Reliability concepts
- Intellectual Property
- Design Cycle Time

- Fabrication and Manufacturing Costs
- Product Life Cycle
- Testing concepts

The primary source of information on the commercial and technical development of the pacemaker is the book *Machines in Our Hearts: The Cardiac Pacemaker, the Implantable Defibrillator, and American Health Care* [6]; in the course of completing the reading assignments for the class, students have read about two-thirds of the book. Reading assignments are followed by class discussion that related the reading to the product design outcomes.

At the completion of this case study, we have performed a preliminary assessment of the effectiveness of the topic and format. This assessment included six of the seven students in the class completing a survey with both Leichert scale and free response questions; the survey is shown in Figure 1 and Table 3. Several themes emerged in this assessment. Students thought the case study was relevant and motivated the associated topics. Researching and writing about a topic helped students learn about the topic; they felt that other students' work was helpful in learning about a topic, although slightly less helpful than their own work. Students generally (but not unanimously) felt that this approach was more effective than a traditional lecture. Students generally gave a positive assessment of their abilities relative to the topics associated with the case study. Students wanted more structure in the initial research of the topics; examples of their suggested structure include guidance to specific sources and indications of the relative importance of different material.

6 Conclusions

We have presented the context and design of a new course on the fabrication of electrical systems. This course is designed to provide practitioners working on multi disciplinary teams the expertise necessary to make design and implementation decisions about electrical systems. We address the lack of an available text book by having students research material and develop summaries of their research that could be used as the nucleus of a text.

What were the strengths of the case study/topic process?
What were the weaknesses of this process?
Did this process facilitate your learning material about these topics? Please explain why or why not.
How would you suggest improving the process?
Other comments?

Table 3: Free response questions for the class survey for Case Study I.

Case Study 1 Assessment
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The purpose of this survey is to evaluate the effectiveness of Case Study 1 in learning the six topics covered in the class:

- Quality
- Reliability
- Intellectual Property
- Product Life Cycle
- Testing
- Design for Excellence

For the following statements, shade the number that corresponds to how strongly you disagree or agree with each item.	**Strongly Agree**	**Agree**	**Neutral**	**Disagree**	**Strongly Disagree**
1. The case study was relevant and interesting.	①	②	③	④	⑤
2. The case study was strongly related to each of the six topics to be learned.	①	②	③	④	⑤
3. The case study helped me understand the need for the six topics.	①	②	③	④	⑤
4. Researching and writing about a topic help me learn it.	①	②	③	④	⑤
5. The written material created by other members of the class was of a high enough quality that I could use it to learn.	①	②	③	④	⑤
6. I used the material written by the others in the class they help me learn about the topics.	①	②	③	④	⑤
7. I used to the presentations given by others in the class to help me learn about the topics.	①	②	③	④	⑤
8. This structure was more effective in helping me learn the topics than a traditional lecture would have been.	①	②	③	④	⑤
9. I can define quality and describe a typical quality improvement process.	①	②	③	④	⑤
10. I can define reliability and describe the primary issues that affect reliability in systems.	①	②	③	④	⑤
11. I can describe the basic categories of intellectual property and how intellectual property concerns affect the design process.	①	②	③	④	⑤
12. I can describe the primary factors considered in design for excellence.	①	②	③	④	⑤
12. I can describe a typical product life cycle.	①	②	③	④	⑤
13. I can describe the primary approaches to test in electrical systems.	①	②	③	④	⑤

Please also answer the open-ended questions on the other side of this survey.

Figure 1: Leichert scale questions for the class survey for Case Study I.

Appendix: Course Competencies

The following are the competencies selected for the course and their description.

Quality concepts Students can define quality and describe a typical quality improvement process.

Designing quality in Students can describe how quality improvement processes are implemented in and affect the design process.

Reliability concepts Students can define reliability and describe the primary issues that affect reliability in systems.

Intellectual Property Students can describe the basic categories of intellectual property and how intellectual property concerns affect the design process.

Design Cycle Time Students can describe design cycle time and identify the primary factors that affect it.

Fabrication and Manufacturing Costs Students can identify primary factors that affect fabrication and manufacturing costs.

Product Life Cycle Students can describe an entire product life cycle.

Product life cycle factors Students can identify the primary factors that must be considered for each phase of the life cycle when designing a product.

Testing concepts Students can describe the primary approaches to test in electrical systems.

Design for test Students can describe how the need to test affects the various aspects of the design process.

CAD Tool Chain Students can describe the major components of an electrical CAD tool chain and their functions.

Schematic Capture Students can use a schematic capture tool and describe its function.

Simulation Students can describe the major types of electrical simulation tools.

PCB Layout Students can perform and describe the major steps in PCB layout: component placement, signal routing, and creation of manufacturing files.

HDL/Software Environments Describes how compilers, debuggers, simulators, etc. are used to develop software/gate array configuration.

Mechanical Fabrication of Electrical Systems Describes how PCBs and other mounting technologies are used to mechanically implement electrical systems.

Types of PCBs Describes major types of PCBs (Multilayer, flexible, etc) and their characteristics.

Electrical system interconnection Describes primary methods (cables, etc.) of connecting electrical subsystems and distributing electrical power.

Component Types Describes through-hole and surface mount packaging and relative advantages and disadvantages.

PCB-based Manufacturing processes Describes the major processing steps in creating a multi-layer PCB and populating it with components.

Electrical System Architecture Describes and implements the process of developing an electrical system architecture (allocation of function to physical components).

Digital vs Analog Describes the relative strengths and weaknesses of digital and analog electrical implementations.

Digital Solutions Describes potential methods of implementing digital solutions, including processors, programmable logic devices, and hard-wired solutions.

Digital Processors Describes issues of cost, performance, fab time, and design time for microcontrollers and microprocessors.

FPGA Describes issues of cost, performance, fab time, and design time for reconfigurable logic devices.

Hard-wired digital solutions Describes issues of cost, performance, fab time, and design time for standard system components (eg COTS chip sets), ASICs (full and semi custom), and component level design.

Analog Solutions Describes potential methods of implementing analog solutions, including reconfigurable device arrays and hard-wired solutions.

Hard-wired analog solutions Describes issues of cost, performance, fab time, and design time for standard system components (eg COTS chip sets), ASICs (full and semi custom), and component level design.

Mixed Analog/Digital solutions Describes issues associated with fabrication of mixed analog/digital systems.

Critical Thinking and Decision Making Level 3 Evaluates alternative perspectives, contexts, and the quality of evidence in making informed judgments.

Engineering Practice Level 3 With direction, identifies and applies an appropriate set of engineering tools in a real world professional context to develop a valid solution to a problem.

Communication Level 3 Purposefully applies communication strategies to interact meaningfully with their audience.

Wiki Editing Edits content on a wiki.

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