DESIGN EXPERIENCE IN ELECTRICAL ENGINEERING CURRICULUM: AN INTEGRATED APPROACH

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Abstract *¾The Department of Electrical Engineering at Saint Louis University has integrated a comprehensive design experience in a four-year undergraduate Electrical Engineering curriculum. This curriculum emphasizes on the integration of a number of design experiences at all levels of engineering education starting from freshman to senior levels. At Saint Louis University, freshman electrical engineering students are exposed to the design process, and introduced to the analytical tools necessary to the interaction and growth in the design process. It focuses on the basics of design methodology, which can be applied and refined in other design work particularly during their senior capstone design projects resulting in a natural progression of design experience throughout the curriculum. The implementation of the present two-semester sequence of capstone design in the senior year focuses on the professional practice, and is drawn from all previously learned concepts of the design process. This integration of well-balanced design experience across the curriculum with an appropriate capstone design course provides a better preparation of graduates to pursue a productive engineering career characterized by continued professional growth.*

Index Terms—Design experience, capstone design, Gant Chart, prototype testing

INTRODUCTION

Engineering design has long been recognized as one of the critical components of the product realization process, and, therefore, deserves a special attention in undergraduate education to better prepare graduating engineers to meet the demands of the industry. Furthermore, the Accreditation Board for Engineering and Technology (ABET) in the USA has been continually increasing emphasis on the integration of design into the engineering curriculum. In fact, one of the criteria of an accredited undergraduate engineering program in the USA is to prepare for engineering practice through the curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier coursework. It is the experience, which must grow with the student's development.

This paper presents an approach to the integration of a comprehensive design experience in a four-year undergraduate Electrical Engineering curriculum at Saint Louis University. This curriculum focuses on the integration of a number of design experiences at all levels of engineering education starting from freshman to senior levels. At Saint Louis University, freshman electrical engineering students are exposed to the design process, and introduced to the analytical tools necessary to the interaction and growth in the design process. It focuses on the basics of design methodology, which can be applied and refined in other design work particularly during their senior capstone design projects. Students experience a natural progression of design problems and problem solving capability throughout the curriculum. A number of these problems are included in dedicated courses in some cases. But, in most cases, these problems are interweaved as exercises in some courses aimed at presenting related theoretical material. Often, a variety of realistic constraints, such as economic factors, safety, reliability, aesthetics, ethics and social impacts are considered whenever appropriate.

The present two-semester sequence of capstone design implementation has evolved over the past decade. This two-semester sequence of capstone design course focuses on the professional practice, and is drawn from all previously learned concepts of the design process. In first semester of the two-semester sequence, students are involved in planning project activities necessary to design the project, and in the creation of drawings to construct and test the prototype. Students make a preliminary project schedule (Gant Chart), and the initial project cost estimate. The completed design project, along with a modified and corrected project plan, is submitted as a proposal to the design instructor. Also, a mini-project of limited scope is carried out by students of the entire class, in parallel with other activities. A balance combination of individual and group projects provides a full spectrum of requirements involved in a typical design process. Oral presentations in the class are necessary which would enable students to learn about the thinking process. The construction and testing phases of the prototype normally take place during the second semester. After the prototype testing is complete, students prepare a report, consisting of both written and oral presentations, on the project. An integration of well-balanced design experience across the curriculum with an appropriate capstone design course provides a better preparation of graduates to pursue a productive engineering career characterized by continued professional growth.

This paper describes the emergence and evolution of integrating the design experience at all levels starting from freshman to senior year, analyzes the challenges

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encountered, and discusses the impact of the implementation on students, academia and industry.

EVOLUTION OF THE DESIGN EXPERIENCE

The evolution of the design experience in undergraduate Electrical Engineering curriculum is based on integration of a number of design experiences into theoretical courses and the design-specific courses. This approach is compatible with the new ABET criteria [1] relative to the design exoperience which requires to include "a meaningful, major engineering design experience that builds upon the fundamental concepts of mathematics, basic sciencs, the humanities and social sciences, engineering topics, and communication skills." The design components, introduced in the theoretical and design-specific courses across the curriculum, must include most of the following features: "development of student creativity, use of open-ended problems, development and use of modern design theory and methodology. Formulation of design problem statements and specifications, consideration of alternative solutions, feasibility considerations, production processes, concurrent engineering design, and detailed system descriptions." Often, a variety of realistic constraints, such as economic factors, safety, reliability, aesthetics, ethics, and social impacts are considered whenever appropriate.

In this design integration, one experiences a natural progression of design problems and problem solving capabilities throughout the curriculum. In most cases, a number of these problems are introduced as exercises in the theoretical and design-specific courses. Two dedicated courses—one, "Introduction to Electrical Engineering" in the freshman year, and the other, "Capstone Design" in the senior year—are included to emphasize the design experience. In the freshmen year, students are first exposed to the basic design concept, assigned group design projects, and introduced to basic communication skills and analytical tools necessary for the design process. Also, the components of design experience are introduced in different theoretical courses in design problem assignments as exercises. The curriculum culminates in a major design experience in the two-semester sequence of capstone design course.

DESIGN EXPERIENCE IN THE FRESHMAN YEAR

Engineering education is changing rapidly to meet the demands of modern mankind. These changes result from the rapid growth of technology and social systems. The primary goal of an engineer is to solve practical problems leading to what is basically known as engineering design. In fact, engineering design is the process of "fashioning a product made for a practical goal in the presence of constraints." Until recently, engineering students seldom encountered engineering design in their undergraduate studies. In order to meet the ABET criteria, accredited engineering schools in the USA must demonstrate that their students obtain sufficient design experience. The design process is incorporated across the curriculum in an orderly and progressive manner. Freshman electrical engineering students are exposed to the design process, and introduced to the analytical tools necessary to solve practical problems. They are also exposed to the interaction and team working experience. This is formally introduced through a course, *Introduction to Electrical Engineering.* Table I lists details of this course contents.

TABLE I
INTRODUCTION TO ELECTRICAL ENGINEERING

EE-P101 Introduction to Electrical Engineering

1999 Catalog Data: Introduction to Electrical Engineering. Credit 3. Electrical Devices, magnetic devices, electronic devices, digital logic, computer organization, communication systems. Design concepts in electrical and computer engineering. Hands-on experience on Afamiliar pieces of electronic gear. Introduction to software packages applicable to electrical engineering.

Prerequisite: MT-A152 or equivalent

Prerequisites by Topic: Engineering Calculus I

Textbook: Dick White and Roger Doering, *Electrical Engineering Uncovered*, Prentice Hall, 1997.

Goals: (1) This course examines the basic principles of electrical engineering as uncovered through the introduction of elementary theory as well the hands-on experience of the laboratory experiments. (2) This course examines the history and the future directions of the profession. (3) This course develops the student's proposal writing, technical writing, and oral communication skills. (4) This course develops the student's expertise in using the software tools that are currently utilized in the electrical engineering curriculum.

Topics:

- Introduction to Electrical Engineering Concepts (9 weeks)
- Basic Parameters (I,V,P,U,KVL,KCL); Resistors; Parallel; Series; DC Power; Thevenin equivalent; AC Sources and Power; Capacitor; RC – Circuit; Inductors; RL – Circuit; Transformer; Rectifier; Op-Amp Circuits; Bode Plots; Semiconductors; p-n Diode; BJT; FET (pmos, nmos, cmos); Binary Logic Gates, Binary Numbers; Boolean Algebra; Binary Adder; Sequential Logic; Flip-Flops; Memory; Introduction to Software Tools for Electrical Engineers , PSPICE; Viewlogic; Matlab; Quickfield (3 weeks)
- Introduction to Design (3 weeks)

Computer Usage: Class assignments are given periodically that require the use of electrical engineering software

In addition to introducing the basic principles of electrical engineering and hands-on laboratory experience, this course develops the student's proposal writing, technical writing, and oral communication skills to some extent. Students are exposed, as a part of analytical tools, to computer aided analysis and design software, computer word processing, plotting software, and spreadsheets. The skills introduced in this course are further developed and enhanced in subsequent courses. In this introductory course, students are also exposed to a well-defined design project, which is simple in scope, interdisciplinary in nature, and relatively short in duration of the order of approximately three weeks. This course includes a laboratory component, which provides an opportunity to the students to get familiarized with the basic laboratory equipment in order to be able to test the design project. Students are finally required to report, both written and orally, on their design project and the outcomes of the testing of the prototype. Each student gives an oral presentation to the class on a particular segment of the design project.

DESIGN EXPERIENCE IN THE SOPHOMORE YEAR

The sophomore year is an important year of electrical engineering students because of several basic courses that are introduced in an attempt to enhance the student capability to understand more of practical problems relevant to electrical engineering. Table II outlines courses taught in the sophomore year. Important analytical tools and communication skills are enhanced through the *Introduction to Computer Science* and *Small Group Presentations* courses respectively. In the *Introduction to Computer Science* course, a scientific programming language like C++ is introduced. In the *Small Group Presentations* course, the technique of power point presentation is introduced. Each student taking this course is required to make a presentation to the class on a selected topic using the power point technique.

TABLE II
SOPHOMORE YEAR--ELECTRICAL ENGINEERING

	FALL SEMESTER	
CM-A293	Small Group Presentations	1
CS-P 125	Intro to Computer Science	4
EE-P 210	Engineering Circuits I	3
MT-A254	Engineering Calculus III	4
PH-P153	Physics II with Calculus	3
PH-P 154	Physics II with Calculus Lab	1
	SPRING SEMESTER	
EE-P 205	Digital Design	3
EE-P 206	Degital Design Laboratory	1
EE-P 211	Engineering Circuits II	3
EE-P 212	Electrical Science Laboratory	1
MT-A354	Differential Equations	3
MT-A403	Probability and Statistics	3

The design experience is integrated into two basic courses in electrical engineering area in the sophomore year. There are limited opportunities in a sophomore year to introduce students to real–world engineering experiences. However, efforts are continued to emphasize the opportunities to develop problems and exercises involving realistic values with various constraints in the circuits and digital design courses. Many application-type problems and exercises, taken from real-world devices such as telephone, hair dryers and automobiles--requiring the kind of insight an electrical engineer is expected to demonstrate--are included in these courses to stimulate students' interest in engineering. Involving students early in the design process provides motivation to apply their knowledge in practical problem solving situations.

Analytical tools using computer programs and software cannot replace the traditional approach of mastering the study of electric circuits and digital circuits. However, such tolls can assist students in the learning process by providing a visual representation of electrical system behavior, and iterating toward a desired solution changing parameters of interest. This computational support is an integral component of the design process. Two popular computer tools, PSpice and MATLAB, are integrated into circuits courses to enhance computer applications.

Lectures and problem sessions are dedicated to teaching various issues facing digital circuits design. Various approaches of function implication, which leads to less cost, less delay, and a more reliable digital system are focused. An emphasis is given on application of programmable logic devices. Sophomore students are assigned individual and group design projects in the *Digital Design* course to help them explore their areas of strengths and weaknesses in performing the tasks required for an engineering design project.

DESIGN EXPERIENCE IN THE JUNIOR YEAR

The junior year includes a number of courses to provide more design experience. It has been recognized that electrical engineering design, in all aspects, is a vast area and must be integrated throughout the curriculum, including but extending well beyond the traditional capstone design courses. At least some of of the elements of design process which includes open ended problems, design methodology, consideration of alternative solutions, and a variety of realistic constraints are stressed in most of the courses in the junior year.

Table III lists the courses that are offered in the junior year. Design problems and problem solving capabilities are introduced as exercises in these theoretical and design-specific courses. In most courses, a design project is assigned involving research into various design-related aspects of the relevant course. Student are required to submit a report, and give an oral presentation, thus enhancing communication skills.

In the *Electronic Circuits Design* course, the design of many advanced electronic circuits, such as power amplifiers, integrated circuits, are discussed. In the highly theoretical course, *Electromagnetic Fields*, the software called *Quickfield* is used to demonstrate the field distribution in some boundary-value problems of practical interest to increase students' interest through visual representations. In the *Microprocessors* course, emphasis is placed throughout upon the nature of the design process, particularly upon the fact that there is no unique "correct" design. For the software aspect of the course, this is demonstrated by uniting two different programs to solve the same problem in two different ways, and for the hardware part, alternative approaches to design under various different constraints are discussed. The laboratory component of this course includes many experiments focusing heavily on design aspects. This laboratory stresses on safety issues.

TABLE III
JUNIOR YEAR—ELECTRICAL ENGINEERING

	FALL SEMESTER	
EE-P301	Signal and Systems	3
EE-P303	Semiconductor Devices	3
EE-P305	Microprocessors	3
EE-P306	Microprocessors Laboratory	1
EE-P307	Energy Conversion	3
Core:	Cultural Diversity	3
	SPRING SEMESTER	
EE-P302	Electromagnetic Fields	3
EE-P309	Electronic Circuit Design	3
EE-P310	Electronics Laboratory	1
EE-P404	Automatic Conrol Systems	3
PL-A205	Ethics	3
----------	Science and Math Elective	3

In the junior year, the students are expected to have gained enough knowledge, confidence, and maturity to understand the elements of design process. Most importantly, the students will have accomplished this independently with the limited advice and guidance from the instructors. In fact, by the end of the junior year, the students should have attained all the preparations required to start the senior capstone design courses.

DESIGN EXPERIENCE IN THE SENIOR YEAR

The senior year places emphasis on the two-semester sequence of capstone design course, and a few more design-based theoretical courses to satisfy the degree requirement as listed in Table IV. In all the courses in the senior year, the elements of the design process are emphasized when appropriate. In the *Transmission Lines and Waveguides* course, concepts of designing a half-wave dielectric window, a quarter-wave transformer, etc., using the elements of design process are introduced. Particularly, a problem of designing an electromagnetic *radome* is discussed.

TABLE IV
SENIOR YEAR—ELECTRICAL ENGINEERING

	FALL SEMESTER	
EE-P403	Communication Systems	3
EE-P407	Transmission Lines and Waves	3
EE-P490	Electrical Engineering Design I	3
----------	Engineering Science Elective	3
----------	Electrical Engineering Elective	3
	SPRING SEMESTER	
EE-P491	Electrical Engineering Design II	3
Core:	General Elective	3
----------	Technical Elective	3
----------	Electrical Engineering Elective	6

In the *Communication Systems* course, the design instruction is particularly emphasized on the receiver design. An example of such is the design of an envelope detector for use in demodulating an amplitude-modulated signal where the elements of design are integrated into the problem. In addition, individual teams are assigned to various smaller segments of an overall design problem.

A sequence of two final capstone design courses in the senior year provides a meaningful, major design experience that focuses on the professional practice, and is meant to review, reinforce and tie together all the previously learned concepts of design. The indivudual design project is normally selected to span the two course design theory and practice sequence to give each student some experience in the many elements of a "total" design project from project definition to prototype construction. Three textbooks [2]-[3] are heavily used for the sequence of two semester capstone design course.

The *Electrical Engineering Design I* course is the first of a two semester sequence in electrcal engineering design. The purpose is to introduce the many aspects related to engineering design and to develop a proposal for an individual design project. The topics covered in this course are following:

- Design Considerations
  1. Experimental Design
  2. Instrumentation
  3. Legal and Ethical Consideration
  4. Ethical Case Studies
  5. Computer Aided Designs
  6. Design Case Studies
  7. Standard and Units
  8. Design Methodology
  9. Safety Consideration
- Development of the Proposal
  1. Need and Library Research
  2. Preliminary Proposal
  3. Cost Consideration
- Initial Report Development
  1. Format and Planning
  2. Technical Reporting

- Aspects of Engineerinf Design
  1. Social, economic, ethical, political, and legal
  2. Environtental, andsafety

The theory and practice of electrical engineering design are presented through a number of instructional modes. The following list contains the activities, modes of presentation, and types of documentation used:

- Individual Design Project: This activity demonstrates the elements of engineering design from inception to prototype construction of a modest desogn p[roject.
- Group Design: This activity is used to experience the elements of design as a group process. Project definition, rules and restraints specifications are emphasized.
- Lectures and Briefings
- Written Progress and Final Reports
- Oral Presentations of the Proposal
- Quizzes and Design Log

Lectures cover the general principles and techniques of design rather than the technical aspect of the design. The stuent is expected to utilize the technical design methods previously learned in other electrical engineering , science, and methematics courses.Students also utilize the faculty in their areas of expertise as technical "consultants." Much of the materials including professional ethical codes is provided in handouts.

Case studies and role playing are also introduced as a means of enhancing engineering design experince. The oral and written reports are toe be presented from the view point of one of the case characters as assigned by the course instructor. All aspects of the case are presented using a prepared video tape presentation. A preview and final role playing direction are given by the instructor. The written and oral reports must include the case summary, analysis of the of the problem, alternative solutions and the final solution selected.

Lectures, design activities, and discussion are integrated to correspond to the development of the final proposal. The emphasis of the project is on the design process and strenghening the basic knowledge of the student.

The *Electical Engineering Design II* course is the second of a two-semester capstone design sequence, and the purpose of this course is to continue the study of the design process and to implement the design project developed in the first course in the sequence. The formal topics covered in this course include the following:

- The Engineering Method
  1. Engineering as a design process
  2. Characteristics
  3. Engineering heuristics
  4. Definition of the engineering method
  5. Stae-of-the-art (SOTA)
  6. Evulution engineering design
- Implementing the Proposal
- Prototype Design and Construction
- Fault Analysis
- Design Management

The major emphasis of this course is on the elements of the individual and group design process. Lectures on the engineering method are provided along with selected advanced design concepts. Students focus on individual design project breadboards. During this process, possible changes in the given design may be required. Design changes may be formally proposed and reviewed. Upon approval of the change by the instructor, the student will initiate the change, and begin constructing the prototype. Once the construction of the prototype is completed, the can start the testing process.

Students are required to submit weekly progress reports, group project reports, midterm design reports, final design reports, and operating and maintenance manual for the individual design project. The course instructor provides the final report outlines. The final design report will consist of both written and oral presentations.

CONCLUSION

Integration of a design experience in electrical engineering undergraduate curriculum has been presented. Salient features of this design experience includes introducing the concepts of design process in the theoretical and design-oriented courses across the curriculum, and providing a meaningful, major engineering design experience through a two-semester sequence of capstone design course in the senior year. The present two-semester sequence of capstone design implementation focuses on the professional practice, and is drawn from all previously learned concepts of the design process. The integration of a well-balanced design experience across the curriculum with an appropriate capstone design course provides a better preparation of graduates to meet the demands of modern mankind. This integration of design experience across the curriculum is implemented in all ABET accredited engineering disciplines [4] in the USA enabling graduates to pursue a productive and efficient engineering career.

REFERENCES

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