EIGHT-SEMESTER MULTIDISCIPLINARY ENGINEERING DESIGN EXPERIENCES AT TRINITY UNIVERSITY

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Abstract *¾ The Department of Engineering Science at Trinity University in San Antonio, Texas, USA is one of the nation's top ranked, ABET accredited undergraduate engineering programs. An eight-semester multidisciplinary engineering design course sequence is a unique feature for engineering programs in the USA. The design sequence provides students with an introduction to design processes in the freshman year, followed by mini capstone courses in the sophomore and junior years and terminates with yearlong capstone design projects in the senior year. The eight-semester design experience integrates student learning experiences in science, mathematics, engineering,, and liberal arts education. These experiences develop students' creative and critical thinking skills, technical knowledge and reasoning, problem solving skills, oral, and written communication skills, professional and interpersonal skills and, teamwork and leadership skills. Participation in the design sequence also provides students an opportunity to consider the moral, ethical, economical, environmental, social, and geo-political impact of engineering design decisions.*

Index Terms ¾ capstone design, design curriculum, design integration, multidisciplinary design.

INTRODUCTION

The Department of Engineering Science at Trinity University offers a design-oriented multidisciplinary engineering curriculum leading to an ABET accredited Bachelor of Science Degree in Engineering Science. The primary mission of the engineering science program is to provide talented students with a broad-based engineering education in the context of the University's traditions of the liberal arts and sciences. The Engineering Science program is directed toward developing students' creative and critical thinking skills for innovative design and problem solving within the context of society's heritage and value systems. The Engineering Science program requires a minimum of 129 semester credit hours and consists of four basic categories. These include core engineering courses (51 credit hours), mathematics and science courses (33 credit hours), liberal arts and humanities courses (33 credit hours), and engineering elective courses (12 credit hours). The tools of basic science, mathematics, engineering science, technology, and behavioral science complemented by the perspective of the liberal arts and humanities provide the means for a broad based engineering education. [1]

Engineering design, specifically creative design, is the central focus of our program. An eight-semester engineering design course sequence that begins in the first semester of the freshman year and terminates with a two-semester senior capstone design project form the backbone of our curriculum. [2]

The first design course introduces students to the engineering design process utilizing a competitive design project. The second semester freshman design course continues the introduction to engineering design concepts with another interactive team-oriented design project.

Freshman design courses are followed by one credit hour mini capstone design projects in the sophomore and junior years. The first sophomore design project builds on the students' background in solid mechanics with the introduction of competitive mechanical engineering design projects. The second semester sophomore design course continues the development of students' prediction, decision-making, and optimization skills with a project oriented to the statistical design of multivariable industrial systems.

The first mini capstone design course in the junior year builds on the students' background in electrical engineering while the second junior mini capstone course involves a thermal/fluids competitive design project.

The senior year capstone engineering design experience includes two three credit hour design courses in which year long comprehensive projects are undertaken by groups of three or four students. By the time students reach senior year, they have experienced mini capstone projects in electrical, chemical, and mechanical engineering. In the development of senior design projects, industry/university partnerships are heavily emphasized. [2]

ENGINEERING DESIGN EXPERIENCES - FRESHMAN YEAR

Engineering Design I

This is the first design course that students take in their freshman year at Trinity. The primary objective of this course is to introduce students to the engineering profession and the methodology of engineering design through two engineering design projects. The first design project focuses on the engineering design process and the activities of the engineering profession and its responsibility to employer, client, and society. Each student is to identify a need in the home or office and conceptually design a solution to satisfy that need. This design process stresses critical and creative

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thinking, problem solving, and the application of the various stages of the engineering design process.

The second design project focuses on the application of the iterative decision making process of engineering design. A group of 4 – 5 students conceive, design, build, test, and analyze the performance of a wooden truss that meets a set of specific design criteria. Prior to the assignment of this project, students are taught the fundamentals of truss analysis, including the calculations of forces, stresses, and safety factors. These concepts are reinforced with a homework assignment. In this course, students also learn how to use Pro Engineer, a computer aided design package and are required to model their final design using the software. Students use computer software in the calculation of forces in the truss and are required to compute stresses and safety factors. In a final design competition, students' trusses are tested and judged in a number of design categories. A written report, a group presentation, and short written performance self-evaluation are required at the end of the project.

A significant component of the second design project is for students to learn to work on a team. Thus, each student is randomly assigned to a team of four or five students. Each team is responsible for scheduling and assigning tasks, and coordinating results.

While the first design project stresses critical thinking, creativity, and the stages of the design process, the second project requires students to synthesize design, analysis, modeling, and testing. The projects teach students to think critically about the designs they encounter and to think creatively to find solutions.

Engineering Design II

The second semester freshman design course continues to focus on creative and critical thinking, problem solving through another interactive team- oriented competitive design project. In this course, emphasis is placed on numerical analysis using computer software (MATLAB), mathematical modeling, data collection, data analysis, and essential computer skills (web page, electronic spreadsheet, and database).

The water balloon launcher design project has become the traditional design project in this course. The goal is to design, build, test, and analyze the performance of a device that will accurately launch a water balloon through the air over a 50 yard range to a target. The best performance design is determined through a friendly competition where two groups launch balloons at the other's target. Students have several months to complete the project. After forming groups (three to four in each group), students are first asked to brainstorm and submit at least three design concepts. This exercise is followed by work on trajectory calculations to determine a required maximum release velocity for a 50 yard launch. Each student prepares a spreadsheet that calculates the range for a projectile launched at a given angle and velocity. The effect of air drag is also accounted for in the spreadsheet. Students determine the relative sensitivity of launch velocity and angle of the range.

About a month before the competition, each group decides on a final design and presents their plans for the project to the instructor in a design review meeting. Construction begins after the review. Most groups work in the shop area to complete their project. After initial testing, many designs are modified to improve performance.

The completed launcher is weighed and measured two days before the competition to determine if the device is within design specifications. The design specifications are used to determine the pairings for a single elimination tournament. Groups that do not meet specifications are usually penalized by a reduction in the maximum number of balloons they can fire at a target.

The tournament rules allow the competitors to place their opponents target within a 25-50 yard range of the launcher. Each event is limited to 10 minutes. Winners from the first round advance to face other winning groups. A group must win at least two events to advance to the final round so durability is also a factor in the competition.

ENGINEERING DESIGN EXPERIENCES - SOPHOMORE YEAR

Engineering Design III

This course builds on the students' background in solid mechanics with a competitive mechanical engineering design project. Supporting topics include engineering economics, mathematical modeling, uncertainty, and sensitivity analysis. The concepts of sustainability, renewable energy, and energy efficiency are also introduced in this course.

A recent design project in this course included the design, building, testing, and analyzing of a solar powered vehicle. The objective of the solar power vehicle competition was to design and build a vehicle that could complete a race on a 20-meter racecourse in the shortest possible time and with a few modifications climb a 30-degree inclined surface with added weight using the available power. There were several other design constraints such as dimensions of the vehicle, weight, cost, etc. Students use knowledge gained from Statics and Dynamics courses to design the vehicle, drive train, transmission, and chassis.

Each team races with their designed vehicle in a friendly competition where the winner is chosen based on the performance of the vehicle in a series of head to head elimination rounds.

Oral presentations, two intermediate, and a final written report on the design project are required.

Engineering Design IV

This course continues the development of students' prediction, decision making, modeling, and optimization skills with applications of principles and methods of probability and statistics. Students are introduced to the concepts of statistical process control (two, three, and six sigma methods), analysis of variance (ANOVA), factorial design of experiment (DOE), and multiple regression analysis. Students are also introduced to a statistical computer software package (MINITAB).

Students apply their knowledge of ANOVA, DOE, and regression analysis to optimize the design parameters of a catapult launch. Students develop a prediction model by running factorial design of experiments. In a final competition, students apply their developed mathematical model to accurately place ping pong balls at a random target using a catapult launcher.

The catapult design project provides students with the understanding of the importance and effectiveness of the use of industrial design of experiment (DOE) techniques and motivates them to use these concepts in future engineering design projects.

ENGINEERING DESIGN EXPERIENCES - JUNIOR YEAR

Engineering Design V

This course builds on the students' background in electrical engineering with emphasis on the design of a system that may employ circuits, electronics, electromagnetics, and controls. The objective of the mini capstone design project in this course is to introduce students to the design and analysis of sequential machines. These machines have memory and make decisions based on the present inputs and the state they are currently in. Sequential systems are extremely important in real life applications and form the majority of digital systems designed for industrial applications. In this course, students go through the design of a real life sequential system, simulate their design on a computer using Altera tools to analyze its behavior and finally download the design into a programmable logic device to implement the design. Simulation of the project on a computer is very fast and gives students the opportunity to go through several design iterations in a very short time. Some of the recent projects for this course are as follows: 1) a traffic light controller for a major intersection which allows for emergency vehicles by making lights red in both directions. The traffic light controller also allows for longer time for green light in the direction with heavier traffic; 2) the electronic brain of a vending machine that keeps track of money deposited, product selected, and its price, and the change due to the customer; 3) an electronic system that keeps track of how many people enter a room, turns the light on when the first person enters the room and turns the light off when the last person leaves the room; 4) a heart monitor system that keeps track of a patient's heart rate.

This course also introduces other supporting topics such as safety, electrical measurements, component tolerance, specification, performance standards, etc. Oral presentations and written reports are required.

Engineering Design VI

This mini capstone course builds on the students' background in introductory chemical engineering, thermodynamics, controls, electronics, and fluid mechanics courses. The primary focus of this design project is testing and data collection, analysis, redesign and improvement of equipment or a system which is designed to function in a thermal-fluid environment. Recent product redesign projects include commercially available home appliances such as bread and bagel toasters, toaster ovens, electric heaters, refrigerators, etc. Students are required to design and conduct experiments they think are necessary and analyze the resulting data. They make design improvements and conduct appropriate experiments to validate product redesign recommendations. Students are expected to consider the following factors in their redesign recommendations: accuracy and reliability of data, validity of analysis, design specifications, ease of manufacture, ease of maintenance, ease of operations, reliability, health, safety and environmental issues, aesthetics, and cost. Oral presentations and final reports are required in this course.

ENGINEERING DESIGN EXPERIENCES - SENIOR YEAR

Engineering Design VII and VIII

The senior year capstone engineering experience includes two three credit hour design courses in which yearlong comprehensive projects are undertaken by groups of three or four students.

The senior design experience constitutes a capstone design experience and is intended to integrate a student's entire undergraduate engineering education at Trinity. These two courses focus on the practice of all phases of the engineering design process including problem identification, establishment of project goals, design specifications and criteria, analysis, synthesis, construction, testing, evaluation, and communication. Students are also encouraged to address the following topics (as they find it appropriate to their projects): mathematical modeling, simulation, control, optimization, ethics, safety, aesthetics, economics, life cycle analysis, reliability, manufacturability, sustainability, social, economical, and political considerations, etc.

PROJECT DEVELOPMENT, STRUCTURE, TYPE AND ADMINISTRATION

Unlike most other schools, engineering students at Trinity are required to develop capstone senior design project proposals in their junior year. Project proposals are solicited from students, faculty and industry representatives and are developed based on the following criteria: [3]

- the project should be interdisciplinary in nature and scope
- project must include at least one cycle that includes design, construction, testing, and evaluation
- a student's background should be appropriate for a selected project
- the project should be carried to completion during the senior year
- the department will contribute up to $1000 towards the project budget

After consultations with colleagues, faculty members and industrial representatives, each student develops a formal senior design proposal. The formal proposal contains: project title, objective, a brief description of the project, design criteria and specifications. Students also provide a description of their skills and abilities relevant to successfully completing the project. They are required to select two alternate projects. The senior design course administrator in consultation with the faculty advisors makes the final selection of the senior design projects and the student group members. Selection of the topic for a senior design project at the end of the junior year provides considerable advantages to students, faculty, and industry representatives. Students are able to spend the entire summer thinking about the project and conducting a preliminary literature search.

A typical senior design project group consists of 3 or 4 students. The projects are generally interdisciplinary with a major thrust in either chemical, electrical, or mechanical engineering. A faculty member is assigned as senior design course administrator. The course administrator is responsible for the coordination among faculty advisers and design groups, helps set policy, manages logistics, schedules and moderates presentations, collects and analyzes students feedback and assigns students final grades.

Each design group is advised by a faculty advisor. The group advisor brings to a project their own expertise and acts as a consultant. Typically, the design group meets with their advisor once or twice a week.

The current course structure contains six generic phases: 1) generation of design specifications; 2) consideration of alternative solutions; 3) design and construction of a prototype solution; 4) design , execution, testing, and analysis of prototype solution; 5) modification of the prototype solution based on feedback analysis ; and 6) testing and analysis of the final design solution. Each phase includes specific deadlines, written reports, and four oral presentations. [3]

Examples of senior design projects completed in the academic year 2001-2002 are as follows:

- Baja car transmission: this project involved the design and construction of a manual transmission for the engineering science department society of automotive engineers (SAE) student group's Baja car project.
- CPS power plant noise reduction: City Public Service has a 100 MW natural gas power plant located on Mission Road in San Antonio, Texas. This plant, built in 1958, is operational during the peak energy usage period, usually from April through September. The plant rarely operates during the night and is thus shutdown at the end of each day and started up again the following morning. The four to eight hour startup period is extremely loud and disturbing to the surrounding community. The purpose of this project is to determine a means by which this noise can be significantly reduced.
- DALM: This project involves the design of a personal detector of radio frequency (RF) radiation using diazoluminomelanin (DALM). If a successful prototype is developed, Beam Tech Corporation, industrial sponsor of the project, plans to manufacture the prototype for distribution. Under certain conditions, RF radiation can be dangerous to humans; therefore, a relatively inexpensive detector would be useful as a recording system for people who are exposed to the radiation.
- Neural Network: The goal of this project is to design a neural network that extracts a voice signal from background noise. The background noise will be a predetermined sound that is unwanted and could distort the voice signal. This network should be robust in the sense that the noise can change yet the voice can still be determined. A sample application would be to extract the voice of a pilot from background noise as transmitted from an aircraft cockpit over the radio.
- CMOS Imaging: The objective of this project is to create a system capable of successfully tracking a moving object in 3-dimensional space. Current systems accomplish this task by utilizing a pair of CCD (digital) cameras mounted on a pan-tilt head. Since each camera provides a slightly different view of the object, stereo

image algorithms may be used to successfully track the object.

- Simple Machine: The objective of this project is to design and build an interactive learning exhibit based on simple machines – inclined plane, wedge, screw, pulley, lever, and wheel and axle – for the San Antonio Children's Museum.

A summary of the eight-semester design sequence is included in Table 1.

TABLE I
SUMMARY OF ENGINEERING DESIGN COURSE SEQUENCE [4]

ENGR 1381 - Engineering Analysis and Design I
Introduces students to the engineering design process utilizing a competitive design project. Small groups of students conceive, design, build and test a structure or device to best achieve specified performance criteria. Emphasis is placed on Computer Aided Design (CAD). Supporting topics include sketching, construction and testing techniques, measurement concepts, data analysis and communication.
ENGR 1382 - Engineering Analysis and Design II
Continues the introduction to engineering design with another interactive team-oriented design project. Emphasis is placed on numerical analysis using computational software. Supporting topics include programming mathematical models of physical systems, and data gathering, analysis and presentation.
ENGR 2181 - Engineering Design III
Builds on the students' background in solid mechanics with the introduction of a competitive mechanical design project. Engineering economics is introduced in support of the project. Other supporting topics include mathematical modeling, sensitivity and uncertainty analysis and statistical concepts. Oral and written reports are required.
ENGR 2182 - Engineering Design IV
Continues the development of student's prediction, decision-making and optimization skills with a project oriented to the statistical design of multivariable industrial systems. Supporting topics include engineering modeling, problem solving and industrial design of experiments with related mathematical statistics. Oral and written reports are required.
ENGR 3181 - Engineering Design V
Builds on the students' background in electrical engineering with emphasis on the design of a system that may employ circuits, electronics, electromagnetics, component tolerances, specification and performance standards. Oral and written reports are required.
ENGR 3182 - Engineering Design VI
Builds on the students' background in thermodynamics/fluids with the introduction of a competitive thermal-fluids design project. Supporting topics include thermal-fluids measurements and computerized data acquisition, analysis and visualization. Oral and written reports are required.
ENGR 4381 - Engineering Design VII
A capstone design experience with small groups of students, each group advised by a designated engineering faculty member. The establishment of objectives and criteria, synthesis, analysis, safety, aesthetics and preliminary design of a different project for each group. Robust product design considerations. Formal written and oral presentations.
ENGR 4382 - Engineering Design VIII
The capstone experience continued covering final design, construction, testing and evaluation of the projects started in ENGR 4381. Life cycle testing and reliability. Formal final written report and presentations open to the public.

CONCLUSIONS

The eight-semester design experience allows students to apply the knowledge of science, mathematics, and engineering in disciplinary and multidisciplinary engineering design projects. It reinforces the foundation of their knowledge of core engineering disciplines and offers opportunities to extend it with advanced engineering practice. It develops students' professional, interpersonal, teamwork, and leadership skills. Students practice their oral and written communication skills through design presentations and project report writing in engineering design courses and continuously improve these skills by incorporating feedback from faculty and student colleagues. [5]

The liberal arts component of our curriculum is significant and also plays an important role in engineering design courses. Through the liberal arts courses, engineering students form a basis for understanding the varied domains of human knowledge and experience and develop understanding and appreciation of their cultures and religions. Liberal arts and engineering design courses have a synergistic effect on the development of creative and critical thinking skills, oral, and written communication skills, interpersonal and leadership skills, and a quest for life-long learning. Our design sequence provides our students with a wonderful opportunity to consider the moral, ethical, economical, environmental, societal, and geo-political impact of engineering design decisions. [5]

Feedback from student and alumni indicates that our eight semester multidisciplinary design experiences are the hallmark of our broad based undergraduate engineering curriculum and have a profound influence in the success of our graduates' professional advancement.

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