Hands- on Learning: A Four Year Laboratory Sequence for Electrical Engineering Students

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Abstract

In an academic era that is embracing online education, it can be easy to overlook the hands-on portion of an engineering education. However, it remains critical to producing quality engineers. This paper discusses an undergraduate program solution for incorporating hands-on learning into every semester of an undergraduate Electrical Engineering program. The paper provides a semester-by-semester description of the courses and corresponding activities used to engage students, and promote active learning from the first freshman introduction class through the final capstone senior design project. As feasible, a detailed description of the course content, projects, lab experiments, and the lab equipment are provided. When necessary any co-requisite classes or prerequisite knowledge required of the students is included. Similar to most BSEE programs, many of the laboratory experiments and activities correspond to the circuit analysis, electronics and machines theory classes from which they originate. However, a recent effort was made to expand the scope of the laboratory sequence to include experiments in digital circuits, microprocessors, control theory, and electromagnetics. The paper will outline the learning objectives and the related ABET outcomes associated with the hands-on approach.

Keywords

Electrical Engineering Curriculum, Electrical Engineering Laboratories, Laboratory Projects.

Introduction

The Citadel is a four-year residential college with roughly 200 electrical and computer engineering students, granting approximately 30 BSEE degrees annually. The program consist of 126 credit hours including 35 credit hours of math and science, 61 credit hours of ECE classes, and 30 credit hours of general education requirements. The electrical engineering faculty has been encouraged to increase the hands-on portion of the curriculum. Group and individual activities are one of a number of high impact practices that have been shown to improve understanding, motivate students, improve information retention, and also add interest and fun to the topics. Also, it has been shown that hands on activities boost student learning outcomes[1].

Importantly they also provide a means to attain ABET student outcomes[2]. In particular, outcomes 6 “an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgement to draw conclusions.” Also, ABET outcome 7 “an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.” It is not hard to imagine how both of these outcomes can be satisfied using practical activities.

Hands on learning throughout the curriculum not only serves to inspire students to learn more it also provides them with the job related skills to assist them in landing internships and entry level summer jobs. These practical skills give them confidence and make them begin to feel like engineers long before they reach the capstone design project[3].

The Freshman Year

The freshman *Fundamentals of Electrical Engineering* class, is an introduction to the engineering profession, branches, and functions of engineering. It includes engineering problem solving, the use of calculators and computers as tools. It introduces the engineering design process, teamwork, and laboratory skills, through the use of project examples. Hands on projects in this class include simple bread boarding and basic electrical measurements using a multi-meter. Basic circuits are constructed and demonstrated using Analog Discovery hardware and software[4-6]. After a lesson on soldering, students construct a timer and Op Amp circuit, build a LED flasher, build a light sensitive oscillator, and a digital counter. Design iteration is displayed via building a Lego® robot that plays golf. Simple engineering drawing using *sketch-up software* is also taught. The format of this three hour class is two hours of lecture followed by a single hour of hands on learning every week.

In the second semester of freshman year, the students are required to take *Computer Applications in Electrical Engineering*. This three credit hour class introduces the computer as a tool for the solution of engineering problems. The fundamentals of programing are introduced using the C++ programming language. Although "programming" is taught, the focus in this class is the solution of problems using the computer. Applications programs such as Matlab and Orcad Pspice[7] are taught. Here the students gain confidence and job skills necessary for a many entry level internship opportunities. This class is taught in a computer laboratory not in a traditional classroom, so that students can interact with the software and do examples as they are presented. This way hands on activities can occur regularly, and projects can be worked on and assistance provided by the instructor during the classroom sessions. The hands-on activities are primarily coding, writing, and compiling code, plotting and drawing.

Thus by the end of the freshman year, the ECE students have not just gained a basic understanding in math and science. They have had a real opportunity to learn about engineering through hands on exercises, and team projects. More importantly, they have gained useful job skills and can identify with the engineering profession.

The Sophomore Year

The sophomore year includes four classes with significant hands on activities. *Electrical Circuit Analysis I* is a three credit hour lecture course. It is not paired with a laboratory; instead both Pspice[7] simulations and breadboard exercises using the Analog Discovery[6] kits are utilized.

Electrical circuit laboratory is a one credit hour course taken along with *Circuit Analysis II*. This traditional circuit analysis laboratory class covers the topics of DC and AC resistive circuits, impedance, RLC circuits, frequency response, transformers, and three phase systems. An added feature of this class is the necessity to write a cogent technical laboratory report. This report must include, background, description, procedure, data presentation, data analysis, and conclusions. Traditional measurement techniques are emphasized, and laboratory safety is adhered to.

Also during the sophomore year students take *Digital Logic and Circuits* which includes design of combinational and sequential logic circuits, hardware modelling using VHDL, and implementation and testing of digital circuits using field programmable gate arrays (FPGA)[8]. In addition to traditional homework problems students also complete hand-on projects using Xilinx[9] industry standard design tools and Digilent FPGA development boards[10]. These out-of-class projects allow the students to apply the theory they have learned in class to real-life hardware applications.

Additionally, in the spring semester of the sophomore year, *Digital Systems Engineering* teaches microcontroller fundamentals including architecture, assembly language programming, and interfacing[8]. Embedded systems applications are emphasized using Microchip industry standard microcontrollers[11]. Hands-on demonstrations include basic I/O, timer applications, analog-to-digital conversion, and serial communications. The final student project is an assembly language simulation[12] of a microwave oven controller, including a matrix keypad, interrupt driven timing, and seven-segment time display.

The students at the end of the sophomore year have significant practical engineering skills at a point in their education that many traditional programs have only engaged in theory. These students have numerous projects to list on their resumes and to discuss with potential employers for internships and summer job opportunities.

The Junior Year

In the junior year the students are exposed to a two semester lab sequence. Each lab is a one credit hour two contact hour traditional laboratory class creatively titled *Junior Lab 1* and *Junior Lab II*. These laboratories have an electronics focus in the fall offering of Lab I and an electro-mechanical machines focus in the spring offering of Lab II. In the fall semester the many of the laboratories and projects involve the study of discrete solid state devices to complement the conventional electronics class taught simultaneously. Lab projects include diodes, BJT and FET transistors circuit constructions on breadboards. Also more advanced applications focusing on using traditional electrical engineering measurement devices such as oscilloscopes and spectrum analyzers. This lab also incorporates the construction of an H- bridge from a kit, and exposure to its use as DC motor driver.

In the spring semester *Junior Lab II* switches the focus to three phase transformers, DC and AC motors, torque, speed and stability measurement, and PID controllers. These labs are sequenced to run nearly in parallel with the corresponding theory classes in electromechanical energy conversion and feedback control systems. Each of these labs requires the construction of apparatus, or circuits, or bread boarding of components, the measurement of parameters, and the detailed analysis of data in a typed and complete lab report. Recently, two new microcontroller application labs have been added. These labs give the students hands-on experience with programming and interactive debugging of microcontroller circuits used for basic I/O, analog-to-digital conversion, and pulse-width-modulation for DC motor speed control.

The students have now completed three formal electrical engineering laboratory classes, and at least four additional project oriented classes. Combined with the required four science laboratories from our general education curriculum, students entering senior capstone have been exposed to a significant number of hands on activities.

The Senior Year Design

In the senior year the major hands-on component is found in the two semester sequence of capstone senior design. The first semester hands-on portion concludes with a working demonstration of a feasibility of the design (a proof of concept demonstration). For this, each design team is required to assemble the demo and show its operation to the instructor prior to ordering the parts necessary for phase II of the class. A typical concept demo would be to transmit and receive a signal, or to perform A/D conversion, or demonstrate serial communication over an interface.

In the second semester of the capstone design process the team must complete the construction of the prototype and demonstrate its operation vs. its design specifications. They must fully document the design process and present the results at a conference setting in the school.

One of the recent senior capstone design project is a competition robot for the intelligent ground vehicle competition (IGVC). The IGVC robot is shown in Figure 1.

Figure 1 IGVC robot preparing for competition

Each BSEE senior must select five electrical engineering electives for program completion. Many of these electives have a hands-on or project component. Indeed, the popularity of the electives is in many cases directly related to the student's perception of the practicality the course topics. Here are four course examples. The first course is *Communications Engineering,* in which students will simulate in Pspice® software and also breadboard an AM modulator and a FM demodulator[13]. A second class example is *Electrical Measurements*, where students perform a variety of projects using National Instruments MyRio microcontroller and Labview® software. A third course example, is *Digital Control Systems,* where students use Matlab/Simulink® to design a variety of control systems. The fourth is *Interference Control in Electronics*, where two in-class lab exercises are conducted. For each of these exercises, the class takes place in the electronics lab rather than the classroom. A non-ideal elements lab is designed to show students when electronics don't behave according to ideal (sophomore-year) models, even at tens-of-kilohertz. The "crosstalk mitigation" lab shows students that circuits constructed adjacent to each other act as noise sources to each other.

Activity Inventory

A table has been developed to illustrate the approximate classroom hours dedicated to hand-on activities mentioned in this paper. The title *approximate* hours is used since it is a good faith estimate based on anecdotal evidence. A typical one hour a week activity was assigned 12 hours a semester in order to be conservative and account for holidays, exams, or other disruptions. The listing of hands on activity is presented below in table 1.

Course	Hands on activity description	Approx. Hr.s per semester	Comment
Introduction to EE	Soldering, bread boarding, Analog Discovery, Lego robots	12	Freshman, 1 hr/week
Computer Apps for EE	Coding, C++, Matlab	12	Freshman, 1 hr/week
Circuit Analysis	Analog Discovery, Pspice	12	Sophomore, 1 hr/week
Circuits Lab	Electrical measurements	24	Sophomore, 2 hr/week
Digital Logic & Microcontrollers	VHDL FPGA projects, microcontroller simulations	12	Sophomore, 1 hr/week
Junior Lab I & II	Electronics, machines, controllers	48	Junior, 2 hr/week
Capstone Design I &II	Coding, design, prototyping	48	Senior, 2 hr/week
Five Senior Electives	Simulations/coding/bread boarding/design	24	Senior, 2 hr/week
	TOTAL Class hours	**192**	

Table 1 List of hands-on activities by course.

The table 1 above does not account for the required science classes and associated laboratories. More importantly, it does not account for any of a number of other high impact practices that are used to enhance the traditional lecture course. For example, the paper does not attempt to quantify time spent on in class demonstrations, or problem solving sessions, or with guest lecturers, or on field trips, etc. Only actual hand-on activities as defined in this paper have been counted.

Conclusions and Future Work

This paper has outlined a systematic approach to the inclusion of hands on learning activities into every semester of an undergraduate electrical and computer engineering program. Clearly, there are many more possibilities to increase hands on learning. Our goal was not to imply that our program is a model to be emulated, but to provide information as a basis for discussion among our peer institutions. Our hope is that a dialog will emerge, and best practices can be disseminated.

A future goal is to try to find a method to bring hands on activities to every course. One possible idea is to move away from a traditional three hour course lecture format. Instead promote a two hour lecture plus two hour lab structure for many engineering classes. The two hour lab can be used primarily for hands-on activities, but can also be used for demonstrations, guest lectures, problem solving sessions, or for extended exam time.

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