Embedding Core Skills in First-Year Engineering Students with Applications in Embedded System Design

Dr. Michael Cross, Norwich University

Michael Cross is a Lecturer of Electrical and Computer Engineering teaching classes in the areas of circuits, electronics, energy systems, and engineering design. Cross received degrees from the Rochester Institute of Technology and the University of Vermont and began his academic career at UVM where he taught courses in the areas of analog and digital circuits, electronics, semiconductor physics, power electronics, and engineering design.

Dr. David M. Feinauer P.E., Norwich University

Dr. Feinauer is an Assistant Professor of Electrical and Computer Engineering, and the Freshman Engineering Coordinator at Norwich University. His scholarly work spans a number of areas related to engineering education, including P-12 engineering outreach, the first-year engineering experience, and incorporating innovation and entrepreneurship practice in the engineering classroom. Additionally, he has research experience in the areas of automation and control theory, and system identification. His work has been published through the American Society for Engineering Education (ASEE) and the Institute for Electrical and Electronics Engineering (IEEE); he is an active member of both organizations. He serves as advisor to the student entrepreneurship club and as the State Partner for the FIRST LEGO League Program—a nationally recognized program that incorporates robotics with innovation and community engagement. He holds a PhD and BS in Electrical Engineering from the University of Kentucky.

Full Paper: Embedding Core Skills in First-Year Engineering Students with Applications in Embedded System Design

Abstract

This paper details a discipline-specific first-year engineering course in electrical and computer engineering that employs a project-focused approach built around the use of embedded systems: to connect the varied course activities, to practice foundational skills to support the students in their future endeavors, and to showcase fundamental and future areas of study for Electrical and Computer Engineering students at Norwich University. Additionally, the lecture and lab experiences provide a rich common set of experiences for instructors to reference throughout future courses, connecting students to the School of Engineering, serving as motivating, mastery experiences for students early in their academic careers. In this paper the pedagogical motivations behind the course design and an outline of the laboratory exercises developed are presented. Lessons learned from multiple course offerings and results of a student attitudinal survey are shared. Students self-report making strong connections between the course exercises and their expected future studies both during the course and one year after completing the course.

Introduction

In the first-year engineering course sequence at Norwich University, students of civil and environmental (CEE), electrical and computer (ECE), and mechanical (ME) engineering, along with construction management (CM) learn and practice professional and technical skills that unite engineers across all disciplines in a common, general introductory course [1]. Historically, students completed a second, common introductory course that was developed around four multi-week projects—one predominantly from each discipline. In this operational mode, many instructors felt uncomfortable supporting the larger projects outside of their own disciplines. It became common for instructors to cover multiple sections for the projects in their own discipline and trade away their section on projects they were less comfortable with. This resulted in heightened instructor exhaustion along with increased student frustration and confusion—consequences in agreement with the reports of others [2].

In 2012, the second, common introductory course ended. Each department was tasked with developing and offering a discipline-specific introductory course to replace it. Initially, the ECE department faculty developed this course around a series of interesting projects from various sub-disciplines within the field: robotics, wireless communications, energy conversion, and power electronics. The initial course offering also included a culminating project inspired by a real-world challenge that was detailed in [3]. The course was then taught by a team of four instructors. Students in the course reported a high sense of engagement, substantial work outside-of-class hours, and an overall enthusiasm and excitement for their intended program of study. However, they also articulated frustration with the course born out of confusion about faculty expectations and a sense of inadequacy related to their understanding of the technical content.

Starting in 2013, and over multiple subsequent offerings, the authors have built upon the great foundational exercises and pivoted the course to its current form. The course exercises were redesigned to: increase opportunities for the students to practice design; intentionally connect them to future courses the students will experience; and unite all of the exercises with a common, scaffolded experience thread (embedded systems), allowing the students to develop a sense of mastery of key skills as they progressed through the diverse exercises. To this end, use of an Arduino embedded system increased from 1/4 of the initial exercises to 6/7 of the lab exercises in its current form. The underlying pedagogical principles that informed the approach are based on self-motivation theory [4,5], and the belief that intentionally designing the course experience so students feel a sense of autonomy, a connection to something larger than themselves, and progress towards mastery of skills results in increased intrinsic motivation for learning.

As a result of this evolutionary, discipline-specific, project-focused, introductory course redesign for first-year ECE students at Norwich, it is hypothesized that the new course offering: (1) helps students see the relevance of an ECE education and connects the projects to future educational pursuits; (2) provides a rich common set of student experiences for instructors to call upon throughout future courses; (3) connects students to the School of Engineering and their department; (4) serves as a motivating, mastery experience for students early in their academic careers; (5) resulted in improvements to the consistency of the student experience.

Course Structure

This course consists of two 50-minute lectures and one 3-hour lab per week; it is a discipline specific follow-on course to a common engineering course taken in the fall semester. The lecture portion of the course is used to introduce and practice fundamental topics from the discipline as well as to prepare the students for the foundational laboratory exercises. Material is presented in a traditional format with all required assignments and laboratory exercises distributed through Norwich's Learning Management System (LMS). Students are assessed through multiple in-class exams, homework assignments, as well as written reports for each laboratory exercise.

Engineering faculty at Norwich have decided that participation in this course should contribute to a student's achievement of ABET student outcomes b-d, f-h, j-k [6], and a program specific outcome, l, described as "an ability to demonstrate initiative and perform in leadership roles."

Laboratory Experience

A description of the hands-on lab exercises built around use of the Arduino UNO and designed for teams of two students to build skill with foundational technical concepts is given below.

Lab 1: Test and Measurement Equipment (T&ME) and the 7-Segment Display (2 Weeks)

This lab introduces students to fundamental circuit concepts including Ohm's Law, voltage dividers, and LED biasing. Practical lab experience with resistor color codes, Arduino digital I/O, and the use of T&ME such as digital multimeters (DMMs), function generators, and oscilloscopes are introduced. Students progress from blinking an LED to displaying the numbers 0 – 9 on a 7-segment display, making measurements and verifying expectations throughout.

Lab 2: Arduino I/O (3 Weeks)

Students use the Arduino to sample a sinusoidal input and display information on a serial monitor. The sampling rate of the Arduino is investigated and its effect on the measurement of signals of different frequencies is explored. Conditional logic is used to control the output of a three LED system based on the sinusoidal input. The concept of pulse-width modulation (PWM) is demonstrated and a simple low-pass RC circuit is used to convert the PWM output to a constant DC voltage. Finally, a pushbutton and PWM signal are used to control a servo motor.

Lab 3: Brushless DC (BLDC) Motors (3 Weeks)
Students investigate BLDC motor operation and examine control mechanisms including a reed switch, a Hall effect sensor, and an optical encoder. They begin with the kit shown in Figure 1. In addition to using an optical encoder to control the motor, the encoder is used as a sensor with the Arduino, enabling calculation of rotational speed. Transistor circuits are introduced as well.

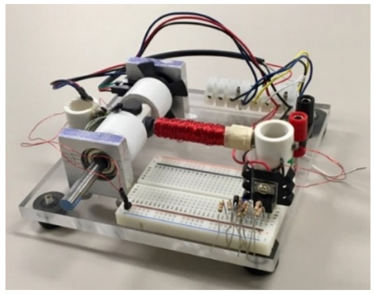

Figure 1: BLDC kit used for Lab 3. This is a modified Simple Motors kit [7]; the modifications include: reinforced, threaded mounts, a rotor mechanism including a robust steel axle/roller skate bearing assembly, and DC power supply ports to combat current supply issues with the batteries.

Lab 4: Boost Switchmode Converters (2 Weeks)
Initially, students construct a 350 μH inductor by hand and build a boost converter using the Arduino to control a MOSFET in a standard boost converter design. They then implement a feedback control system and dynamically modify the switching characteristics to maintain a constant voltage output for a range of voltage inputs. Then students learn soldering and schematic reading skills by assembling their own PCB-based portable boost converter.

Lab 5: Circuit Analysis and Visualization in MATLAB (1 Week)
Building on exercises from the previous term, students use MATLAB to solve systems of equations resultant from circuit analysis problems and to generate professional data plots.

Lab 6: Kirchoff's Current Law (KCL) (1 Week)
Students build resistive networks and use a DMM as an ammeter and voltmeter to verify KCL-based analysis. Experimental voltage and current measurements are compared to theoretical values determined with MATLAB. This lab is used to help explicitly connect the students' experiences in this course to the next ECE course they will take, Circuits I.

Lab 7: Culminating Project (2 Weeks)
The culminating project requires students to draw on skills learned in previous labs to solve a societally-relevant, complex problem. In [8], outcomes from a project connecting mechanical engineering students to the course to design a hydroelectric generator are detailed. Recently, the project has involved the design and implementation of an affordable, portable spectrophotometer to determine heavy metal concentrations in water supplies in developing nations. In addition to connecting students to a relevant real-world problem, this project connected the students to junior ECE students designing key circuits and subsystems and to researchers in the Chemistry department studying detection methods and other aspects of this global problem [9]-[10].

Starting from the system design of Figure 2 and customer requirements related to measuring sample contamination, the first-year students were tasked with developing the user interface and related control signals to operate the spectrophotometer with an Arduino Uno and LCD shield.

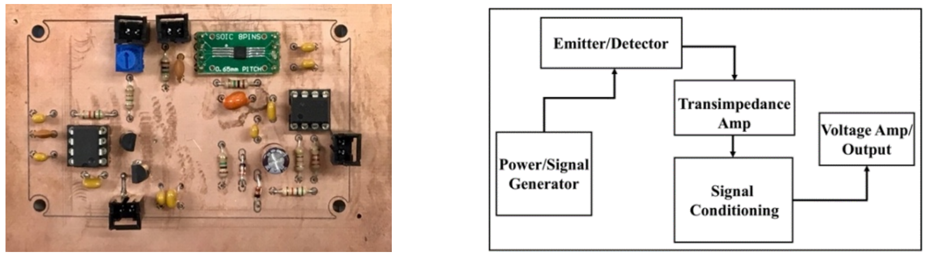

Figure 2: Spectrophotometer circuit designed and constructed at Norwich. Key subsystems/functions of the circuit (right) are shown alongside the physical board (left).

Initially, calibration data was hard-coded into the system and students applied their knowledge of control structures, conditional logic, digital and analog I/O, and basic electric circuits to develop, test, and verify the functionality of the system. In its second iteration, students built on previous work and applied their skills to develop the user interface required for calibrating the system prior to measuring the sample contamination. Example UI display messages are shown in Figure 3 below. In addition to introducing technical skills and applying them to real-world design, the laboratory exercises support the development of proper report writing skills. These skills include report organization, structure, and syntax, as well as the presentation of measured data.

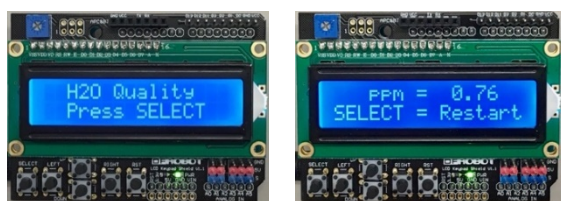

Figure 3: Example of the user interface and displays from the final project.

Discussion

In each exercise, students are given step by step directions to build a base circuit and then are required to measure signals at key points and analyze them comparing them to expected results. Progressing beyond the base circuit, students solve problems by filling in missing information, developing software, and interfacing the Arduino to the circuit in new ways to achieve the desired behavior. These opportunities for problem solving and design require a level of understanding and synthesis essential to the experience and student learning outcomes. For example, in the boost converter lab (*Lab 4*), students are given a reference design that boosts a 2V input to a 5V output. They are asked to redesign the system so that it works for inputs from 1 to 5V. Prior to the lab, the students learned how to setup a voltage divider and read an analog voltage with the ADC. In the initial phase of the lab, they investigate the relationship between duty cycle and output voltage. The students also observe what happens when the voltage drops. They are then required to take those observations and implement a feedback loop to maintain the regulated voltage. While they have had no instruction in controls theory, most are able to modify the system to change the duty cycle up or down based on the measured output voltage.

The laboratory exercises were designed to cover major topical areas in ECE. Table 1 indicates the correlation between material introduced in the course and future topical areas of study. In particular, embedded systems (the Arduino) apply directly to computer engineering. A survey was deployed through a LMS to collect feedback from current first-year students in the course as well as second-year ECE students who participated in the course last year. Students quantified their level of agreement with statements using a scale from 1 (Strongly disagree/No apparent correlation) to 5 (Strongly agree/Strong correlation). A summary of the questions and survey responses for both first-year and second-year students are shown in Table 2 below.

Table 1: Mapping of laboratory exercises to ECE areas of study. Note: X indicates a correlation and XA indicates that the Arduino UNO is used.

Area of Study	Circuits & Systems	Power & Energy	Communi-cations	Electronics & Semiconductors	Comp. Engr.	E & M	Design
Lab1	X			X	XA		
Lab2	X		X		XA		X
Lab3	X	X		X	XA	X	
Lab4	X	X		X	XA		X
Lab5					X		
Lab6	X				X		
Lab7	X				XA		X

Table 2: First-year and second-year survey results based on 13 and 12 responses, respectively.

Question	First Yr		Second Yr	
	Mean	StdDev	Mean	StdDev
The material presented in class relates to the work performed in the lab.	4.7	0.6	4.4	0.5
The material studied in lab will be helpful in my academic career at Norwich.	4.5	0.5	4.1	0.8
The principles studied in class/executed in lab provided me with a better understanding of the world.	4.7	0.5	4.0	1.0
I feel this class will be useful in my future career (post-Norwich).	4.8	0.4	4.5	0.5

These results indicate that while taking the course, students have very strong perceptions of the relevance of the lab exercises—relevance to their current and future coursework (1), real-world contexts (4), and future careers (4). While those perceptions soften a year after the course, it is interesting that the perception of the relevance of the course towards their future careers remains very strong among the students. In addition to the numerical responses, students had the opportunity to explain the connections they were making for each survey item. It is interesting that in response to Q2, students reported coding, circuit analysis and problem solving as elements helpful to their future. In response to Q3, one student explained, "Growing up, I always watched my dad wire cars and he used the circuit diagrams and I never understood them. After taking this lab, I can look at the circuits that confused me and understand them without any problems." For the second-year survey, students were also asked, "If you could travel back in time, what is one piece of advice that you would give your EG110-self?" The responses were fairly consistent: take better notes (42% of responses) and study more (25%). This is not surprising as students taking EG110 are first-year students and are adjusting to the pace and rigor of college versus high school. Other interesting responses include: "I would tell myself to study more as well as to take the class more seriously." and "I would tell myself never to underestimate the labs. Really invest in perfecting the reports as it will not go away, and whatever criticisms you receive take seriously so you won't make the same in the work force."

Conclusions

This paper details the design of an introductory ECE course to help students form connections: (1) to their future education; (2) to their future instructors; and (3) to their department/school. It was also crafted to: (4) serve as a motivating, mastery experience for students early in their academic careers; and (5) result in improvements to the consistency of the student experience. A rich set of experiential lab exercises reasonable for the audience of first-year students and connected to the subdisciplines of the field was developed. Students perceive strong relationships between these activities and their future studies and careers. The students' perceptions that the activities are relevant to society, their future, and their future classes should support intrinsic motivation among the learners in the environment. The course material was developed to be general enough that it is reasonable to expect a single instructor to cover the broad array of topics, improving the consistency of the experience. By engaging many departmental faculty members in the design of the exercises, the goal of connecting the students to the department can be met and the opportunity for instructors to call upon the lab experiences in future courses still exists. The authors hope that sufficient detail exists in this account that others may find inspiration as they work to attune their offerings to constituencies at their home institutions.

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