Tackling Real-World Problems in First-Year Electrical Engineering Experiences

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Full Paper: Tackling Real-World Problems in First-Year Electrical Engineering Experiences

Abstract

This paper details how a spectrophotometer design project was scaffolded into a first-year introductory electrical engineering course to model the engineering design process for students, and to motivate students to practice their design skills and contribute to the project by testing design variations. The goal of the project is the creation of a low-cost, portable, reliable water quality measurement device to support people working to address water quality contamination issues around the world. While much of the design was ultimately the responsibility of key ECE and Chemistry faculty members, students in the first-year program engaged in the project, further developing their embedded system programming skills. Lessons learned from multiple project iterations are discussed. Instructor observations combined with student survey data are presented to explore the effect of a real-world design project on student attitudes, commitment, effort, and performance.

Introduction

For the past three years, first-year students in the Electrical and Computer Engineering program at Norwich University have participated in the development of a water quality measurement device intended to serve as an inexpensive, reliable, hand-held replacement for a conventional bench-top water quality measurement system. Students in this introductory course have tested design concepts and developed the user interface for the system which consists of an Arduino Uno and an LCD shield with buttons to help the user navigate through the calibration and measurement process. The work performed by the students in this course constitutes a portion of the overall project, shared with other ECE and Chemistry students. While the final design was ultimately the responsibility of key ECE and Chemistry faculty members, the designs were developed to serve as examples / case studies of the engineering design process as well as to provide opportunities for the students to practice their design skills and contribute to the project by testing design iterations and variations. In this paper, we: discuss the educational and real-world contexts of the aforementioned design project, detail the evolution of the project over multiple iterations, discuss how the project reinforces key embedded system programming skills that students have been developing throughout the course [1], and show how the project is used to introduce more advanced electrical engineering concepts. Following the presentation of the project details, a discussion of student attitudes and lessons learned from multiple executions is presented. The discussion explores the impacts on student commitment, effort, and performance.

Educational Motivation

Engaging first-year engineering students with projects rooted in real-world problems can help keep the students engaged both in the project as well as the course overall. In their work studying intrinsic motivation [2], Deci and Ryan found that connecting one's work to greater contexts of significance or social import is a key factor in motivating better understanding and connecting one's work to other experiences. They also found that it results in improved commitment, effort, and performance. The work in [3] underscores the importance of active, discipline-based lab-learning on student retention and further supports the use of such activities. Situative learning and other learner-centered approaches [4-5] are frequently developed around exercises with real-world contexts grounded in experiences the learner can relate to; they have also been linked to improved student learning outcomes and persistence. In its 7th annual "Millennial survey," Deloitte [6] details this generation's desire to make an impact on society and their lack of patience for organizations or roles within organizations that are not proactively doing so. Work on any of the key subsystems in this overall project (a spectrophotometer, microcontroller for data acquisition, and display with keypad for a user interface) would easily comprise an active project grounded in electrical and computer engineering concepts that has real-world applications the students can relate to. However, a spectrophotometer alone, is not of significant social import. The connection of the project to real, human users and needs and the potential for the students' work to help others are critical in motivating student learners.

Societal Motivation

Spectrophotometers are commonly used to measure the concentrations of a wide variety of chemicals in hospitals, public health laboratories, and manufacturing. For example, they are used to measure the concentrations of glucose ($C_6H_{12}O_6$) in the serum and urine of people with type 1 diabetes [7], the concentration of total arsenic (As) in drinking water [8, 9], and the concentration of hydrogen cyanide (HCN) generated by the catalytic cracking of crude oil [10]. Unfortunately, many hospitals, laboratories, and factories in the developing world cannot afford the approximately $2,300 United States Dollar (USD) minimum cost for a commercial spectrophotometer. For example, a 10-to-15-year-old Hach DR/3-analog spectrophotometer was the most expensive laboratory instrument in 1997 at the International Centre for Diarrhoeal Disease Research, Bangladesh (ICDDR,B), an international health research organization and the national cholera hospital of Bangladesh. This spectrophotometer was used to make the first national-scale map of arsenic-affected drinking water in Bangladesh [8, 9]. This map suggested that 45 percent of Bangladesh's area has drinking well water with total arsenic concentrations greater than the 0.050-mg/L national standard; affecting over 50 million people [11, 8-9]. At this time, the nearby Dhaka Community Hospital did not even have a laboratory.

In response to this need for affordable spectrophotometers in the developing world and as a meaningful challenge to our students, Norwich faculty and students designed, built, and evaluated a light emitting diode (LED) analog spectrophotometer. In its current form, this instrument costs approximately $80 USD in parts and performs comparability to commercial spectrophotometers that cost between $2,382 and $7,510 USD. To date, this spectrophotometer has been used to measure the concentrations of total iron (Fe) and total manganese (Mn) in drinking water from Vermont, USA by the University. It has also been used to measure the concentrations of total copper (Cu), total chromium (Cr), and hexavalent chromium (Cr (VI)) in drinking water from Puerto Rico by researchers at the Massachusetts Institute of Technology. It has been used to measure the concentration of total fluoride (F^-) in drinking water in India by the Indian Institute of Science. It is currently being used for drinking water testing in China and Nepal. In the future it is expected to be used for serum and urine glucose testing in Honduras.

Design Motivation

The requirements of a design exercise for the ECE students included: (1) improve the performance of the instrument described in [12]; (2) power the instrument with a 6-V battery (initially); and (3) minimize the cost of the instrument. The performance improvement was ultimately measured as the linearity of the absorption curve for known reference samples with various concentrations of iron, and the range of detectable concentrations. These translated to measurements of input and output voltage ranges at each of the subsystems, and measuring the distortion of the signal. The power requirement was the driver for the power rail configuration of the circuit, and the low-cost requirement lead to the decision to design the system around a 5-V, single-rail system, initially using a low-dropout voltage regulator and currently an Arduino Uno. The resultant design challenge for the upper-division students was to develop systems to exploit the input and output ranges of available amplifiers.

Project Development

The culminating project in the introductory course requires students to draw on skills learned in previous labs to solve a societally-relevant, complex problem. For the past three years, the final project has involved the design and implementation of an affordable, robust, portable spectro-photometer to determine contaminant concentrations in water. The students in this course have focused primarily on the development of the user interface consisting of a LCD shield with buttons for navigation. In year one of the project, a circuit was constructed on a solderless breadboard and the students in the first-year course developed the user interface and related control signals to operate the spectrophotometer with an Arduino Uno, see Figure 1. In this version of the circuit, calibration data was provided and hard-coded into the system.

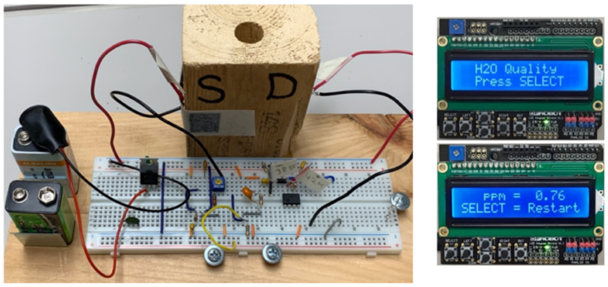

Figure 1: Left: Initial spectrophotometer circuit designed and constructed at Norwich Univ. Readily available materials were used for the sample holder (labeled S D in the photo). Right: Example menu displays are also shown. The calibration data was hard-coded into the program.

In year 2 of the project, the circuit was improved as a result of an engineering design challenge presented to Junior ECE students (see Figure 2). Students in the first-year course applied their programming skills to implement an automated calibration routine. This routine allowed the user to set the upper and lower limits of contaminant concentrations.

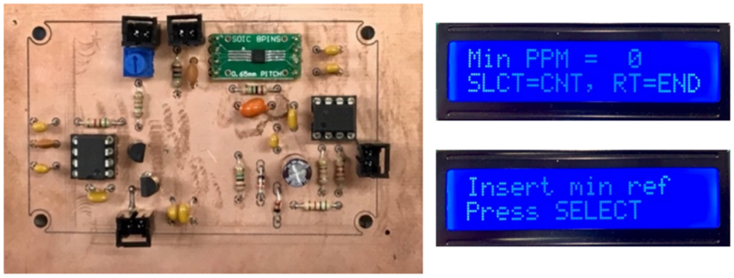

Figure 2: Left: Spectrophotometer circuit designed and constructed at Norwich Univ. Right: Example of the user interface and displays from the final project showing the auto-calibration routine. Here, the minimum calibration sample has been entered as 0 ppm (pure water).

In the previous circuit iteration, several analog circuits were implemented to increase the sensitivity and range of the instrument by accounting for the dark current in the photodetector.

In year 3 of the project, the faculty worked to simplify the system by relying on the Arduino to provide some of that functionality. Students were tasked with developing software to compensate for the dark current by controlling the emitter and sampling readings in both the light and dark states. As part of the development of this iteration, the circuit construction returned to the use of a breadboard. In the circuit below, the Arduino would be interfaced at the position of the large blue circles (i represents the input signal from the Arduino, o represents the output of the circuit, providing feedback to the Arduino). As before, upper division students are being engaged to develop a custom PCB so the in-house board printer may be used to produce a circuit similar to that shown above in Figure 3.

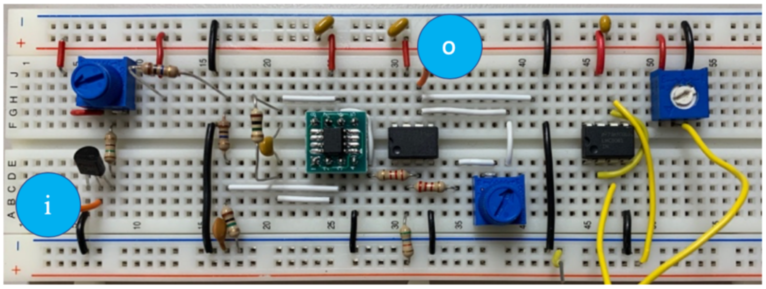

Figure 3: Spectrophotometer circuit designed and constructed at Norwich Univ. In this circuit, an Arduino provided the control signal for the operation of the LED (blue circuit labeled i).

Additionally, minor usability improvements were incorporated into the overall GUI menu system. Future project iterations will involve the design and implementation of a more robust multi-point calibration routine that reports measured data along with reliability information.

Discussion

Students were required to understand the high-level functionality of the spectrophotometer circuitry, to measure signals at key points, and to analyze the measurements in comparison to expected results. The students were required to develop and implement software changes to make the new design functional and to verify that the desired behavior was achieved. These small opportunities for problem solving and design require a degree of understanding and synthesis, but are essential to the experience and student learning outcomes. For example, in an early lab exercise the students investigated sampling analog signals with the ADC on the Arduino, and the students had to expand upon this technique for the spectrophotometer circuit.

A short survey was deployed through the University's Learning Management System to collect feedback from the first-year students in the course. 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 the students currently enrolled in the course and the students who took the class last spring are shown in Table 1 below.

When asked to discuss their impressions/take-aways from working on a project with real-world applications, one student responded: "Being able to work on something that has the potential to help thousands has given me a new perspective regarding the kind of work that we do." and another student responded: "I really enjoyed the real world application because it connects these little things we are learning which seem irrelevant by themselves but can be applied to bigger solutions."

The students who worked on this project in the previous year were given a similar survey. When asked to discuss their impressions/take-aways from working on a project with real-world applications, one student responded: "It reinforced my love for what I was doing and gave me an understanding of the possibilities my major has to offer."

Table 1: Course survey results based on 14, 13, and 14 responses, respectively. *Students who took the course and survey in 2018. **Same students that took the course in 2018 and the survey in 2019 (reflections on the course).

Question	Spring 19		Spring 18*		Spring 18**	
	Mean	StdDev	Mean	StdDev	Mean	StdDev
Class material relates to lab.	4.36	0.74	4.7	0.6	4.29	0.83
Class material relates to project.	3.93	1.00	NA	NA	4.21	0.71
Material studied will be beneficial in my academic career.	4.36	1.08	4.5	0.5	4.07	1.21
Course principles provided a better understanding of the world.	3.79	1.05	4.7	0.5	4.14	0.86
This class will be useful in my future career.	4.07	1.00	4.8	0.4	4.14	1.03
I feel that my work done in this course will impact society.	3.79	0.89	NA	NA	3.93	1.44
I would like to contribute to the advancement of this project.	4.36	0.74	NA	NA	3.86	1.17

In [1], the authors' efforts to use the Arduino microcontroller as a platform for introducing many of the key sub-disciplines within electrical and computer engineering and to design the assignments to help students form connections: (1) to their future education, (2) to their future instructors, and (3) to their department/school, were detailed. Throughout multiple years of running the course in this manner, with a culminating real-world project to conclude the term, the instructors have observed a difference in the student attitudes, commitment, effort, and performance on content related to the final project versus the regular laboratory exercises. Despite the fact that almost every interim lab exercise provides students with a hands-on way to explore and further understand course content by interfacing the Arduino to the physical world, many students are not fully-engaged in the exercises. While the comments below are certainly not true of all students in the course, the dominant impression of the instructors is that students: are unlikely to read documentation before coming to lab, are unlikely to make an effort to come back and complete an exercise if they fail to do so in the allotted time, and are likely to "go through the motions" moving from task to task even when they suspect the information they are collecting is odd or incorrect. Much of this behavior changes for the real-world project. The authors have frequently seen students stay beyond lab time or return in the evenings to keep working on the real-world design project. They are also far more likely to ask questions about it during and after class time. This increased level of engagement translates to improved comprehension.

Conclusions

This paper details the progression of the culminating project in an introductory ECE course. The project directly relates to research in the area of contaminants in water. Students were able to apply the knowledge and skills introduced in foundational lab exercises (state machines, conditional logic, digital and analog microcontroller inputs and outputs) to contribute to the development of a low-cost, reliable, portable water contamination measurement tool. Students demonstrated increased engagement and commitment to the project and improved learning outcomes when compared to typical, hands-on laboratory exercises in the same course. A single course survey response sums this up nicely: "I feel as the original labs I was only going through the motions whereas in the final lab I see how it has real world affect and can see the usage and how the small details we originally learned come together to make something useful."

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