Integrating Electrical Engineering Fundamentals with Instrumentation and Data Acquisition in an Undergraduate Mechanical Engineering Curriculum

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***Abstract*—The Anonymous University Mechanical Engineering department was awarded a grant from the National Science Foundation to revolutionize its undergraduate program. The goal of the grant is to implement department wide changes that create a focus on doing engineering with engineers and fosters stronger engineering identities in students and faculty. One area of change is the program's curriculum. This paper describes how the Electrical Engineering Fundamentals course was integrated into the Mechanical Engineering Instrumentation and Data Acquisition (DAQ) course with the goal of creating connections between electrical engineering concepts and applications in mechanical engineering. Design and implementation of this course sequence are presented. Assessment and evaluation methods are also discussed.**

Keywords—Engineering Identity, Data Acquisition, Mechanical Engineering, Electrical Engineering, Laboratory

I. Introduction

The Mechanical Engineering (ME) Department at Anonymous University was awarded a National Science Foundation RED (Revolutionizing Engineering and Computer Science Departments) grant in July 2017. This award provided the opportunity to create a program where students and faculty are immersed in a culture of doing engineering with practicing engineers that in turn fosters an identity of being an engineer [1], [2]. To build this culture of doing engineering, changes in four essential areas indicated by research are needed: a shared department vision, faculty, curriculum, and supportive policies [3].

As an important step towards creating the new culture, the curriculum was thoroughly reviewed by all shareholders including faculty, students, and industry advisory board members. The review surfaced an issue common in ME programs--that many ME students see Electrical Engineering (EE) concepts as abstract and removed from ME. For example, students said, "*Electrical (Engineering) is very theoretical,*" and *"We need to do more actual circuit building* [in the EE class]*."*

Table 1: Previous Curriculum in Junior Year

Fall	Winter	Spring
Thermo-dynamics w/labs	*Electrical Engineering (EE) w/ labs*	*Instrumentation and Data Acquisition (DAQ)*
Materials Science w/labs	Machine Elements w/ labs	Heat Transfer w/ labs
Engineering Economics	Fluid Mechanics	Machine Elements II or Thermodynamics II

In their junior year, ME students take nine ME required courses, which can be seen in Table 1. These courses are only offered once each year and students rarely take them out of sequence. In the previous curriculum, the EE course was taught by an EE faculty during the winter quarter, and the Instrumentation and Data Acquisition (DAQ) was taught by a ME faculty the following quarter. The disconnect between these two courses was noted by students as one suggested, "*Whoever teaches the DAQ class should also teach the circuits class the quarter before because they could give a lot more relevant information, or at least have them work together.*" In addition to student feedback, industry partners also expressed their need for skilled engineers who can integrate the fundamentals of EE and ME. How to integrate EE and ME in the new curriculum became the challenge.

To respond to these issues and the recommendation for a stronger connection between the faculty and these two subject areas, a change in the new curriculum was proposed. See Table 2. Under the new proposal, in the junior year, students take a two-course sequence of Instrumentation and Data Acquisition (DAQ) in the winter and spring quarters that combine essential content from the previous EE and DAQ curriculum.

Table 2: New Curriculum in Junior Year

Fall	Winter	Spring
Thermodynamics w/lab	*DAQ I*	*DAQ II*
Materials Science w/lab	Machine Elements w/o labs	Heat Transfer w/o labs
Engineering Economics	Fluid Mechanics	Integrated Engineering Project course*

* Machine Elements II and Thermodynamics II are moved from spring of junior to the senior year and are replaced by an Integrated Engineering Design Project course.

II. COURSE DESIGN AND IMPLEMENTATION

Many researchers have discussed the benefits of hands-on laboratory work to engineering education [4-6]. One of ABET's (Accreditation Board for Engineering and Technology) specified student outcomes is "an ability to develop and conduct appropriate experimentation……" [7]. Researchers also show that engineers are more "likely to be active learners" as a result of such classes [8]. Hence, this two-course DAQ sequence was designed with a unique format: there are two lecture/laboratory combinations every week, one for EE and one for DAQ. EE content is discussed in a 50-minute lecture followed by a 100-minute laboratory early in the week, and a 50-minute DAQ lecture and 100-minute laboratory occurs later in the week. The EE and DAQ content are carefully designed and coordinated. Both emphasize hands-on learning with team laboratory exercises connected to in-lecture examples, and they implement the curriculum focusing on doing engineering.

The new course also includes labs that connect to outside classes. This change accommodates curricular changes and strengthens connections across the curriculum. As noted in Tables 1 & 2, labs are eliminated from the machine elements and heat transfer courses. The new EE/DAQ course includes laboratory experiments that are related to other junior-level ME courses such as Machine Elements, Fluids, and Heat Transfer. These labs further help students connect concepts and synthesize their knowledge from different courses.

Tables 3 & 4 summarize lecture and lab topics for the winter and spring quarter respectively. Two ME faculty work closely together to co-teach this two-course sequence; one leads the EE and the other guides the DAQ portion. The EE lectures provide basics for students to prepare for their Fundamentals of Engineering (FE) exam [9], which is the first requirement towards their professional engineering license. The DAQ lectures cover fundamentals in Data Acquisition as well as Internet of Things (IoT). The labs facilitate their learning through hands-on exercises and real-life applications.

The first (winter) quarter begins with an introduction to electrical engineering. Various electronic components are introduced in the EE lab each week. These components are then used in the DAQ lab to support the microcontroller used in the course. In the middle of the quarter, students begin to build more complicated circuits and begin connecting their project using simple IoT applications. Towards the end of the quarter, students conduct experiments that connect with other ME courses to facilitate the integration of knowledge.

Table 3: Winter Quarter

Week		Lecture	Lab
1	EE	Voltage, Current, Power & Energy	Building a Simple Circuit w/ an LED
	DAQ	Introduction to data collection and μP.	Time Varying Measurement & Sources
2	EE	Basic Laws	Resistive Network
	DAQ	Programming in C	Programming a Microcontroller
3	EE	Nodal analysis	Potentiometer & LED Brightness
	DAQ	Analog to Digital Converter & Pause Width Modulation	Controlling the Brightness of an LED with PWM
4	EE	Mesh analysis, Diodes & Transistors	Voltage Regulator & Phototransistor
	DAQ	Digital Input, Digital Output & Counters	Timers, Digital Input & Digital Output
5	EE	Source Transformation	Optoisolators
	DAQ	IoT	Ambient Light Controller
6	EE	Thevenin & Norton Equivalent Circuits	Thevenin's Theorem and Wheatstone Bridge
	DAQ	Midterm Exam	IoT
7	EE	Op Amps	Op Amp Circuits & Strain Gauge
	DAQ	IoT Continued	Strain Gauge for Coin Scale
8	EE	Op Amp Applications	Op Amp Circuits & Strain Gauge Cont.
	DAQ	Measurement Uncertainty	Coin Scale Cont.
9	EE	Capacitors	Op Amp Applications & Capacitance Water Level Measurement
	DAQ	Measurement Statistics	Water Level Alarm
10	EE	RC circuits	Water Level Measurement Cont.
	DAQ	Review	Water Level Alarm Cont.

For example, in the DAQ/EE course, students rely on their knowledge of stress and strain theory acquired in their Mechanics of Materials course to relate the strain in a cantilevered beam to the force at the end of the beam. Students begin by instrumenting a cantilevered beam with a strain gauge. They then build a Wheatstone bridge and analyze it using Thevenin's theorem. Next, students create a basic HTML webpage program and demonstrate how to transmit data via internet through a microcontroller. Building on their knowledge of the Wheatstone bridge, students add an instrumentation op-amp to their circuit and connect their circuit to the microcontroller. By the end of the lab exercise, students are able to use the beam and strain gauge to weigh pennies and display the resulting number of coins on a web page.

In another lab, students build a capacitive water level measurement circuit [10], connect their circuit to a microcontroller, and turn on a buzzer when the water level is over a certain height. This exercise connects to content in Fluid Mechanics that students are concurrently taking. Furthermore, the system can potentially be utilized in an ME required course in the senior year, Dynamic Systems, when students are tasked to take water level measurements with various input and output flows.

The second (spring) quarter of the EE/DAQ class begins with a review of electronic components using the circuit simulation software, Multisim, and an introduction to RTOS (Real-Time Operating System). The emphases of the second quarter are on various sensors, time-domain and frequency-domain analyses. Most of labs in this quarter are designed to last for two weeks, similar to the format of the strain gauge coin scale and the water level alarm labs in the first quarter.

In one lab, students use an ultrasonic sensor as an intruder alarm. In this lab exercise, students track distance from an ultrasonic sensor by measuring a pulse width using a timer on the microcontroller. The distance measurement is displayed on a webpage and the buzzer sounds when the distance measurement is below a limit set on the web page. The alarm is latched until a disarming signal is sent from the webpage to the microcontroller.

In another lab, student apply knowledge learned in their Heat Transfer course. In Heat Transfer students learn to analyze systems using a lumped capacitance model. In the EE/DAQ lab a thermocouple is inserted in the center of a metal sphere. Students build a circuit to amplify signals from the thermocouple and measure its temperature. As they remove the metal sphere from the boiling water, they record temperature readings using the microcontroller. Students then perform transient heat transfer analysis that requires them to integrate knowledge they learn concurrently in the Heat Transfer course.

These lab exercises[a] are all designed with an integrated ME curriculum in mind and intended to utilize hands-on, real-life applications to facilitate the goal of doing engineering in our program.

Table 4: Spring Quarter

Week		Lecture	Lab
1	EE	Inductors & RL Circuits	Multisim
	DAQ	Timing, Polling, RTOS	RTOS & State Machines
2	EE	Sinusoids	DPDT Relays & Intruder Alarm Circuit I
	DAQ	Free RTOS, Counters &Timing	Ultrasonic sensor, timing measurements relays, IOT
3	EE	Phasors	Intruder Alarm Circuit Cont.
	DAQ	Frequency Content & Fourier Transforms	Ultrasonic sensor, timing measurements relays, IOT.
4	EE	Impedance and Admittance	Microphone (mic) Circuit
	DAQ	FFT	Sampling, capturing sound with a mic & frequency content analysis
5	EE	Sinusoidal Steady-State Analysis	Microphone Circuit Cont.
	DAQ	Frequency Response, Bode & Filtering	Sampling, capturing sound with a mic & frequency content analysis
6	EE	Sinusoidal Steady-State Analysis	Transient Heat Transfer Measurement Circuit
	DAQ	Midterm	Thermocouple (TC), TC amps, Transient Heat Transfer Measurement
7	EE	Second Order Circuits	1st & 2nd Order Analog Filters
	DAQ	Antialiasing filters & Digital Filters	Digital Filter to PWM to 1st Order Analog Filter
8	EE	Second Order Circuits	1st & 2nd Order Analog Filters Cont.
	DAQ	Interrupts review. Quadrature Proportional Feedback	Digital Filter to PWM to 1st Order Analog Filter Cont.
9	EE	Transistor Circuits	H-Bridge for Servo Motor
	DAQ	Sensors	Servo Motor Position Control
10	EE	AC Power Analysis	H-Bridge for Servo Motor Cont.
	DAQ	Sensors	Servo Motor Position Control Cont.

III. Evaluation and Assessment

As students go through the sequence, they are being assessed in traditional ways such as exams, and also through more real-world mechanisms like online engineering notebooks. Students also regularly reflect on their experiences and participate in focused interviews. These assessments provide both instructors and students with important information about students' learning and development.

Research has shown that maintaining engineering notebooks helps students build their engineering identity [11, 12]. Throughout the sequence, students in teams of two use OneNote® to maintain an online engineering notebook that documents their progress in labs. In their online notebook, students write down their procedures, discuss their results, and reflect on their observations. They also post photos, videos, and drawings in their notebook. A general format for each lab is as follows:

I. Overview- What are the goals of the lab?
II. Design and Calculations- Document your design and any relevant calculations.
III. Hardware-
   - If you design and built something, document your completed hardware. Include a figure, picture or video of the final system. Include a description/link/picture of all hardware. Provide enough documentation so that someone could build your hardware.
   - If this was an experiment, document the equipment used in the lab.
IV. Procedure and Results- Document any procedures you used when collecting data and the corresponding results.
V. Discussion- Discuss your results. Address any assigned lab discussion questions here.
VI. Observation- Provide any general observations you have about the lab or results. These don't have to be tied directly to results.

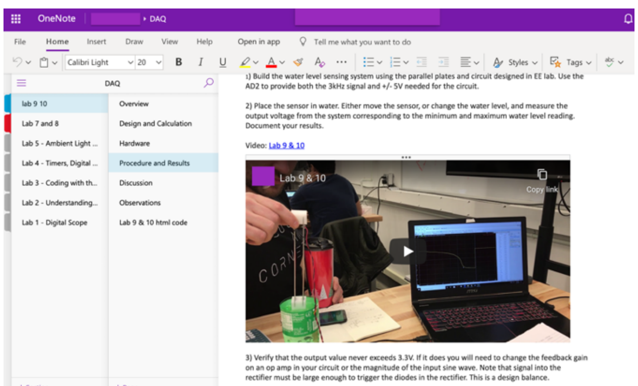

Figure 1. Screenshot of an online engineering notebook.

Students also participate in bi-weekly reflection exercises, called "reflection breadcrumbs". These reflections provide additional information to help instructors assess the student learning experience throughout the quarter [13]. For each reflection breadcrumb, each student is asked to write a paragraph(s) to report the key takeaway(s) from the previous two weeks, and to respond to a prompt. The prompt combines three steps: 1. a starting reaction (students have options of emotions); 2. add an explanation for the reaction; 3. provide an action to the reaction. Here is an example of the reflection breadcrumb prompt:

Q1: In the last two weeks, what part of the lab took longer than you expected?

or

Think about what frustrated you. What was it?

Q2: Is there anything you don't understand in this?

Q3: What is a small action you/we could take to change your reaction?

The reflection exercises are done using the Canvas Learning Management System (LMS) that provides statistics on how much time students spend on each exercise. During the first quarter, students took an average of 20 minutes to complete each reflection exercise. These exercises result in rich information that will be helpful in implementing future iterations of this course.

IV. Future Work

The department's goal of creating a program that supports a culture of doing engineering with practicing engineers to foster engineering identities necessitates a curriculum that is inclusive and engaging, both in design and in the way it's experienced. An integrated EE/DAQ sequence is one essential part of such a curriculum. This sequence is in progress in Winter and Spring quarters 2020[b]. More data on the effect of this sequence and its overall impact to the goal of doing engineering are being collected and will be shared in the future.

Acknowledgment

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[a] Lab exercises are available. Please email the author Yen-Lin Han (hanye@seattleu.edu) for details.

[b] The winter quarter has just concluded, and the spring quarter is about to begin at the time this paper is submitted. However, with the Covid-19 situation, some adjustments are made to the second quarter by making all labs sections remote. In this paper, we would not discuss details on the adjustments we have to make but focus on presenting a plan to be adapted under the regular circumstance.