ENEE 101: On a gadgets driven freshman course for improving first year retention rates

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***Abstract* - We introduced a hands-on course on "Introduction to Electrical and Computer Engineering", to improve first-year student retention rates in our department. It is a one semester course taught to all incoming Electrical Engineering (EE) and Computer Engineering (CpE) first-year students and undeclared students. The material is comprised of 8 applications-based modules that span the core disciplinary concepts for our electrical and computer engineering curricula. The rationale, course structure and brief descriptions of the modules are presented.**

Index Terms – courseware, first-year retention, hands-on pedagogy, engineering education

INTRODUCTION

The highest attrition rate of students among our electrical and computer engineering (ECE) students occurs after the first year and before students take any ECE courses other than introductory programming. Sadly, some students leave the program based only on a meager understanding of the relevance of ECE in everyday life, in favor of programs that are more conspicuous. A similar first year retention problem of students within the College of Engineering existed decades ago. But this was mitigated by the introduction of a well-structured 'Keystone Introduction to Engineering Design', ENES100, which provides a hands-on design experience that cuts across all engineering disciplines [1-3]. The result was positive: the first-year retention of engineering students steadily improved from 72% in 1996, prior to the Keystone program to more than 92% today. The main features of the Keystone program are appointing the best instructors, offering just-in-time teaching and assigning a single design challenge to be solved by teams. The original challenge was to build an autonomous hovercraft, which can navigate to a given site and perform a mission such as locating and picking up a target object. Nowadays, the challenge is to build a terrestrial vehicle that can autonomously navigate to a given location and perform missions on sand while guided by a local positioning system. These challenges require a synthesis of several engineering disciplines – electrical, computer, mechanical, aerospace, civil, chemical, fire protection and biomedical and material science, which force the creation of multidisciplinary teams.

Following this model, we offer ENEE 101 "What's Cool in ECE" to complement ENES100 with the intention of anchoring students into our ECE program. The course, piloted in Fall 2015, is a requirement for all incoming first-year ECE students. Undecided Engineering first-year students who express an interest in ECE, have the opportunity to enroll in the course as well. It features activities that highlight key concepts in our ECE curricula, which are taught using hands-on modules that focus on real gadgets. Each week, students listen to a 75-minute lecture by faculty and spend a total of 4 hours in the laboratory split between 2 days. The lectures provide an overview of advances in the field. Like TED Talks, the lectures are designed to inspire and present broad ideas that are reinforced in the lab work. Some of the lectures are recorded.

COURSE STRUCTURE

The course is divided into 8 diverse yet structured modules. All but the ethics module, are gadgets-based in which the students assemble, disassemble, use, measure or analyze. The modules are carefully chosen and arranged to introduce the foundational concepts in the ECE curriculum in bite-size chunks and builds upon the previous lesson. Each module is allotted 1 to 3 weeks total. About 100 students per semester are enrolled, and they are divided in smaller laboratory sections of about 12 per section. Students work in pairs and are guided by a peer instructor and support technical staff. This ensures are all having ample opportunity to be immersed in the activity. Students are assessed on participation, completed projects, laboratory reports, short quizzes, an ethics paper and final report.

MODULES

The modules, in order of instructional delivery are:

1. Optical Communication
2. Energy Harvesting
3. Control systems and the 65C Egg
4. Brainwaves and Cognition
5. Image and Video Processing
6. Engineering Software Development

7. Android™ and microcontroller programming
8. Engineering Ethics

Optical Communication

This is aimed at introducing analog circuits, This module is aimed at introducing analog circuits, measurement techniques of DC and time varying electrical quantities, Fourier transforms, spectral decomposition, filtering and optical AM modulation. Students are given preassembled kits of an optical transmitter and a receiver, along with a schematic diagram. They are taught basic kit operation and perform electrical measurements on various nodes using an Analog Discovery™ [4] scope to learn rudimentary circuit analysis. They also learn to verify the predictions simulations using Pspice or the cloud based CircuitLab™ [5]. Students are taught that any periodic or pseudo-periodic signal can be represented by a superposition of harmonics of sinusoidal waves. This is reinforced by digitally computing the Fourier spectra of periodic signals in the audio range using Matlab™ [6] and verifying the results using an audio frequency spectrum analyzer. The concept of superposition is further ingrained as a property of waves regardless of the frequency by using a home-built spectrometer to observe the spatial separation of the frequency components of various light sources. Students then learn the rudimentary concepts of wavelength multiplexing by placing different audio signals on different optical wavelengths and extracting the material using appropriate optical filters.

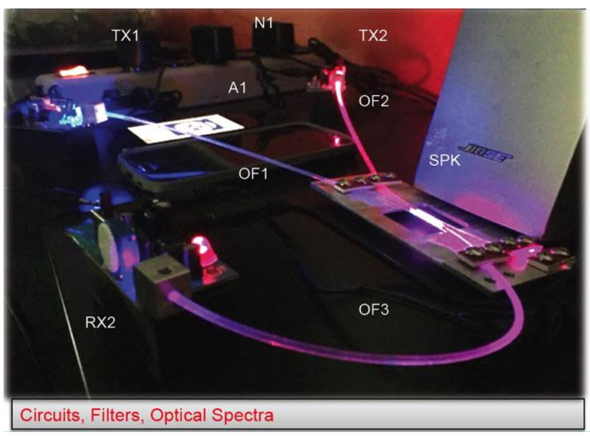

FIGURE 1. Student setup for "Optical Communication Module showing principle of wavelength division multiplexing. Audio source A1 modulates the intensity of the blue LED emitted by transmitter TX1, while 1kHz sine noise modulates intensity of red LED. The light beams are coupled to optical fibers, which are spliced to combine both colors into a single fiber OF3. The signal from OF3 is collected and filtered at the received RX, which drives the speaker.

Energy Harvesting

The energy-harvesting module is aimed at reinforcing the concepts in circuit analysis, with emphasis on power generation from alternative energy sources. Students are exposed to concepts of renewable energy harvesting systems such as solar energy conversion, wind energy conversion, thermoelectric energy conversion and piezoelectric energy conversion. Students reinforce their knowledge of circuits, instrumentation and data acquisition, and modeling within the context of voltage (I-V) and power-voltage (P-V) characteristics of PV systems. They learn concepts such as fill-factor, and impacts of irradiation and temperature on the I-V curves of the PV system. On wind energy conversion, students become familiar with various components of a wind energy conversion system including turbine, nacelle, blades, generator, rotor, pitch system, gearbox, anemometer and yaw mechanism. In addition, piezoelectric energy conversion is taught with a full-wave rectifier and a capacitor to demonstrate DC conversion and storage. We use the energy harvesting board developed by Würth Elektronik and Linear Technology [7]. It is capable of accepting four kinds of energy sources: piezoelectric energy source, solar energy source, thermoelectric energy source or magnetic energy source. A solar cell (32mm×50mm) and a thermo-generator (40mm×40mm) are incorporated on the board itself with provisions to add other external energy sources, i.e. piezoelectric and electromagnetic sources. We again use the scope function of the Digilent Analog Discovery™ to observe the waveforms.

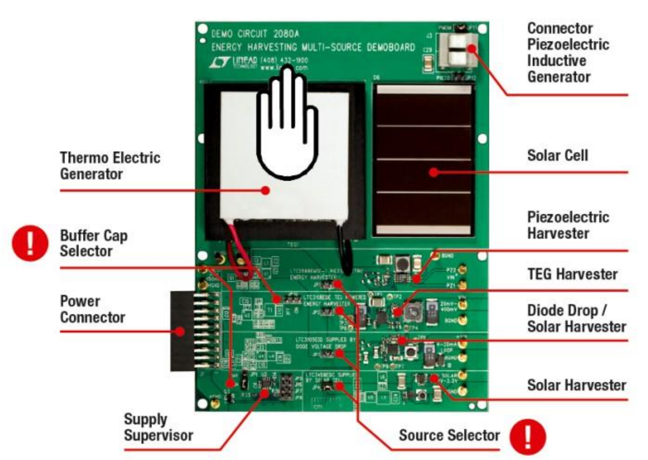

FIGURE 2. The energy harvesting demonstration board equipped with solar, thermo and piezoelectric sources.

Control systems and the 65C Egg

This module is aimed at teaching fundamentals of linear feedback control systems. Although control systems are ubiquitous in our lives it is difficult to find an example of a control system that is both exciting enough to inspire first-year students, yet technically easy to understand and design. Our solution to this dilemma was to ask the students to develop a Proportional plus Integral (PI) controller to maintain the temperature of a cup of water at 65° C for several hours. PI-controllers are extremely common and important in the real world but hardly inspiring. Cooking an egg provides the inspiration. Cooking an egg for at least one hour at 65° C is purported to produce the best tasting “hard-boiled” egg [8]. Our hope is that tasting the eggs, although not required, will generate enthusiasm and interest in controls. The students are provided with an uncontrolled egg cooker consisting of a 24 Volt DC source that is capable of supplying up to 120 Watts to a hot plate on which an aluminum cup filled with water is placed. The voltage supplied to the hot plate is controlled by Pulse Width Modulation (PWM) from an Arduino Mega that is programmed using MATLAB®/Simulink on a desktop computer. A temperature sensor (thermistor in a voltage divider) is provided and its signal is put in to the Arduino. Thus, the PI Controller, implemented in the Arduino has an input voltage from the temperature sensor and an output voltage determined by the controller. The students are asked to calibrate the sensor with a special emphasis on the sensor voltage that corresponds to 65° C. They are then asked to identify a linear mathematical model for the egg cooker from the response to a small step. They use the MATLAB® Toolbox IDENT. The controller has two modes. In the first mode, maximum voltage is applied to the heater to drive the water temperature to about 60° C as quickly as possible. There is no need for great accuracy in this mode. Once 60° C is reached, the controller switches to a conventional PI Controller tuned to have minimal overshoot. At the end of the hour the eggs are removed from the water, peeled, and eaten by those students wish to do so. Comparison of their results with photos of previously cooked eggs allows them to tell the temperature at which the egg was cooked to within a degree. Most of the students who have tasted the eggs have liked them.

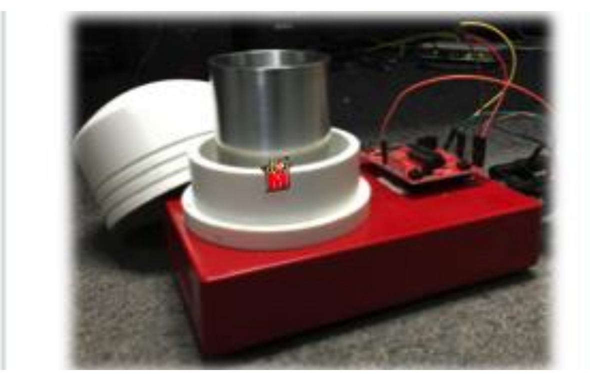

FIGURE 3. A microprocessor controlled water bath to illustrate proportional and integral gain active feedback control to maintain a fixed water temperature.

Brainwaves and Cognition

This module is aimed at teaching the fundamentals of signal processing and computation. Students learn basic concepts of signal processing by analyzing EEG (electro-encephalogram) data from 16 channels placed at various locations of the brain. They use an inexpensive wireless headset marketed as EPOC Plus^{TM}, with the option to access the raw data. Students learn how to perform discrete Fourier transform in one dimension, implement appropriate signal conditioning, as well as digital filtering and analysis of recorded EEG data. Students use MATLAB® extensively to convert the data into frequency space and develop algorithms to identify specific mental or physical activity into characteristic brain wave patterns. Students are challenged to develop a system of communication that relies solely on brain wave patterns. And as a by-product, students learn rudimentary concepts in neuroscience.

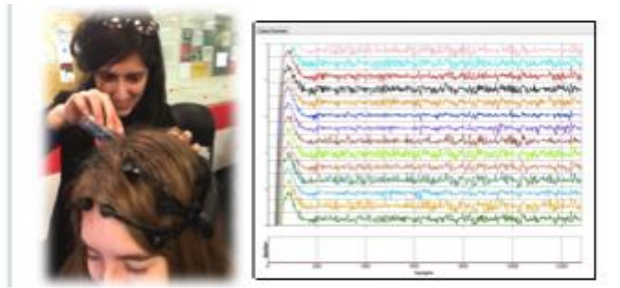

FIGURE 4. (LEFT) A teaching assistant is installing a 16-node EEG headset. (RIGHT) Representative EEG signals from selected electrodes.

Image and Video Processing

This module is designed to provide behind-the-scenes exposure and first-hand practice on key techniques of image and video processing. Students learn by following step-by-step illustrative guides to process images in MATLAB® to enhance contrast, extract boundaries, segment objects, and compress file size. Students learn 2D image processing techniques. They review concepts of transforms and students learn methods of image representation, preprocessing, enhancement, reconstruction and data compression.

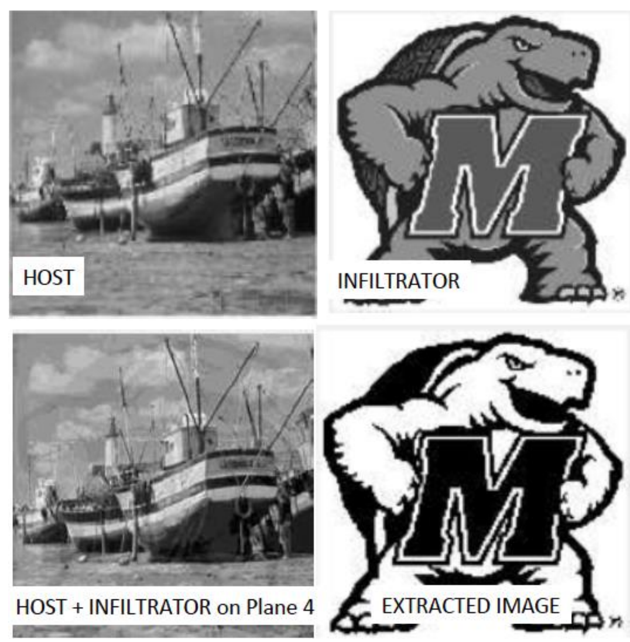

FIGURE 5. Data hiding in an 8-bit gray scalc image. Images are represented as 8 planes of 2 dimensional matrices. The infiltrator image (Testudo the turtle) is hidden with its most significant bit intermingled with plane 4 (out of 8 planes) of the host image. The resulting image is shown in the composite (lower left), where traces of

the infiltrator can be gleaned. The contents of plane 4 can be extracted from the composite image to show a 1 bit rendition of the hidden image.

Students are taught how to perform matrix operations in MATLAB® to implement various algorithms such as correlation and convolution and various types of image filters. Similarly, in the spirit of developing the synergy between research and education, this module also offers first-hand exposure on the latest and emerging research utilizing image and video processing, including embedding invisible messages in images. An example is shown in Figure 5, where the infiltrator image is hidden on plane 4 (out of 8 planes). The resulting image is shown in the composite, where traces of Testudo the infiltrator can be gleaned if one stares long enough. The students learn that if the infiltrator were hidden on plane 5 or 6, it is virtually impossible to detect the infiltrator with the naked eye. However, by using appropriate bit processing techniques, it is possible to extract the hidden image.

Engineering Software Development

In this module, students are exposed to fundamental concepts and methods in engineering software design. Students learn about design methodologies and software techniques that are important in the construction of practical engineering software systems. Specific topics that are covered include the use of UNIX commands for engineering software development; the use and design of scripts forautomating software tasks; and the development and application of automated test suites for efficiently validating software implementations. Examples from the area of parallel software implementation for deep waveform measurement (DWM) are used to help motivate the concepts and methods presented in the module. In digital communications and signal analysis, DWM refers to analysis of characteristics, such as timing properties, associated with signals that have relatively long durations. Students are exposed to the design methodologies and software tools used in DWM that are important in the construction of practical signal processing software systems.

Android™ and microcontroller programming

This module is aimed at introducing concepts for Internet of Things. Students learn to program an Android OS device, such as a tablet, to use the Bluetooth communication channel to remotely actuate a robot cart controlled by a Texas Instruments MSP430™ [9] microcontroller board. Students learn two concepts: the first being Android™ programming by itself and learning to use the built-in sensors and various libraries of the web. The second is to learn the basics of microcontroller development environment, including I/O control, analog input/output and logic controls to implement movements of a robot cart. These elements are combined to learn programming with communication protocols. Students are provided with skeleton Android™ and microcontroller codes that allow rudimentary movement of their toy bot. They are then required to enhance the capabilities of the bot by adding more logic and more onboard sensors, as well as accessing the added functions on the Android™ device.

FIGURE 6. An Android (Kindle Fire) and a microcontroller bot communicating via the Bluetooth channel.

Ethics

This module introduces students to topics in engineering ethics, such as conflict of interest and the IEEE Code of Conduct. Students learn intellectual property issues, along with non-disclosure agreements and patents. Students also discuss the ethical ramifications surrounding new technologies such as self-driving cars and exploding airbags. This model serves as an introduction to what students would explore in a 200-level ethics course.

SAMPLE WORKSHEET

Students are given instructional slides and worksheets online and during laboratory hours. And each student pair goes through the material at their own pace. Their peer instructors provide clarifications, background material and help with instrumentation. In the labs, they complete the worksheets from which they write the reports. The reports are graded, with some critiques, to give students feedback on their progress. A sample worksheet is exemplified as follows:

Lab3.1 Brainwaves and EEG Module
Name:_______________________

Part 1: Synthesis and Analysis of Signals
In this section, you will learn to synthesize signals with desired frequency contents.
Review: The most important concept of discrete signal processing is the notion of sampling frequency. In Fig.7(a), the signal is sampled at intervals of 1 millisecond, whereas in Fig.7(b), the same signal is sampled at intervals of 6 milliseconds. If we denote the sampling interval by T_s, then the sampling frequency is defined as:

$$F_s = \frac{1}{T_s}$$

in units of Hertz (Hz). For instance, in Figure 1 (a), the sampling frequency is $F_s = 1000$ Hz or 1Khz.

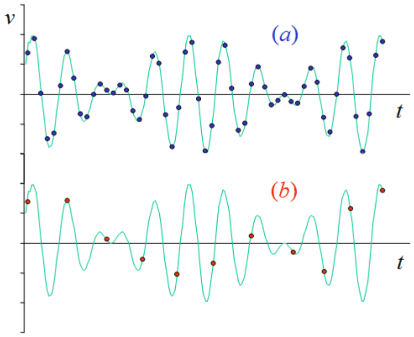

FIGURE 7. Sampling at (a) high and (b) low rates.

Synthesis and Analysis Operations

Task 1: Generating a pure tone 20Hz signal of duration 1 minute with a sampling rate of 250Hz. In MATLAB® work-space, generate a vector of sampling times denoted by t:
>> t = (0:60*250)/250; %Then, define the signal x as:
>> x = sin(2*pi*20*t); % Now, plot the first 250 samples of x. You will see the following plot.

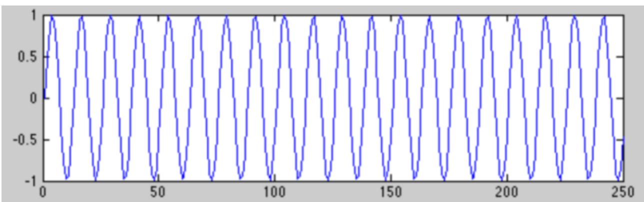

FIGURE 8. Time-domain plot of x (first 250 samples, i.e., 1 sec)

Question: How many periods of the sinusoidal wave do you see in the plot? Is this consistent with the frequency of the tone?

This simple operation is known as **Synthesis**, when you realize a time-domain sample of a signal with prescribed spectral properties (e.g., 20Hz pure tone). Now, we will see how the **Analysis** can be done.

Task 2: Viewing a signal in the spectral domain. Using the pmtm function as follows, plot the Power Spectral Density (PSD) of x:
>> pmtm(x, 5, [], 250); %You will see the following plot:

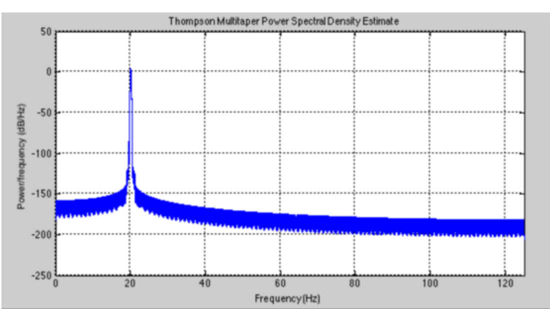

FIGURE 9. Power spectral density (PSD) of x(t).

The PSD of a signal shows how much power the signal has for any given frequency in the dB scale. The first argument of pmtm is the data vector, the second is the Time-Bandwidth Product which we will keep equal to 5 in this lab, the third argument is the epoch number which we will keep as null [], and the fourth argument is the sampling rate.

Question: What is the value of the PSD at 60Hz? How many times is it smaller than the value of the PSD at 20Hz?

Task 3: Viewing a signal in the spectro-temporal domain. Using the mtspecgram function as follows, plot the spectrogram of the signal x:
>> mtspecgram(x, 250, 40, 4);
You will see the following plot: [

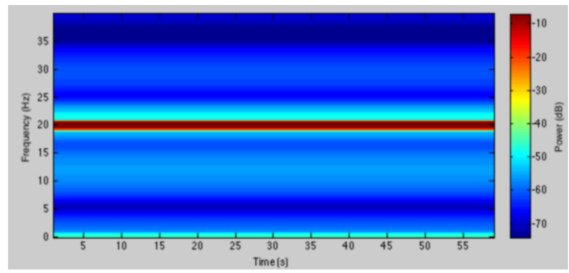

FIGURE 10. Spectrogram of x(t).

The spectrogram shows the power of the signal at time t, and frequency f, in the dB scale. The first argument is the data, the second argument is the sampling rate, the third argument is the maximum frequency to display, and the last argument is the time resolution in seconds.

Throughout this lab, you will frequently use the **Analysis** commands pmtm and mtspecgram to analyze signals in spectral and spectro-temporal domains, respectively.

Before moving on to learning how to synthesize and analyze EEG signals, we will first focus on acoustic signals. [continues]

COST OF OPERATION

Setting aside the development, the cost for the equipment is fairly reasonable and well within the means of typical ECE departments. Software licensing is required for Matlab™ and Circuitlab™. Hardware instrumentation are needed for the optics, renewable energy, brain waves and Android/Microcontroller modules. These run about \$450, \$500, \$500 and \$250 respectively. Other requirements are standard equipment in any circuit laboratory such as a PC scope, function generator and breadboards. The lab assistants or undergraduate teaching fellows (UTF) are required to spend about 7 hours per week, which includes meetings and office hours. Each UTF can comfortably handle a section with 12 students. The instructor spends about 10 hours per week to instruct the UTF's, review the material, give talks coordinate guest speakers, assess student performance and hold office hours. Finally, a lab technician whose primary roles are to ensure that the equipment are fully functioning, and to be available during lab hours to assist the TAs, spends approximately 4 hours per week.

SUMMARY AND OUTLOOK

In the course of 14 weeks, ENEE 101 introduces first-year students to a wide and intensive range of topics. To accomplish this, much of the complexity was purposefully hidden from the students. For example, instead of requiring students to write software codes from scratch, prewritten software libraries are provided which they can modify. Similarly, the teaching materials do not assume prior knowledge and experience, which is important as students come from diverse backgrounds. With regards to hardware, the circuit boards and experiments are either commercially procured or homemade,and all have undergone extensive reliability and performance tests to ensure their trustworthiness.

The students are presented with a bird's eye view of the ECE curriculum and the context upon which their upper division technical courses are built. In addition to technical material, students also learn some important soft skills such as teamwork, writing reports, and, perhaps most important, the ability to learn on their own. The writing component is assessed from their completed worksheets. They are given immediate feedback on how their writing can be improved in technical content, prose and style. This course also benefits the senior students, i.e, UTFs (undergraduate teaching fellows), who are hired as peer instructors to run the day-to-day lab operations, perform the lab activities a week prior to their delivery, and offer revisions to the material to make them even more accessible to the students. Their duties reinforce their knowledge of key ECE concepts, as well as develop their communication, leadership and administrative skills.

Our method differs significantly from traditional Introduction to ECE, where the emphasis is depth. Students are asked to join a topical group among a number of subject foci, depending upon their current interest and space. Students are then immersed in the arcane elements of a given topic. Consequently, students intensively learn a given topic yet remain relatively uninformed in other areas. The fact the students are asked to choose an area early on the process presumes that they are knowledgeable enough to make the decisions in the first place. We recognize that most of our 18-year-old students are not informed enough to decide which areas interest them. Hence we created the course with the purpose of exposing them to a wide variety of topics, to allow them to make better decisions about their career plans.

This course was piloted in Fall 2015, and as of this writing, retention data is still unavailable. However, the interest of students who took the course is very promising. Excerpts from student comments are as follows.

- "This was one of my favorite classes so far. I was able to learn a lot and practice what was taught. I was also able to hear from people working in the field and figured out what electrical engineers really do outside of college".

- "I really liked the modules-based class, the lectures, and the fact that work was mainly restrained to in-class time".

- "I am very thankful that the ECE Department decided to add this course to our requirements. It helped put my major courses into perspective".

- "Another very big reason that this class was great is because I had an awesome TA. She knew all of the content really well, and it is was nice to know that whenever we had a question about any of the course matter, we could ask her, and she would explain very clearly and concisely".

- "The course pushed my boundaries of understanding of what is possible with Electrical and Computer Engineering. The guest lectures once a week were a thrill to watch because there were so many talented professors brought in who could share their experience and research with us in an involved and open-to-questions atmosphere. I highly enjoyed this class and only wish I could retake it".

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