Combining Flipped Classroom and Integrating Entrepreneurially Minded Learning in DC Circuit Analysis and Design Course

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Introduction

To accommodate the diverse student population of adult-learners, the College of Engineering (CoE) at Colorado Technical University (CTU) offer both evening and daytime classes, the majority of students in CoE work full-time in civilian or military sectors, or are military veterans. The CoE successfully implemented an eleven-week program curriculum, designed for these non-traditional students who are dealing with many distractions. The active-learning approach and flipped-classroom better engages these students and also targets higher-levels of thinking [1]. The flipped-classroom helps students determining knowledge, stimulates curiosity, and fosters engagement. Applying the flipped-classroom in different course sequences also provides the first step in converting the face-to-face to online course delivery. The flipped classroom method has been applied by the COE to the online delivery of the freshman Introduction to Engineering (EE110) course [1].

Engineers solve challenging, complex real-world applications. In recent years, universities are engaged in incorporating Entrepreneurial-Minded Learning (EML) into the engineering curriculum. "EML is not about start-ups, it is about thinking creatively and creating value for society" [2]. Since it is not easy to effectively build entrepreneurial skills within a single course, the university's College of Engineering (CoE) decided to embed these throughout the programs. In this way, students are introduced to an entrepreneurial mindset early and integrate these skills into the students' problem solving in later courses. The sophomore-level course (EE221) in DC Circuit Analysis is the first circuit-analyses course in the Electrical and Computer Engineering Programs. The CoE has embedded EML in this course, using the flipped classroom, to support the development of an entrepreneurial mindset.

EE221 is a calculus-based circuit-analysis course developing proficiency with complex combinations of series and parallel circuits by applying of Ohm's Law, Kirchhoff's Voltage Law (KVL), Kirchhoff's Current Laws (KCL) and network theorems. Practical circuits are designed using industry-relevant simulation tools, then constructed, analyzed and verified in a laboratory. The EE221 course is the basic fundamentals course that serves as a foundation for all follow-on courses of the CoE students.

The EE221 course includes both lecture and lab components, and requires an abundance of practice and constructive feedback in order to fully understand the concepts. Some challenges were encountered during integration of EML, and preparation for online delivery. With the limited face-to-face time, it is challenging for instructors to both explain fundamentals and provide sufficient exercises to help students develop problem-solving skills. As an introductory course, inclusion of multiple real-world applications is necessary for students to understand the applications of fundamentals. Alternative teaching pedagogies become urgent and important.

This paper reviews the experiences and preliminary results of combining the flipped-classroom techniques and embedding EML in the EE221 course. Traditional lectures have been replaced by flipped-classroom practices, and labs have been modified to integrate EML fundamentals. The preliminary results from courses survey and grades show positive feedback.

Literature Review of Flipped-classroom and EML in Engineering Education

- **Flipped-classroom**

In traditional education, instructors provide lectures in classes, and students play a passive role and are responsible for listening and note-taking [3]. To maximize their understanding [3] research suggests that students need to engage actively with the course material. Kerr [4] reviewed 24 studies about using the flipped-classroom model in undergraduate engineering education. Most of her studies reported high satisfaction and increased performance in a flipped-classroom environment. The flipped-classroom changed the teaching strategies from instructor-centered instruction to student-centered where students are more engaged in their own learning. Just like every kid is different, every student learns differently. Students can adjust their investment in self-paced learning with the flipped-classroom, but must submit assignments on time. If not, they will not fully benefit from the in-class discussion, which provide opportunities for students to correct and cement what they have learned. This method may transforms students from passive-learners to active-learners, thereby augmenting student engagement.

The flipped-classroom is a pedagogical approach which moves the traditional in-class lectures out of the classroom, as preparation, and converts homework and out-of-class learning into in-class activities. The study from the Department of Electrical and Computer Engineering at the University of Florida showed that this flipped format notably improved student performance and retention in introductory circuit analysis courses [5] . Engineering students need to first accept basic engineering concepts before doing “homework”. Instructors can assign pre-recorded lecture videos to students, and require them watch videos before they come to classes which leaves more time for interactive in-class learning activities [6].

Western Carolina University applied “Flipped-classroom Pedagogy” to their Power Electronics course. Active student engagement is facilitated through on-line pre-recorded lectures. A short online quiz through a virtual learning environment (Blackboard) before each course module and a short quiz at the start of class session after each module were used to improve student participation. Their survey results showed the students were “motivated and greatly benefited” from this approach [7]. The flipped-classroom model also helps students develop necessary skills for life-long learning [8] while improving critical thinking abilities and teamwork skills [9].

To gain the benefits of flipped-classroom, active learning activities are needed, such as small group discussions, student presentations, self and peer evaluations [10]. Dr. Furse and Dr. Ziegenfuss described a faculty development program “Teach-Flip MOOC (teach-flip.utah.edu)” to help faculty implement the flipped-classroom techniques. Three modules were created: "(1) Backwards Design Applied to the Flipped-class; (2) Creating Online Materials (video lectures); and (3) Active Learning Strategies for the Face-To-Face classroom" [11].

- **Entrepreneurial Minded Learning in Engineering Education**

Engineers solve complex, challenging real-world problems. Preparing engineers to accept challenges and solve complex practical application issues are the most important contributions that colleges and universities can make [12].

Previously, entrepreneurship education has only been found in business schools. In recent years, with the rapid world changes and globalization of engineering area, more higher-education institutions worldwide are engaged in incorporating entrepreneurial minded learning (EML) into engineering curriculums. Having an entrepreneurial mindset helps students become innovative and effective engineers. "Engineers with an entrepreneurial mindset transform the world [13]." Engineers equipped with an entrepreneurial mindset will understand the bigger picture, recognize additional opportunities, be sensitive to markets, and better learn from mistakes to create value for themselves, employers and society [13].

Institutions have implemented a variety of methods and techniques to implement EML. The University of Detroit Mercy developed technical entrepreneurship case studies to integrate EML into existing engineering fundamentals courses [14]. Some universities have developed an Entrepreneurship Center. For example, MIT has several departments, labs, centers, and over 40 student clubs and initiatives to foster entrepreneurship and innovation. Educational efforts in this area have an impressive impact at local, regional, and global levels [15]. Stanford's School of Engineering has an Entrepreneurship Center. The Stanford Technology Ventures Program (STVP) attempts to accelerate entrepreneurship education at their university, and around the world [16]. Santa Clara University has an aggressive extracurricular program that complements elements of the EML program. Each quarter, they host activities including seminars, lunches with entrepreneur events, business and law-primer presentations. One highlight of the program is an EML challenge in which teams of students develop ideas in order to validate markets and assess the creation of value. The winner is often offered a "contract" to produce a product for university purposes [17] . Ohio Northern University extended the 3Cs ("Curiosity, Connections, and Creating Value" [18]) to "6Cs: curiosity, connections, creating value, collaboration, communication and character", then further broke these into multi-actionable student outcomes, to enable more intentional scaffolding of the entrepreneurial mindset [19]. In their Electric Circuits course, Question Formulation Technique (QFT) and Entrepreneurially Minded Circuit Design-Build-Test with Value Proposition method are used to implement EML [19]. The authors of the paper "Entrepreneurial Mindset and the University Curriculum [20]" applied technology-based and a dynamic live case-study with color graphics animated computer simulation in their entrepreneurial course. The live case-study involves multiple student visits to companies. Students construct a company supply-chain under the professor's guidance. Bilen, et al, suggested providing students with multiple exposures to an entrepreneurial mindset [21]. Chasaki described a seven-week mini-project "Cyber Crime Scene Investigation", and they reserved in a new course for EML activity [22]. The author found that the freshman year is a great time to introduce EML concepts. The University of Florida College Of Engineering offers an entrepreneurship course which mimics the real-world experiences of enterprise formation and growth in an academic environment [23]. Tabrizi [24] fostered an entrepreneurial mindset in “digital systems” class through a jigsaw-puzzle model.

Several universities developed detailed four-year plans to implement EML in curriculums. Lawrence Technological University merges a technical skills curriculum with EML. Engineering students will advance through the “Interdisciplinary Design & Entrepreneurial Applications Sequence (IDEAS)”, a four-year entrepreneurial engineering curriculum [25]. Welker, et al, [2]summarized the classes with EML in the four-year Civil Engineering Curriculum at Villanova University. University of New Haven created short, self-paced, e-learning modules for courses spanning all four years of all engineering and computer science programs. They used a flipped-classroom instructional model to integrate the modules into courses [26].

Combining Flipped-classroom and EML in EE221 DC Circuit Analysis and Design

Combining Flipped-classroom and EML in EE221, DC Circuit Analysis and Design, were tested in classes of winter 2018 and summer 2018. Both classes were daytime class with very small class size. Winter 2018 class had 3 students, and summer 2018 class has 2. Both sections were taught by the same instructor, one of the authors.

- **Flipped-classroom in EE221**

Circuit Analysis I (EE221) is the first course in a series of circuit analysis courses. Per accreditation requirements, it is a calculus-based course that covers the fundamental laws of DC circuit analysis and evaluation via the application of Ohm’s and Kirchhoff’s laws. Circuit simulation tools and laboratory exercises are implemented in this course to further cement the essential concepts. The EE221 Course Objectives are to:

- Analyze resistive circuits using fundamental circuit analysis techniques: Ohm’s Law, Kirchoff’s laws, Thevenin’s and Norton’s laws.
- Apply the fundamental circuit analysis techniques to determine the characteristics of basic functional op-amp models.
- Apply the circuit analysis techniques to design simple functional circuits composed of resisters and op-amps.
- Construct simple circuits on a breadboard and use basic laboratory equipment (digital multi-meters, power supplies, and function generators) to analyze a circuit and/or to test a circuit design.
- Document laboratory work in a professional manner.

The course is a first calculus-based circuit analysis course in the CoE’s Electrical and Computer Engineering Programs, and students typically find it quite challenging. While some students have previous experience as with electricity, there is a noteworthy difference using a check-list, and creating the checklist of the components, test equipment, and laws. Students need a lot of practice to improve analysis and design skills. How to effectively help students improve technical skills is the ongoing question.

The flipped-classroom changed the teaching strategies from instructor-centered instruction to one that is student-centered where students are responsible for their own learning. In traditional classroom settings, an instructor presents a lecture, explains the concepts and theorems, and provides examples. Then students complete related homework and exercises outside of the classroom. Most of CTU's students are working adults, which means that students attend classes at night after working during the day. They also wish to minimize the number of trips to the university. Lecture during class period (2-3 hours) causes students to disengage during the late evening class. It was found that short (5 to 15 minutes) discussions followed short exercises completed by the students, achieve better learning. This face-to-face active learning mode is similar to the "the flipped-classroom". For example, the steps for the face-to-face lecture class at CoE are listed in Table 1.

Table 1: Steps of course construction in face-to-face traditional classroom at CoE [27]

Step 1	Instructor introduces or presents a theorem, provide and solving an engineering example for 5 to 10 minutes,
Step 2	Assign an engineering problem to students, and provides them some time (usually 10 to 15 minutes) to think and solve the problem.
Step 3	Instructor and students work together to discuss and solve the problem.
Step 4	Go back to Step 1; repeat this process for the next theorem in class.

Feedback from students and evaluation of past performance of learning outcomes showed that this approach effectively improved engagement**.**

The faculty in the CoE started applied the flipped-classroom approach in EE221 in winter quarter of 2018. The class size was very small, three students in that class. All the courses at CTU are quarter based. EE221 is an 11 weeks long course. Based on the experience from the tradition face-to-face class, 5 to 10 minutes videos are considered appropriate for the flipped-classroom. The steps of the flipped-classroom method are listed in Table 2.

Table 2: Steps of course construction in flipped-classroom at CoE

Step 1	Students review recorded videos, each video is about 5 to 10 minutes long.
Step 2	Tools such as Google Forms combine videos and quizzes questions. Each short video is followed by several relevant question. The format of the questions could be true or false, multiple choice, or short answers. One quiz is provided each week to encourage participation.
Step 3	Students are required to watch videos and finish quizzes at home before the class start.
Step 4	Instructors do not repeat the lecture, but use the class time to answer questions, and help students solve problems.
Step 5	Go back to Step 1; repeat this process for the next engineering theorem in class.

At the beginning of the quarter, the EE221 instructor explained the flipped-classroom methodology and advantages to allow students to grasp their role and responsibility in the process. Instructor required students to finish the videos with embedded quizzes prior to attending class. This way, instructors have more class time to demonstrate examples, and students are better able to practice applications, discuss in groups, and ask questions in the classroom. Since EE221 is a “hard” course for some students, more practice in understanding the concepts and learning problem analysis, solving and design skills is paramount.

An example of a Google forms quizzes question is shown in figure 1.

Each quiz has several short (5 to 10 minutes) embedded videos; and each video is followed by several true or false, multiple choice or short answer questions. Students are permitted to submit answers more than once. The objective is to help students concentrate on the contents of the videos. Students are encouraged to ask about any confusion in class.

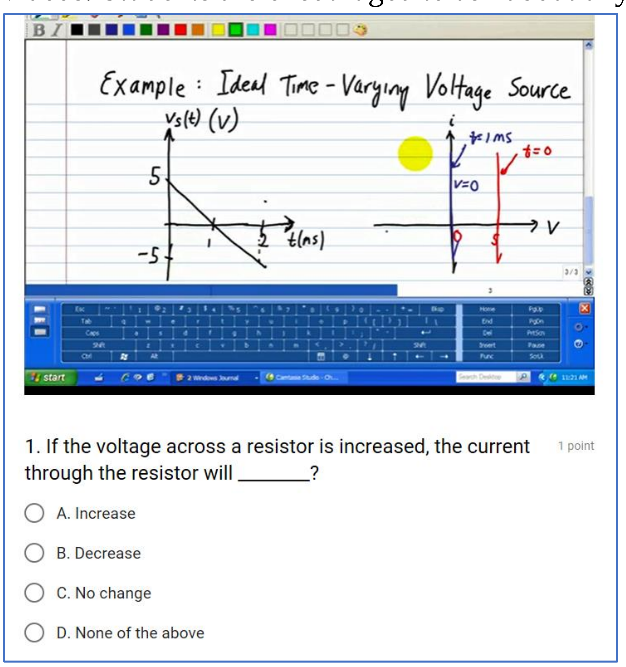


Figure 1: Example: Google Forms quizzes including videos and quiz questions

- **Integrating Entrepreneurial Minded Learning in Circuit Analysis and Design Course**

The challenge of integrating EML in engineering curriculum is adding the EML activities without additional workload to the currently packed curriculum. Instead of developing separate courses in entrepreneurship, CoE plans to integrate EML into numerous engineering courses. Each course will have EML elements to help students grow with KEEN's "the three Cs" (Curiosity, Connections, Creating Value) [13]. Incorporating EML in different course sequences such as analog and digital circuits, electronic design, and communication sequences will provide students an opportunity to develop an entrepreneurial mindset. EML has already been integrated into Electronics Design I (EE375), Analog Communications (EE443), and Digital Communications (EE463) courses. EE221 is the first course of Circuits Analysis and Design series. Introducing the EML in the earlier stage of engineering education curriculum will help students absorb the entrepreneurial mindsets.

EE221 includes basic DC circuit components and laws. The laboratory experiments include KEEN's 3Cs to develop the entrepreneurial mindset [28]. Entrepreneurial elements were added to the labs to help students focus attention on investigating the market and assessing policy and regulatory issues.

There are originally four labs come with EE221:
Lab 1: KVL and Ohm's Law
Lab 2: Node Voltage Analysis
Lab 3: The OpAmp Circuit
Lab 4: OpAmp Design

EML is introduced in Lab 3 and Lab 4. A comparison of original and modified lab 3 and lab 4 are shown in table 3 and table 4.

Table 3: Original and EML lab 3s' comparisons

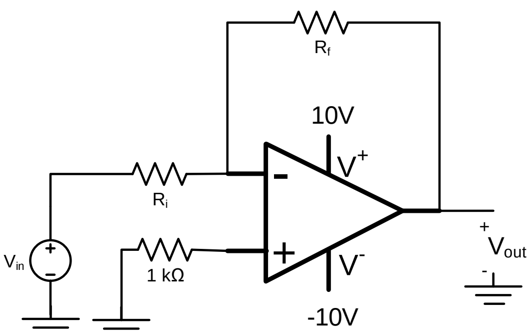
Original Lab 3 OpAmp Circuit	Modified Lab 3 How to Connect a microphone to a Speaker?
Objectives: The objective of this lab is to verify Ohm's Law and Kirchhoff's Voltage Law (KVL) on a simple series circuit. The student will also compare the ideal electrical behavior to the actual behavior of linear and non-linear elements.	**Add on EML Objectives**: Demonstrate constant curiosity about our changing world. Integrate information from many sources to gain insight. Identify unexpected opportunities to create extraordinary value. Persist through and learn from failure.
Problem Statement: For the circuit shown below, choose R_f and R_i from the set of standard resistor values so that $V_{out} = -2.5 V_{in}$. 	**Problem Statement**: Our lab has a microphone with 1.7 Volts DC output. We also have an audio speaker which needs 4V to drive. Do we need to design an amplifier to connect the microphone and the speaker? If needed, propose two designs, compare the two designs, and select the best one. Based on our lab's limited budget, we prefer low cost. Hand calculation, simulation, and prototype designed are required. Please also provide a budget with price and "the venders" of all the components in your design.

Table 4: Original and EML lab 4s' comparisons

Original Lab 4 OpAmp Design	Modified Lab 4 Help Needed
Objectives: Design an OpAmp circuit to perform the transform.	**Add on EML Objectives**: Demonstrate constant curiosity about our changing world. Integrate information from many sources to gain insight. Identify unexpected opportunities to create extraordinary value. Persist through and learn from failure.
Problem Statement: As part of an instrument and data system, an incoming signal of -10V to +10V must be linearly transformed to 0V to 1.0V. Design an OpAmp circuit to perform the transform.	**Problem Statement**: Our customer Tom bought a temperature sensor "AD22100". He wants to use it in his home temperature control system. The controller's input needs to be between -5V to 5V. After read the datasheet of AD22100, he found the output of the temperature sensor does not match the input of the controller. He is asking our EE221 design team for help. He only has limited budget for the project.

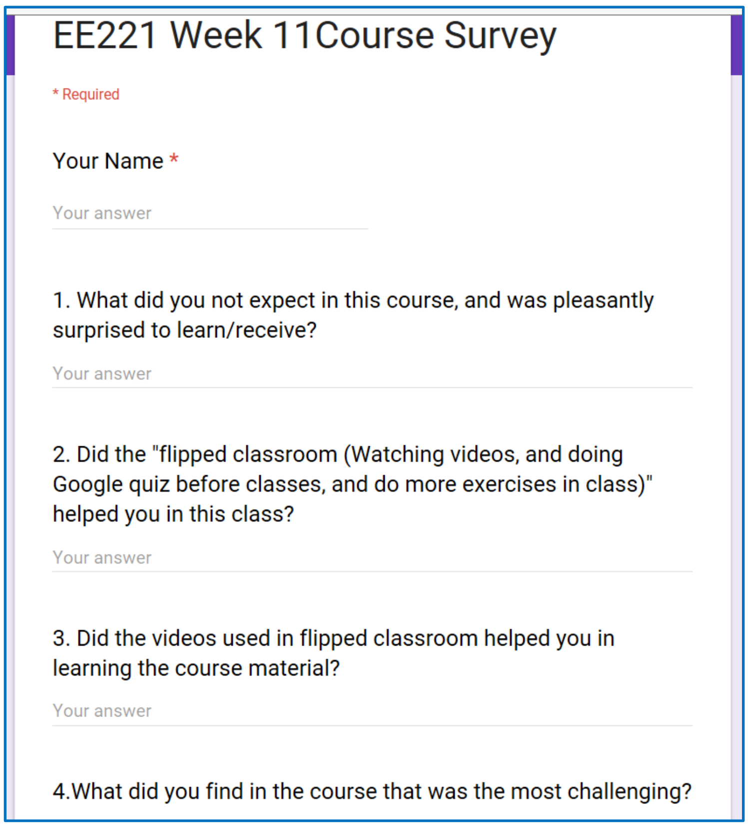
Lab 3 and Lab 4 were modified to include EML objectives. The EML objectives are directly from KEEN's educational outcomes [28] . The original labs directly tell students the design requirements. The modified labs only tell students the customers' need. Students have to do analysis and research, talk to the customer (instructor acts like customer in class), and find requirement specifications by themselves. After students proposed the design requirements, they will follow normal lab steps, such as hand calculation, P-Spice simulation and implement the prototype design on breadboards. Students are also required to provide budget for the design in the modified labs. The budget for Lab 3 provided by a student team in winter 2018 team is shown in Table 4 as an example.

Table 5: Lab 3 Design Budget (winter 2018 term)

Part Name	Quantity	Price	Manufacturer	Notes	Total cost
uA741 OP AMP	1	$7.50	Texas Instruments	It comes as a package of 6 pieces	
27k ohm	1	$5.89	Parts Express	10 items	
20k ohm	1	$5.12	Parts Express	10 items	
					$18.51

Students Course Survey Results

Students are required to finish the survey at the end of the courses. To minimize the instructor's workload when consolidating the data received from students, the authors used Google Forms. An example of evaluation form in Google form is shown in figure 2. And the survey results from winter and summer classes are show in Table 6.
From the Time Stamp it can be seen that the first three results are from winter 2018 class and the last two are from the summer 2018. From the survey answers of the students, the feedbacks were generally positive overall. Students appear to appreciate what has been learned from the course using the flipped format. For the "flipped-classroom", all students mentioned the method is helpful.



EE221 Week 11Course Survey

* Required

Your Name *

Your answer

1. What did you not expect in this course, and was pleasantly surprised to learn/receive?

Your answer

2. Did the "flipped classroom (Watching videos, and doing Google quiz before classes, and do more exercises in class)" helped you in this class?

Your answer

3. Did the videos used in flipped classroom helped you in learning the course material?

Your answer

4.What did you find in the course that was the most challenging?

Figure 2: EE221 End Course Survey Questions

Table 6: EE221 Survey Results from Winter 2018, and Summer 2018 Classes

Timestamp	1. What did you not expect in this course, and was pleasantly surprised to learn/receive?	2. Did the "flipped classroom (Watching videos, and doing Google quiz before classes, and do more exercises in class)" helped you in this class?	3. Did the videos used in flipped classroom helped you in learning the course material?	4.What did you find in the course that was the most challenging?
3/19/2018 12:33	It was better once I got used to the format but was a little rough starting out	It was helpful but The teacher explained things more easily for me in class	Somewhat	The source files
3/19/2018 12:40	i didn't expect the material to be so straight forward and was very pleasantly surprised by this.	the video's did help a lot in understanding to material but i think what we learned in class was just as valuable if not more so.	yes very much.	trying to remember the different formulas and keeping the signs right in the equations.
3/19/2018 12:44	I didn't expect I will learn a lot in this class but I was surprised with the knowledge that I gained out of this class.	Yes, it did. It helped me had a strong introduction and made me use the classroom for advanced classes.	They did, but sometimes they are too long to watch.	Actually the class was easy to me.
9/13/2018 12:01	I did not have any expectations coming into the class, I appreciate everything I learned.	Yes, this was very helpful	Yes, the videos are very informative and prepared me for lectures	Node voltage analysis
9/13/2018 12:02	I did not expect to learn about interface design and designing inside the "black box."	The flipped classroom helped me in this class.	The flipped classroom videos were helpful. However, sometimes they were very long and I had to skip parts of it to complete the quizzes.	It was hard to know when to try another method.

We also compared courses grades with and without flipped classroom and EML as shown in table 7. The three sections (winter 2017, winter 2018 and summer 2018) of EE221 were taught by the same instructor. The average class grades improved by applying flipped classroom and including EML in course. But the data sample size is two small, so we need to continue collect data in future EE221 classes.

Table 7: Grades comparison of EE221 with/without Flipped Classroom and EML

	Without Flipped-classroom and EML	With Flipped-classroom and EML	
	Winter 2017	Winter 2018	Summer 2018
Number of Students in Class	10	3	2
Average Course Grade (100)	81.48	88.17	94.55

Conclusion and Future Work.

There were only 5 students in winter and summer 2018 EE221 courses. With such small data size, firmed conclusion cannot be drawn. These preliminary results show that the flipped-classroom method helped students in EE221 understand the course material.

The course survey results show positive feedback of flipped-classroom method in EE221. Lab 3 and Lab 4 were edited to involve "customer need" in the statements. With the relatively "blur" statements, students have to do more research and may need to talk to the "customer" to figure out the system-level design requirements. This approach provided students a chance to "integrate information from many sources to gain insight [28]"; and "identify unexpected opportunities to create extraordinary value [28]".

In the future offerings of the EE221 course, EML objectives need to be assessed at the end of the course. The assessment will concentrate on the EML objectives listed in the modified labs. Only two of the four labs were transformed in EE221 to include EML components, but this is just a starting point for students. After the circuit analysis and design series, engineering students will take advanced courses with EML elements in them.

The lessons learned within CoE's Electrical Engineering and Computer Engineering program curriculum include: (1) Appling flipped-classroom method to engineering curriculum in order to prepare the potential online teaching in the future; (2) Embedding EML in different engineering courses throughout the curriculum to improve students' EML skills.

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