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WIP: A course-based undergraduate research experience (CURE) in a microelectronics laboratory course

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WIP: A Course-Based Undergraduate Research Experience in an Audio Engineering Laboratory

Introduction

This work-in-progress innovation-to-practice paper describes the pilot implementation of a course-based undergraduate research experience (CURE) in an electrical and computer engineering (ECE) course at a large, research-intensive public university in the southeast United States. A wealth of literature supports the value of CUREs in promoting persistence in STEM fields and improving undergraduate academic performance. Nevertheless, few CUREs have been studied within ECE contexts. Although both science and engineering curricula commonly include hands-on laboratory experiences, these disciplines often frame inquiry differently, which may shape students' beliefs about what it means to "do" research. To expand hands-on research opportunities for ECE undergraduates, we designed and implemented a CURE within an upper-level elective audio engineering laboratory course in Fall 2024 and Fall 2025. We also analyzed student survey data to examine whether students perceived this CURE unit as a research activity, despite it not being explicitly framed as such.

Background

In science and engineering, traditional laboratory courses offer students an opportunity to apply theoretical knowledge using tools of the discipline. In Course-Based Undergraduate Research Experiences (CUREs), "students address a research question or problem that is of interest to the broader community with an outcome that is unknown both to the students and to the instructor" [1]. Compared to traditional laboratory courses, CUREs emphasize scientific practices, discovery, relevance, collaboration, and iteration [2].

The Council for Undergraduate Research defines undergraduate research as "an inquiry or investigation conducted by an undergraduate student that makes an original intellectual or creative contribution to the discipline." Such experiments can strengthen students' disciplinary knowledge and professional identity by demonstrating content application in innovative contexts. Although undergraduate students often engage in research through faculty-led lab groups, the CUREs model integrates valuable research experiences into curricular environments, making them more accessible to students.

A wealth of literature corroborates the value of CUREs in supporting persistence in STEM and improving undergraduate student academic performance. Evidence supports the idea that CURE exposure can increase student motivation and self-efficacy [3,4] and the acquisition of content knowledge [5]. A systematic literature review by Buchanan and Fisher examined 20 years (2000-2020) of CUREs [6]. They noted that while CUREs have been tested in life science majors, few CUREs have been studied in engineering contexts. Implementing CUREs in ECE raises an important question: when inquiry takes forms common to engineering practice (e.g., troubleshooting, reverse engineering, and system analysis), do students recognize this work as research? Addressing this question helps clarify how CUREs function in engineering contexts.

Further describing CUREs and aligning this exposure with student and instructor needs and outcomes, Brownell and Kloser [7] outlined a "taxonomy" of CUREs that varies in the degree of student independence. Whereas traditional "cookbook" lab experiments are classified as "confirmation" inquiry, CUREs can span "structured", "guided", "open", and "authentic," with increasing student independence at each level. This work describes the implementation of a guided inquiry as defined by Brownell and Kloser [7].

We adapted an existing Device Under Test (DUT) experiment to introduce students to undergraduate research through a CURE-like framework. In this experiment, the behavior of a circuit is interrogated to assess its function and limitations. We designed the experiment such that a) neither students nor instructor knew which DUT structure each student team received (discovery), b) the students developed their hypotheses about the DUT structure (use of scientific practices), and c) the students followed a test and re-test cycle (iteration).

The purpose of this paper is to describe the pilot implementation and early assessment results. We describe the experimental setup in detail, and assess the extent to which students classified the experiment (which was not explicitly framed as research) in relation to their more general understanding of research activities. Through these efforts, we develop a viable example of a CURE in an ECE context and offer evidence for the potential value of making explicit the connections between scientific and engineering practices.

CURE Implementation

Overview

The CURE was a two-week module in an intermediate-level ECE lab course focused on audio engineering applications. It was piloted in Fall 2024 with seven students and scaled to 14 enrolled students in Fall 2025. For this CURE implementation, a standard lab from the course was adapted to incorporate guided inquiry. Over two 3-hour lab sessions, students worked in pairs to analyze the internal circuit components of a two-terminal black box using fundamental electrical engineering concepts, including frequency response, transfer functions, and simulation. The course instructor did not disclose details about the DUT before the experiment; instead, they guided students through a methodical process of characterizing the unknown device. Students performing this experiment are typically electrical engineering students familiar with passive circuit elements, impedance, and frequency analysis, as well as standard electrical engineering test equipment.

The instructor designed each lab session to be inquiry-driven and reinforced a systematic approach. Building on their prior knowledge of circuit elements, testing methods, and equipment, students were guided in understanding and modeling the impedances of passive electrical components (capacitors, inductors, and resistors). A key learning outcome of each session was for students to explore how circuit topologies affected the impedance presented at the port of an unknown DUT. Analysis of the magnitude of the impedance versus frequency plot was used as a graphical technique to enhance understanding and accelerate the model identification process.

Week One

During the first week of the experiment, the instructor led a 15-minute warm-up discussion to review the impedance equations for resistors, capacitors, and inductors. During this discussion, key concepts were introduced, and the instructor asked guiding questions to orient students. Collaboratively, the students helped determine the conclusions. Next, the instructor introduced a log-log plot of impedance magnitude versus frequency and discussed it to build their

Figure 1: Photograph of representative DUT black boxes.

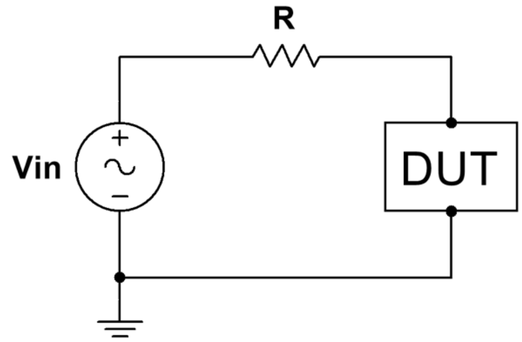

Figure 2: Device Under Test (DUT) testing schematic. Students utilize a function generator and oscilloscope to collect voltage data over a suggested 100 Hz to 10 kHz frequency range. R is 510 ohms.

understanding of the experiment further. Students outlined the impedance equation for each passive component to scaffold the approach and described the appearance of the frequency response plot. For example, the impedance of an inductor was found to follow a straight line with a slope of 1 decade per decade.

Students were provided with two unknown DUTs throughout the experiment (Figure 1). For the first week, the DUTs consist of a single capacitor and a single inductor, whose components are obscured by the selective use of hot glue, shrink wrap, and rigid tubing. These simple structures allowed students to focus on collecting high-quality data and learning to use the discussed graphical techniques to build models of the DUTs. The students constructed a two-element voltage divider circuit using the DUT as one of the elements, as shown in Figure 2. Students used a function generator and an oscilloscope to collect voltage data over a suggested frequency range of 100 Hz to 10 kHz. A suggested value for R is given (510 ohms). The component values of the capacitor and inductor were selected to provide reasonable results under these test conditions.

As voltage data were collected at each frequency, the DUT's impedance was calculated, and its magnitude was plotted on log-log scales, typically using a combination of Microsoft Excel and MATLAB. By observing this plot, students identified points that should be remeasured and decided whether to adjust the input amplitude, the frequency range, or the value of R to collect good data. Other factors that could be encountered and adjusted for include unmodeled component parasitics (such as an inductor's resistance at low frequencies) and noise in the measured data at low amplitudes.

From the appearance of this plot, the students determined the identity of the unknown component. For example, the DUT was likely an inductor if the points generally follow a 1-decade per decade slope. The students must then model the DUT by determining an impedance-versus-frequency equation. This entailed determining the inductance L of the DUT inductor, $L = j\omega L$. The magnitude of this model equation was plotted over the measured data, and the parameter value was adjusted to achieve a good fit. An impedance meter could then be used to validate further that the experimentally determined capacitance or inductance value is correct and to reinforce students' confidence in the techniques used. To prepare for the second week, students used the derived models to predict the resonant impedances of the series and parallel combinations of the two DUTs.

Week Two

In week two, as in week one, the DUT experiment began with a short, interactive discussion on how individual component impedances in more complex circuit topologies affect impedance-versus-frequency plots. Students considered plots of two elements in series or parallel and plots of three or more elements in various topologies. For example, students sketched out a characteristic plot of a resistor in series with the parallel combination of a resistor and a capacitor. Several examples were discussed, and then students were again provided with two unknown DUTs. One DUT typically consisted of two or three resistors and a single reactive element, arranged in various topologies, while the second consisted of a resonant LC combination and resistors.

Students again formed the voltage divider test setup. Still, rather than manually measuring voltage data and calculating impedance as in week one, a frequency response analyzer (Ridley Engineering Model 200/300, Camarillo, CA, USA) automatically collected complex impedance data over frequency. This allowed students to focus on modeling by extending their observations from week one to more complex impedance structures. In discussions with their lab partners, students analyzed the impedance plots to determine a potential circuit topology and component values. Students then formed a model and its impedance plot using equations, circuit simulation software, or both to verify that their proposed model represents the measured data. Students iteratively adjusted the model topology and component values until agreement was achieved.

As a final verification of their proposed DUT models, the students constructed a physical circuit of their model. They repeated the impedance-versus-frequency measurement on this circuit, overlaid the results on the measured DUT impedance, and checked for agreement. In completing the lab, students recognized that additional considerations are often needed when comparing modeled behavior to actual behavior. These included how different topologies may have similar graphical forms, variations in component values, component parasitics, etc. The discrepancies caused by these factors often necessitated additional investigation during the modeling process.

Week 3: Deliverables and Grading

At the beginning of the third week, students submitted a lab report that explained the methods used to characterize the unknown impedances and presented their final models. The lab report was assessed comprehensively: students received full points if they coherently described the steps taken to move from measurements to a model. Sufficient information must be present to indicate an understanding of a methodical process. Points were subtracted for lack of clarity, poor agreement between modeled and measured impedances, missing parts, and missing details.

Assessment - Student Survey Results

We explored how students experienced the CURE using a brief Qualtrics survey that was administered to all students one week after the lab report was submitted. Out of the 21 students, we received eight valid survey responses, representing a response rate of 38%. Student characteristics are outlined in Table 1. All study procedures were reviewed and approved by the university's Institutional Review Board (IRB) prior to data collection. Survey completion was not incentivized.

Table 1: Student Characteristics

Year in ECE program		Gender identity	
2nd	1	Female	3
4th	5	Male	4
5th	2	Non-binary	1

Five Likert response questions explored the students' sentiments and perceived value of the CURE exercise (Table 2). All students either strongly agreed or agreed that the project improved their understanding of modeling unknown passive circuits. Most students (7 out of 8) strongly agreed or agreed with the following: (a) that the project was interesting, (b) that they liked the open-ended nature of this project more than a typical lab assignment, (c) that they valued the instructor's feedback on the in-lab activities, and (d) that this investigative and open-ended assignment should be included in other ECE courses. For these four items, one student each time indicated "neither agree nor disagree;" it was not the same student in each item.

Two open-ended questions contextualized the Likert items by asking students to identify the aspects of the experience that they liked or found challenging. Example responses include:

> *"The DUT project was enjoyable in the sense that we were given complete control of how to go forward. The professor was there to give guidance when needed, but for the most part we were given complete control on how to go about things."*

> *"I liked how it made me visualize RLC components in a different way and forced me to use my knowledge of how they operate to create/model something."*

> *"It was challenging to find the right values for the components because there was measuring errors as well as limitations on that."*

As mentioned previously, the CURE experiment was not presented to students as "research" explicitly. We asked two free-response questions of students: "How would you define undergraduate research?" and "Based on your definition, do you believe there were any research-like aspects to this experiment (DUT project)?" These questions allowed us to probe the extent to which the students made connections between the class activity and research on their own.

In their answers to the first question, students emphasized hypotheses, the use of different techniques to solve problems, and data gathering. Students also framed research as a longer-term activity (i.e., at least a semester) that was often mentored.

When asked about connections between the DUT lab and undergraduate research, many students mentioned that the main task of this experiment was to "reverse engineer" the device. Students were mixed about the extent to which reverse engineering "counted" as research. For example, one student said.

Table 2: Impressions of the DUT module.

	Strongly agree	Agree	Neither agree nor disagree
The project was interesting	5	2	1
The project improved my understanding of modeling unknown passive circuits	5	3	0
I liked the open-ended nature of this project more than a typical lab assignment	5	2	1
Feedback from the instructor helped my team move forward with our project	3	4	1
This type of investigative and open-ended assignment should be included in other ECE courses	6	1	1

Note: responses of count zero were not included in this table (i.e., Disagree or Strongly Disagree categories).

> *"Although similar, it mostly feels like reverse engineering more than anything else. Research often involves significant background reading, but given how this was done over two lab periods, I'd say it would be a reasonable comparison to undergraduate research."*

These data suggest that students are deriving value, but potentially operating with definitional differences between the DUT experiment and their view of undergraduate research.

Finally, the students were given the Council for Undergraduate Research's definition of research [8] as "an inquiry or investigation conducted by an undergraduate student that makes an original intellectual or creative contribution to the discipline." Guided by this definition, students were asked about their participation in undergraduate research (past, present, and future (Table 3). They were also asked to identify the type of research experience. Three students had already participated in undergraduate research, which isn't surprising given the upper-class standing of the students. Student_2 appears confident about graduate school and the connection with undergraduate research when answering this question. Student_1 did not find a positive prior research experience, and team disorganization from another research project contributed. Student_5 appeared unsure about pursuing research, and their response conveyed their high expectations for research contributions.

Table 3: Per Student Response for Undergraduate Research and Connection to the Lab Project

Student	Participation	Write-in Elaboration
Student_1	I have participated in undergraduate research in the past; I am not interested in participating in undergraduate research in the future.	I have participated in undergraduate research before, but did not enjoy my experience. I was a part of [undergraduate] program and felt it was disorganized and my team members did not care about the project. I do not intend on pursuing research in the future.
Student_2	I am currently participating in undergraduate research.	I am currently conducting research on acoustic metasurfaces for personal acoustic spaces. I am interested in grad school and wanted some exposure to how that may look like going forward.
Student_3	I am interested in participating in undergraduate research in the future.	[No response]
Student_4	I have participated in undergraduate research in the past.	[No response]
Student_5	I am unsure about participating in undergraduate research in the future.	I have not made any contributions to the discipline - mostly I have learned and applied concepts. I may be participating in undergraduate research for my senior design project. But I am not sure yet whether it will involve anything original.
Student_6	I have participated in undergraduate research in the past; I am interested in participating in undergraduate research in the future.	[No response]
Student_7	I have participated in undergraduate research in the past; I am currently participating in undergraduate research.	[No response]
Student_8	I am unsure about participating in undergraduate research in the future.	I am graduating after spring so I wouldn't be considered for undergraduate research after next semester.

Discussion

Overall, this was a successful pilot implementation of a CURE in an ECE context. The DUT experiment was “CURE-fied” based on an existing lab activity, meaning that similar learning objectives were achieved, while adding self-direction and discovery that are emblematic of a CURE activity. Similar to a classical lab exposure, the investigative process used in this experiment allows students to validate their circuit topology and behavior models. As the students iterate through ideas and models, they naturally extend fundamental engineering concepts and employ research techniques to arrive at a final model for these complex impedances. Students additionally gain confidence in their methods by verifying that their independently designed and constructed physical models behave like the DUTs. Moreover, despite the open-ended nature of the activities, the students reported being well-supported and guided by the instructor. It is worth noting that, compared with earlier non-CURE implementations of the DUT, the instructor observed no difference in performance. Thus, the CURE approach did not detract from the learning process.

Based on survey data and instructor discussions, students identified the DUT activity as an instance of a “reverse engineering” task but did not necessarily consider it to “count” as research. Many of the survey participants had prior undergraduate research experience, which suggests they may associate research with longer-term efforts within a lab structure guided by graduate students and postdocs, rather than the DUT activity, which spanned two weeks in an instructional context. Thus, students may not have made a connection between the DUT activity and undergraduate research. Additionally, engineering lab courses may not exhibit classical forms of scientific inquiry, such as hypothesis testing, even though hypotheses are implicit in troubleshooting and reverse engineering.

We observed some differences between the Fall 2024 and Fall 2025 offerings. Recall that the instructor scaffolded the students with verbal questions and asked them to visualize possible behaviors (e.g., frequency responses) of the DUTs. This enabled the instructor to gauge, in real time, gaps in their knowledge and potential misinterpretations of the exercise and tasks. As a result, the instructor accomplished direct guidance and intervention. Upon the second offering, a teaching assistant took on the instructor’s role. We found notable differences in how the material was contextualized and supported. The lead instructor, rather than the teaching assistant, intentionally underscored open-endedness to suggest a connection to undergraduate research. However, the teaching assistant was improving in their facilitation skills and focused more on keeping the students on task.

Another point for consideration in any offering is the tradeoff between adding course content to implement a CURE and the curriculum to be covered in a lab course. Ideally, a synergistic overlap between the CURE and existing lab content is attractive.

In summary, we offer the following observations and recommendations. First, an explicit connection between the DUT experiment and undergraduate research should be articulated. This will better contextualize the experiment and align the students’ work with what can be done in research. Second, we considered the duration of our CURE exposure and recognized that students view research as a longer-term. However, if the outcome piques student interest in undergraduate research or introduces them to a portion of the research method, then the shorter time period is perfectly appropriate. Moreover, a well-designed and well-supported "short duration" CURE may also help students boost their confidence in conducting research. Thus, the lab exercise lays a foundation for broader and more enduring undergraduate research activities and projects. Third, a main difference between ECE students vs. students in the sciences is the importance of articulating the hypothesis-driven aspects of the tasks. More specifically, ECE students are guided to debug, innovate, and discover. Hypotheses are implicit in their approach, but not directly articulated. Thus, it is recommended that the connection between debugging/troubleshooting and developing and testing hypotheses be made explicit.

For future work, the goal would be to integrate a CURE into our lower-level required microelectronics lab course. At this insertion point within a student’s course of study, we can explicitly define undergraduate research with a focused immersion within a larger course. By providing a window into the process of conducting undergraduate research and explicitly articulating how students have the necessary background, we hypothesize that such an implementation could reduce the 'barrier to entry' into undergraduate research, especially when integrated into the curriculum earlier. However, as with many institutions, enrollment pressures combined with curriculum requirements leave little room to integrate a CURE without a strategic, natural fit within the course material.

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