Students' Experience of an Integrated Electrical Engineering and Data Acquisition Course in an Undergraduate Mechanical Engineering Curriculum

Yen-Lin Han, Jennifer Turns, Kathleen E. Cook, Gregory S. Mason, and Teodora Rutar Shuman

Abstract*—*Contribution: **This article presents an innovative course sequence to integrate Electrical Engineering (EE) Fundamentals into the Mechanical Engineering (ME) Instrumentation and Data Acquisition (DAQ) course and reports students' experience relevant to the sequence's intended outcomes of helping students learn and connect EE concepts with ME applications and develop their engineering identities.**

Background: **The ME Department at Seattle University was awarded a National Science Foundation Grant to revolutionize its undergraduate program. This project focuses on doing engineering to foster stronger engineering identities. This course sequence is part of the curriculum change for this project and includes open-ended, real-world labs incorporating both EE and DAQ.**

Research Questions: **1)** ***Engineering Learning:*** **What evidence is there that students learned EE and DAQ concepts and integrated them with ME? 2)** ***Identity Development:*** **How did the students connect the experience to their evolving identity as engineers? 3)** ***Over-Time Experience:*** **How did students experience the course?**

Methodology: **A mix of quantitative and qualitative data was used: quantitative data (a standardized test) and qualitative data source (mini reflections that students provided over the course sequence) were analyzed to address the research questions that connect the educational design aspects and the intended outcomes.**

Findings: **The new course sequence created an opportunity to do engineering in a rich way and provided fertile ground for developing engineering identities. Students understood and retained EE and DAQ concepts at a level equal to when the material was taught via separate courses.**

***Index Terms*—Curriculum development, data acquisition (DAQ), engineering education, identities, laboratories, mechanical engineering (ME), reflection.**

Manuscript received 28 June 2021; revised 7 January 2022, 16 March 2022, and 29 April 2022; accepted 22 May 2022. Date of publication 14 June 2022; date of current version 15 August 2022. This work was supported by NSF IUSE/PFE: RED under Grant 1730354. *(Corresponding author: Yen-Lin Han.)*

The authors confirm that all human/animal subject research procedures and protocols are exempt from review board approval.

Yen-Lin Han, Gregory S. Mason, and Teodora Rutar Shuman are with the Department of Mechanical Engineering, Seattle University, Seattle, WA 98122 USA (e-mail: hanye@seattleu.edu).

Jennifer Turns is with the Department of Human Centered Design and Engineering, University of Washington, Seattle, WA 98105 USA.

Kathleen E. Cook is with the Department of Psychology, Seattle University, Seattle, WA 98122 USA.

Digital Object Identifier 10.1109/TE.2022.3178666

I. BACKGROUND

THE MECHANICAL Engineering (ME) Department at Seattle University was awarded a National Science Foundation (NSF) Revolutionizing Engineering and Computer Science Departments (RED) Grant in July 2017. The goal of the award was to create a program where students and faculty are immersed in a culture of doing engineering that, in turn, fosters an identity of being an engineer [1]–[3]. To build this culture of doing engineering, the department concentrated its efforts in four essential change areas that research has shown are key to culture change: 1) a shared department vision; 2) faculty development; 3) supportive policies; and 4) curriculum [4].

As an important step toward creating the new culture, the existing curriculum was thoroughly reviewed by all stakeholders, including the faculty, students, and industry advisory board members. One issue that surfaced from interviews with student focus groups was that many ME students see Electrical Engineering (EE) concepts as abstract and removed from ME. The fact that students perceived a disconnection between EE and ME is not surprising as ME students often struggle to find relevance in EE concepts [5]. Prior to the work reported in this article, Seattle University had required an EE fundamental course *Elements of EE* taught by EE faculty. This approach is common nationwide, while some ME programs do not require an EE-related course at all, and very few programs offer EE-related courses taught internally by ME faculty [6]. The disconnection between EE and ME curricula undoubtedly contributes to students' perception that EE concepts have limited relevance for a mechanical engineer.

In addition to students' perception, ME faculty observed that students struggled when asked to apply concepts taught in the prerequisite EE course during the follow-up Data Acquisition (DAQ) and Instrumentation course. 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 [2]."

Furthermore, industry partners emphasized the importance of, and need for, skilled mechanical engineers who can incorporate EE fundamentals with ME applications and contribute to interdisciplinary projects. Such suggestions are echoed in a report by the American Society of Mechanical Engineers (ASME) that stressed the importance of digital skills for mechanical engineers in the future workforce [7].

Based on this feedback, the ME program began re-envisioning how EE concepts could be incorporated into the ME curriculum by ME faculty in a culture of doing engineering. The new approach needed to maintain students' understanding of fundamental EE concepts while improving students' ability to implement EE concepts in ME applications and also contribute to students' evolving engineering identity. The proposed solution is a new course sequence that emphasizes hands-on laboratories (labs) and incorporates reflection of students' experience with the classes' content.

This article presents this innovative course sequence to integrate EE Fundamentals into the ME DAQ course utilizing open-ended, real-world laboratories (labs) to help students connect EE concepts with ME applications and develop their engineering identities. Students' self-reported experience and standardized tests are analyzed to determine the success of the first offering of this integrated sequence.

II. Theoretical Rationale

The new course sequence combines the EE and follow-up DAQ courses into an integrated two-quarter sequence that emphasizes hands-on, authentic labs and incorporates student reflection of the learning experience. In an integrated course sequence, students have the opportunity to see the mutual relevance of the EE and ME concepts. The inclusion of labs necessitates the interrelation, application, synthesis, and evaluation of EE and ME concepts required in the field. The reflection prompts students to reflect on and report their learning, their effort, and their experience.

Labs specifically invite the integration of theoretical and practical aspects of the course [8]–[10]. Many researchers have discussed the benefits and importance of hands-on laboratory work to engineering education [11]–[14]. "Engineering is a practical discipline. It is a hands-on profession where doing is key [14, p. 122]." Labs also help students develop a "feel for engineering [15]."

Solving real problems in the lab provides "authentic experiential learning opportunities to put into practice in the real world [16, p. 17]." Authentic problems tend to be open-ended with more than one correct answer and connect to real-life applications [17]. Using authentic problems in classrooms have been shown to enhance students' problem-solving ability [18]. Laboratory exercises with real-life applications also motivate; students can see the value and relevance of EE to their interests in ME [19]. Additionally, recent research [20] found that connecting students with real-life design activities enhances engineering identity.

Open-ended, real-world, labs done in teams also address several ABET outcomes [21]. Open-ended labs address in part ABET Student Outcome 2, "an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors" by requiring students to design and build experiments that address constraints. Since all labs are designed as team projects, students must function on a small team addressing in part ABET Student Outcome 5, "an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives." Finally, labs, specifically those that require students to design an experiment to collect and analyze data, address ABET Student Outcome 6 "an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions."

Hands-on learning works best when students reflect on their learning; "Students learn by doing, but only when they have time to reflect [16, p. 20]." Hence, reflection exercises are needed to reinforce hands-on labs. Learning occurs through doing but learning also occurs through reflecting on doing [22]. Reflection leads students to revisit their experience which deepens their understanding of what they are learning and guides future learning experience [23]. Reflective learning also helps students better understand their learning processes and produces active, effective, lifelong learners [24]. Active, hands-on learning combined with reflection reinforces "the end goal of learning as the ability to use knowledge and skills flexibly in novel situations [16, p. 19]." When students engage in repeated, structured reflection about their learning, they are able to "bring a strategic learning orientation to new challenges [25], [26]."

Beyond providing opportunities for students to integrate, apply, synthesize, and evaluate EE and ME concepts and meet ABET outcomes, hands-on labs and reflection also help students develop engineering identities. In engineering education, situated learning is central to identity development [27]. Situated learning, such as labs, provide opportunities for students to demonstrate their capabilities to themselves and others and be recognized as engineers. The relevance and utility of course content cultivates student interest and motivation [5], [19]. When students are interested, feel capable, and feel acknowledged, their engineering identity is formed [28], [29]. However, students must engage in intentional, dialectical reflection about their experience to appreciate their meaning and influence their identity [30].

Supporting student reflection includes deciding what prompts to use, how to integrate reflection into the class flow, and how to analyze results. For example, Clark and Dickerson [31] used guiding questions, had students submit the answers to the guiding questions after the exam, and analyzed the responses via content analysis. Prompts can be particularly important when creating opportunities for reflection since students and faculty may have different *a-priori* ideas about reflection, as suggested in [32]. Prompts can guide the students toward potentially valuable engagements with reflection.

The new course sequence with hands-on labs and reflection adds to a culture of doing engineering. It has the potential to deepen connections, provides practical real-world experience, and helps students develop into active, flexible learners with a feel for engineering. Such reflective students not only are prepared technically and professionally with a practical, realistic understanding of what it is to be an engineer but also are identified with engineering.

III. Method

The intended outcomes of this new integrated EE/DAQ course sequence are to help students connect EE concepts with ME applications and develop their engineering identities. Features of this sequence include using authentic, open-ended labs, integrated course structure, and participants engaging in reflective activities.

This article seeks to address three research questions that connect the design features and the intended outcomes of this new course sequence.

1) *Engineering Learning:* What evidence is there that students learned EE and DAQ concepts and integrated them with ME concepts?
2) *Identity Development:* How did the students connect the experience to their evolving identity as engineers?
3) *Over-Time Experience:* How did students experience the course designed to meet the goals over two quarters?

A mix of quantitative and qualitative data is used. Qualitative data from "mini-reflections," named reflection breadcrumbs (RBCs), are student reflections provided throughout the term. RBC responses were collected at eight separate points in time and provide an ongoing record of student experience. These data are essential in assessing the impacts of this new course design and provide information for improvement of the future offerings. Quantitative data from a standardized test, named the Comprehensive (Comp) exam, were used to add another perspective to understand students' learning.

The following discussion is divided into four sections. Tools, materials, and the structures of the course design are discussed in Section I. Participant demographics are described in Section II. Detailed information on the quantitative and qualitative data sources used in this study, as well as how each data source was analyzed, is presented in Sections III and IV.

A. Course Design and Implementation

The newly designed integrated EE/DAQ course sequence combined the former EE and DAQ courses into a single two-quarter sequence of EE/DAQ I and EE/DAQ II. The sequence is taken during the winter and spring quarters of the third year of the ME program. Although second-year students take Electricity and Magnetism in Physics to learn basic theories of electricity, this course sequence is their first introduction to circuit applications.

During the third year, students are also taking courses on Mechanics of Materials, Material Sciences, Thermodynamics, Fluid Mechanics, Machine Design, and Heat Transfer. The timing of these other courses is important because topics from some of those courses are incorporated into EE/DAQ I and EE/DAQ II labs.

EE/DAQ I and EE/DAQ II are designed with two lecture/lab combinations every week, one for EE and one for DAQ. EE content is discussed in a 50-min lecture followed by a 100-min lab early in the week, and a 50-min DAQ lecture and subsequent 100-min lab occurs later in the week. The EE and DAQ contents are coordinated so that content discussed in the EE lecture and lab are used in the DAQ lecture and lab (see Appendix A for details). Both labs emphasize hands-on learning with team lab exercises connected to in-lecture examples focusing on doing engineering. The lab exercises also are connected to other ME courses that students take concurrently, such as Machine Design, Fluid Mechanics, and Heat Transfer. Thus, the labs have the potential to strengthen connections across the curriculum and further help students connect concepts and synthesize their knowledge from different ME courses and EE.

The EE/DAQ I and EE/DAQ II courses are co-taught by two ME faculty based on their expertise; one leads the EE portion and the other guides the DAQ portion. In addition to providing relevant content for lab use, the EE lectures help prepare students for their fundamentals of engineering (FE) exam [33], which is the first requirement toward the professional engineering license. The DAQ lectures cover fundamentals in DAQ as well as the Internet of Things (IoT). Additionally, the use of reflection aims to further strengthen students' connections and meaning making.

EE/DAQ I begins with an introduction to EE fundamentals. Various electronic components are introduced in the EE lab each week. These components are then used in the DAQ lab to interface sensors and components with a microcontroller. The DAQ portion of the course uses an ARM-based microcontroller development board (STM32 Nucleo) [34] because of the board's low cost, free development system, and the wide industry adoption of ARM-based systems. The microcontroller is used for both DAQ and data processing. In the middle of the quarter, students begin to build more complicated circuits and connect their microcontroller to the Web through IoT applications. The course utilizes a simple IoT protocol that allows students to directly query a shared database using HTTP. This approach makes it feasible for students to debug their IoT applications using a Web browser.

Toward the end of the first quarter, students begin designing and conducting experiments that connect EE and DAQ topics with other ME courses. Fig. 1 shows an example of one of the labs (complete course content can be seen in Appendix A). In this lab project (Strain Gauge Beam), students rely on their knowledge of the stress and strain theory acquired in their Mechanics of Materials and Machine Design courses to relate the strain in a cantilevered beam to the force at the end of the beam. Students begin by instrumenting a cantilever beam with a strain gauge. They then build a Wheatstone bridge and analyze it using Thevenin's theorem in Week 6. Note that DAQ lecture time in Week 6 is used for the midterm exam but basics of IoT is covered in Week 5 DAQ lecture as shown in Appendix A. In Week 7, students create a basic HTML/JS webpage and demonstrate how to share data on an IoT server with their microcontroller. Building on their knowledge of the Wheatstone bridge, students then add an instrumentation op-amp to their circuit and connect their circuit to the microcontroller in Week 8. By the end of this lab project, students can use the beam and strain gauge to weigh

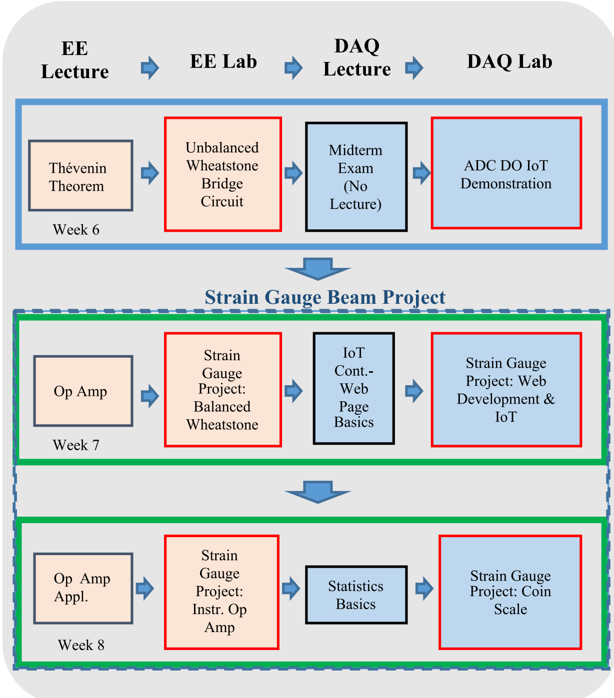

Fig. 1. Course content of the strain gauge beam project in EE/DAQ I.

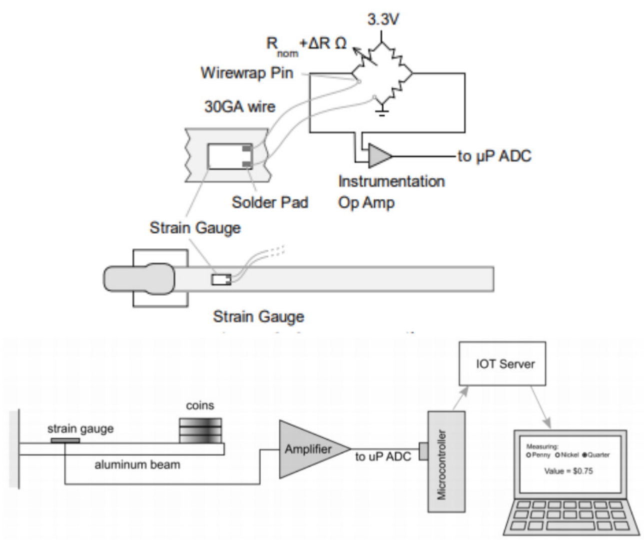

Fig. 2. Strain gauge beam project in EE/DAQ I.

pennies and display the resulting number of coins on a Web page. A schematic of the strain Gauge Beam Project is shown in Fig. 2, which illustrates EE and DAQ lecture and lab content over three weeks of the course in the first quarter.

In another lab, students build a capacitive water-level measurement circuit [35], 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 potentially can be utilized in an ME required course in the fourth year, Dynamic Systems, when students are tasked to take water-level measurements with various input and output flows.

The second quarter of the integrated sequence (EE/DAQ II) begins with a review of electronic components using the circuit simulation software, Multisim, and an introduction to real-time operating systems (RTOS). The emphases of the second quarter are on various sensors, time-domain and frequency-domain analyses. Most of the lab projects in this quarter are designed to last for two to three weeks, similar to the format of the strain gauge beam project in the first quarter.

In one, students use an ultrasonic sensor as an intruder alarm. In this lab exercise, students track the distance from an ultrasonic sensor by measuring a pulse width using the microcontroller's timer. 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, students apply knowledge learned in their Heat Transfer course. In Heat Transfer, students learn to analyze systems using a lumped capacitance model (LCM). Students utilize a thermocouple amplifier chip to measure the temperature of a small (1") brass sphere with a K-type thermocouple inserted in the center of the sphere. As they remove the brass sphere from the hot water, they record temperature readings using the microcontroller via a serial peripheral interface (SPI) communication protocol from the thermocouple chip. Students then perform transient heat transfer analysis that requires them to integrate knowledge they learn concurrently in the Heat Transfer course.

These lab exercises are all designed to incorporate EE concepts into the ME curriculum. They utilize hands-on, real-life applications to facilitate the goals of doing engineering with engineers and fostering students' engineering identity. A summary of course content is shown in Appendix A and detailed lecture and lab topics can be found in [36].

To further connect course work with engineering practice, students are required to maintain an engineering lab notebook in Microsoft OneNote. The format of the notebook is designed to mimic what students might see in industry. Research has shown that engineering notebooks help students build their engineering identity [37], [38].

Students are also required to engage in reflective exercises every other week. These essential reflective exercises are designed to help students look back at what they had learned and experienced in order to stimulate an intentional and dialectical thinking process [23]. The reflective exercises also provide comprehensive information to understand students' learning throughout the sequence.

The EE/DAQ I and EE/DAQ II sequence was first offered in winter and spring 2020. Unfortunately, the COVID-19 pandemic required that the class be moved online during the last week of winter quarter.

To accommodate the online format, the instructors modified the planned lab exercises to allow students to do labs remotely at home [39]. Each student received a USB oscilloscope (Analog Discovery, AD, or Analog Discovery 2, AD2, from Diligent [40]) in the mail and were given a list of parts to purchase from Digikey.com to use in labs on their own. More details on the modifications made for online deliveries of the course can be found in [39]. Readers may contact the authors for lecture and lab materials.

B. Participants

All students enrolled in the courses participated in this study with approval from the Internal Review Board (IRB). In winter 2020, there were 35 students enrolled in EE/DAQ I. Due to the impact of COVID-19, two students could not continue their study in spring 2020, and another student transferred out of the program before the end of the winter quarter. One student who took the EE course offered in the previous curriculum joined EE/DAQ II in spring. Therefore, a total of 33 students enrolled in spring 2020. Based on university course enrollment data in which students reported their gender, age, and race voluntarily, the winter class included 27 male-identifying and eight female-identifying students, with an average age of 24.97 years ($SD = 5.49$) and the spring class had 27 male- and six female-identifying students, with an average age of 24.91 years ($SD = 5.37$). University did not offer other gender-identifying options at the time.

In winter, 18 students indicated their race as White, four as Asian, four as Hispanic, one Native American, two unknowns, and five as nonresidents (international). In spring, 17 students noted their race as White, six as Asian, three Hispanic, two unknowns, and five as nonresidents. No students indicated themselves as more than two races. All race categories reported here are the exact wording used in the university course enrollment data.

C. Quantitative Data Source: Comprehensive Exam

In the fourth year of the ME program, all students are required to take a Comprehensive (Comp) Exam. Questions and topics tested in the Comp Exam are similar to those in the FE exam [33]. The Comp Exam is administered using the university's learning management system, Canvas. The same exam questions are given every year. There are nine subjects and a total of 100 multiple-choice questions. All subjects have ten multiple-choice questions except Math, which has 20 questions. Each subject test lasts 20 min except Math, for which 40 min are allotted. During the exam, students can use the FE reference handbook published by NCEES either in the physical or the electronic form as well as the calculators approved by NCEES, which complies with the rules of the FE exam [41]. Before the COVID-19 pandemic, all students took the exam in the department computer lab where they used desktops in the lab to access Canvas. In fall 2020, students took the exam with their own computers from home, and they were required to be on camera via Zoom and recorded.

The Comp Exam's EE (ten questions) and DAQ (four related questions in Miscellaneous which also includes questions for Engineering Economics and Ethics) results from students in the new EE/DAQ I and EE/DAQ II sequence were compared with those from students who took the EE and DAQ courses previously, before they were integrated. The Comp Exam is taken in the fall quarter of the 4th year, almost six months after students complete the EE/DAQ I and EE/DAQ II sequence. Thus, students in the new integrated sequence in Winter and Spring took their comprehensive exam in Fall 2020 and students who took the EE and DAQ courses separately in Winter and Spring 2019 took their comprehensive exam in Fall 2019.

TABLE I
DUE DATES AND PARTICIPATION RATES OF RBC EXERCISES

Winter DAQ I	RBC 1	RBC 2	RBC 3	RBC 4
Due Date	1/17/2020	1/29/2020	2/12/2020	2/26/2020
Participation Rate	94%	100%	89%	94%
Spring DAQ II	RBC 5	RBC 6	RBC 7	RBC 8
Due Date	4/19/2020	5/3/2020	5/17/2020	5/31/2020 or 6/7/2020
Participation Rate	100%	85%	82%	85%

D. Qualitative Data Source: Reflection Breadcrumbs

Qualitative data were collected via prompts that invited students to reflect on their experience and provide short responses. The name RBCs captures the reflective nature of the responses while signaling that they are not comprehensive but rather a trace of the student experience. This approach is related to the method called ecological momentary assessment [42], in which the participants were sharing parts of the experience as they were progressing through time. However, the approach differs from ecological momentary assessment because the responses were part of an instructional situation, as discussed below. Regardless, reflection exercises did provide an opportunity for identity development through narrative [43]. These reflection exercises were administered using Canvas. An RBC exercise was given every other week under the Quizzes section of the course Canvas site. There was no time limit on how long the student could spend on each exercise but there was a due date for each exercise. Students had between five and seven days to complete their reflection once the prompt was posted on Canvas.

RBC exercises were a small portion of students' grades each quarter (less than 1% in winter and less than 4% in spring). Students received full points automatically once they submitted their exercises on Canvas. There were eight RBC exercises from the two quarters. The date and participation rate of each exercise are shown in Table I. Seattle University switched to online classes during week 10 of the winter quarter in 2020 due to the COVID-19 pandemic. All homework assignments were optional to accommodate this sudden change, so there was no RBC exercise given at the end of the winter quarter. Also, in consideration of students' reaction to George Floyd's killing at the end of the spring quarter, the last RBC exercise due date was extended, and a duplicate assignment was created on Canvas to encourage participation. Submissions on Canvas for both reflection exercises were combined into Spring RBC 8 as the same prompt was used.

For each RBC exercise, students responded to the following five questions.

Question 1: Write a paragraph(s) to your manager to report the key takeaway(s) from last two weeks.

Question 2: Document the contribution of each member in your lab group.

Questions 3–5 asked students to respond to a prompt that varied from exercise to exercise. All prompts followed these three steps: 1) *start a reaction*; 2) *add an explanation for the reaction*; and 3) *provide an action to the reaction*. These steps of the prompt encompassed essential elements of reflection [23]—students identified features of their experience, applied lenses to make meaning of those features, and sought actions. Prompts for Questions 3–5 of all RBC exercises are detailed in Appendix B. The prompts for RBC 5–8 in the spring quarter were repeated from the prompts given in the winter quarter in RBC 1–4, except Q4 in RBC 5 which probed deeper into students' perceptions of understanding the materials as they stepped into the second quarter of the sequence.

The analysis of the RBC data involved inductive thematic analysis that was sensitized by the concepts in the research questions. The work followed three phases. First, each RBC response was put onto a separate sticky note in the online collaboration tool, Miro (Miro.com), to permit an initial inductive sort of the responses to look for initial themes. Second, the first author used a spreadsheet to code all the RBC responses into the thematic categories that had been identified. The second author then reviewed the identified themes to confirm the coding of the RBC responses. Finally, the first author analyzed the RBC response associated with each theme to understand the ideas represented in the RBC responses, to draft the text for the results section, and to identify salient examples to include as evidence. All other authors then reviewed examples associated with each theme and finalized the sections to be presented in the findings section.

IV. Findings

The findings from this study are presented in three categories to demonstrate the connection between the course design features and the intended outcomes: 1) what evidence is there that students learned EE and DAQ concepts and integrated them with ME concepts? 2) how did the students connect the experience to their evolving identity as engineers? and 3) how did students experience the course designed to meet the intended outcomes, with particular attention to the students' experience over the two quarters of the course sequence?

A. Achievement of Learning and Integration

Achievement of learning and integration is supported in three areas: 1) learning fundamental EE and DAQ concepts; 2) developing hands-on EE skills applied in ME; and 3) students' perception and understanding of how EE and ME concepts are integrated.

1) Learning Fundamental EE and DAQ Concepts: The Comp Exam provides a quantitative measure of student learning. Results of the exam comparing students who took EE and DAQ as separate courses and those who took the new integrated sequence were compared. The Comp Exam is administered in the 4th year of the program, so the 2019 results are for students who took EE and DAQ as separate courses and the 2020 results are for students who took the EE/DAQ I and EE/DAQ II courses in 2020.

Students taking the EE/DAQ I and EE/DAQ II sequence performed slightly better or on par with students from the previous year, $t(61)$ -1.452, $p = 0.151$ for EE questions ($M_{2019} = 5.15$, $SD_{2019} = 2.31$; $M_{2020} = 5.93$, $SD_{2020} = 1.91$) and $t(61)$ -0.904, $p = 0.370$ for DAQ questions ($M_{2019} = 1.79$, $SD_{2019} = 0.914$; $M_{2020} = 2.00$, $SD_{2020} = 0.886$). The lack of statistically significant differences means that students taking the integrated sequence demonstrated as much or more understanding of EE and DAQ concepts as those who had separate courses. These results are particularly encouraging because the 2020 offering of EE/DAQ I and EE/DAQ II was during the COVID 19 pandemic.

Achievement of learning and integration is also supported by qualitative data collected from RBC responses. These data are self-reported by students, and used to analyze students' experience of integrating EE and DAQ with ME. Note that each number at the end of the student quote corresponds to the identifier of the students shown in Appendix C.

2) Developing Hands-on EE Skills Applied in Mechanical Engineering: Many of the labs required students to design and build circuits to support an experiment relevant to ME. These lab experiments (e.g., measuring strain on a beam, measuring fluid level, analyzing the frequency content of a signal, controlling the position of a motor, etc.) are designed to provide opportunities for students to develop hands-on EE skills and apply them to common problems in ME and to meet ABET outcomes 2 and 6 [21].

The emphasis on doing engineering lab work was well understood and well received by students. From RBC responses, three major themes emerged related to this subject as shown in Table II.

1) Students naturally made connections between laboratory exercises and hands-on learning. Several comments included the term *hands-on* regardless of which prompt they were responding to.
2) Some students spontaneously observed that one of the goals of laboratory work is to *link theory and practice*.
3) The connection to *real-life applications*, which aimed to highlight the authenticity of the lab exercise, was also appreciated by students.

The sequence is designed to emphasize learning by doing and hands-on experience through authentic problems. Students' comments confirm the need for laboratories in this sequence. Most students expressed their preference for hands-on learning and seeing things in action.

3) Perception and Understanding of How EE and ME Concepts Are Integrated: The integrated design sequence was developed to improve student perception and understanding of how EE and ME concepts connect. The RBC responses presented in Table III showed that students naturally spotted *the connection between EE and the DAQ course content* and appreciated the integration. In fact, no students had negative comments about the integration.

TABLE II
RBC RESPONSES FOR DEVELOPING HANDS-ON EE SKILLS APPLIED TO ME

Themes	Student Responses
Hands-on	*"The surprising part to me is that the class is a lot of hands-on, which I like a lot, I learn better that way……"* (1) *"This class is all about hands-on learning."* (2) *"I enjoyed using the ultrasonic sensor because it definitely brings a more hands-on feel to the class, where there are physical things that work with our circuits, much like the water capacitor from last quarter."* (3)
Link theory and practice	*"... I am a visual learner and I like making connections so going from drawing a circuit and seeing it on paper to hands on building it on a breadboard and seeing it work is really exciting and helps my learning."* (4) *"... I enjoy seeing a design be realized in something practical and enjoy turning theory into practice."* (5)
Real-life applications	*"One thing I enjoyed was using components I have encountered or heard about in my daily life, such as a relay……"* (6) *"I think this lab is really fun and useful in real life. We can actually set up a bigger model to build a house thief alarm product."* (7) *"I'm really enjoying building the circuits and using all the new components. It's been cool to see how everyday components like microphones and ultrasonic sensors are used on a basic level."* (8)

TABLE III
RBC RESPONSES ON HOW EE AND ME INTEGRATED

Themes	Student Responses
Recognizing EE & ME integration	*"It was interesting to see the two labs being linked to each other when we made Wheatstone bridge in one lab and it would be helpful for Thursday's lab. I think that also used to happen previously, but it seemed at a bigger scale and more noticeable now because the lab assignment is a huge assignment to be completed after about two weeks."* (9) *"I have really enjoyed applying my knowledge of circuits to the DAQ labs…… It was very interesting to see this process carried out in multiple ways."* (10) *"It makes me feel more confident and gives me more motivation to work on building circuits outside of class and in the future. I think it's a valuable skill to have especially as a mechanical engineer."* (8)
Praised on how to apply the theories	*"One thing I really like is that the coding and circuits are now linked to what we know as mechanical engineering students (strain in a beam). Although I like theoretical work and I think it is very important to understand theoretical aspects, I think it is nice to see how we would be able to use our knowledge in electricity or electrical engineering for mechanical engineering projects."* (9) *"What I was most proud of was building the circuits, because of how difficult it was to balance the Wheatstone Bridge. Another one would be building the cantilever beam because getting the strain gauge on properly was difficult."* (11)

Integrating with other ME subjects also was praised by students and students noticed how to apply the theories they learned.

TABLE IV
RBC RESPONSES ON INTERESTS AND ENGINEERING IDENTITY

Themes	Student Responses
Interests	*"Perhaps robotics might be an interesting field of study to pursue..."* (5) *"... I think that this reaction shows me how I am interested in the field of data acquisition."* (13) *"I think I should look into jobs that involve with circuit since this class and lab are kind of fun even if it could be very frustrated sometime."* (14)
Confidence in engineering tasks	*"I know at the start of this lab that would have been a really difficult task to accomplish. I feel more confident in my ability to build circuits from scratch without direction now and also troubleshoot."* (15) *"I feel very confident in building neat circuits that I can troubleshoot given accurate procedures…"* (16)
Felt more like an engineer	*"I was proud of my efficiency and professionalism in my circuit building."* (17) *"It's given me a lot of motivation to keep working on my coding skills because I will probably be using them when I'm at my internship. I feel good about what I've learned so far and will continue to make improvements."* (8)

B. Identity and Doing Engineering

One intended outcome of the integrated sequence is to foster students' engineering identity. As noted, students form their engineering identity from having interests in engineering subjects, feeling confidence in engineering-related tasks, and being recognized as engineers [28], [29]. As shown in Table IV, students expressed *interest in engineering subjects* and found *confidence in engineering tasks.* Some *felt more like engineers.*

It is worth noting that one student brought up a concern that some other ME students may share:

> *"How and when I'd use these things? I find myself trying to imagine ME and being confused; will I be doing a bunch of circuits and programming stuff?"* (12)

Although this is the only comment in all responses questioning what mechanical engineers should do, it would not be an uncommon question for some students or engineers in the ME field to ask. This comment perhaps demonstrates a more traditional perception of mechanical engineers' jobs. As technologies evolve and demands for new skills appear, it is evident that integrated knowledge will be beneficial and necessary for all engineers and the boundary of disciplines will become less defined [7]. Although this particular student seems to be puzzled by this prospect, it also shows that they have been thinking about what they would do as a future mechanical engineer. They are considering their engineering identity.

The RBC data also provide a glimpse into the sequence's impact on students' perceptions as self-driven life-long learners. As shown in Table V, several students talked about their plans for expanding the knowledge they gained into making their own projects or applying to real-life examples.

TABLE V
RBC RESPONSES ON LONG-TERM IMPACTS

Themes	Student Responses
Long-term impacts	*"Overall, the last two weeks both expanded my knowledge in the subject and inspired me to start investigating similar topics on my own."* (16) *"I want to think about the cumulation of this class and how I can use it in personal projects."* (3) *"I think I will think more about filter applications in real life. For example, I was tuning my car stereo and I realized that the filters for bass and treble are just selectively filtering their corresponding wavelengths and either amplifying or damping them based on the setting."* (18)

C. Learning Trajectory

The last research question relates to students' experience over the six months of the course sequence. Student comments in their RBC exercises provide evidence of student growth and learning across the sequence. 20% of students mentioned in the first RBC exercise that they had not built a circuit on a breadboard before, and several students said that they were new to microcontrollers and coding. Despite being unfamiliar with circuits and coding, students were eager to learn new knowledge and began to understand basics of circuits during the first couple of weeks:

> *"Pretty much everything in the labs last week was new for me. What I found most helpful was starting to learn how to translate a schematic of a circuit diagram to a breadboard. It is similar in many ways but different in some other ways. Seeing an LED light up and understanding how that happens is really exciting!"* (4)

As the first quarter went on, more comments about how they were having a hard time understanding certain course materials began to emerge. In the second and third RBC exercises, when asked what made them enjoy or feel uncomfortable about the course, many mentioned the coding part of the lab exercise:

> *"... I am getting better with circuits, but once it gets to coding things tend to be above what I can grasp. I need to focus more on the coding parts that I'm struggling with..."* (19)

Some brought up specific topics related to circuits with which they were having issues:

> *"I am still struggling to solve circuits using Thevenin equivalent circuits. I do not understand how nodal analysis comes into play after the circuit has been simplified to a certain extent."* (10)

Although it could seem discouraging for instructors to see students struggle, these comments show that students are reflecting on their learning and identifying learning issues to address. These RBCs also can give instructors more context on what to adjust in the course to better students' learning. Both are benefits of frequent reflection exercises.

Toward the end of the first quarter, more students talked about the progress they had made in more detail and felt a sense of accomplishment when they overcame obstacles. It is important for students to recognize their achievements when building their engineering identity. For example, when asked what they were proud of:

> *"Our success in making a working ambient light controller was easily my most rewarding lab experience so far. Involving both code and space efficient circuit construction, this lab presented the greatest challenges. It was deeply satisfying to have such a complex development process come together and produce the expected results."* (5)

The first quarter was to build the foundation for more complicated projects in the second quarter. Students slowly got into the concepts of integrating circuits with their microcontroller and got more comfortable building circuits as ME majors. As one student put it:

> *"For the circuit expertise, I felt like that since I have been leading to build the circuits lately and I can feel that I am definitely getting better at it. Although I thought I might hate circuits at the start of the quarter but turns out I am looking forward to it lately. What a surprise!"* (17)

One can see that by the end of the first quarter, students began to understand the traits of an engineer and what engineers do. Although the two-quarter sequence is uncommon, it is necessary. The two-quarter sequence not only allows enough time to deliver necessary technical content but also gives students more experience to do and frequently reflect on their learning.

As the second quarter went on, more students expressed their confidence in the tasks given:

> *"Seeing circuit diagrams has become a lot easier after practicing it many times. The flow of coding is getting clearer, I still need to learn the formatting and how each command affects each other when running."* (11)
> *"In terms of the Labs, I didn't feel as overwhelmed as normal which was a relieving feeling. Also I was very happy to see that my coding skills were improving as I was able to do everything I was trying to do if I spent enough time on it."* (16)

They were more likely to identify things to improve on in order to complete the given tasks:

> *"What took me a little longer than expected was building the circuit since I had to revise previous lecture on op amp. But I liked that because it gave me a chance to look back at previous lecture."* (9)

From these responses, one can see a clear trajectory of students' learning across this sequence. Starting from not knowing much and wanting to learn, to feeling frustrated as they struggle to better understand, students gained confidence and could identify actions to take to complete certain tasks. Students not only learned by doing but also by reflecting on their learning.

V. Discussion

In this section, how the design features (open-ended, hands-on labs, integrated structure, and reflective activities) connect to the intended outcomes of this new course sequence is discussed based on each of the three research questions. Potential improvements and limitations of this study are also discussed.

A. RQ 1: What Evidence Is There That Students Learned EE and DAQ Concepts and Integrated Them With ME Concepts?

This research question can be addressed through three findings: Students 1) learned fundamental EE and DAQ concepts; 2) worked on hands-on EE and ME skills; and 3) understood how EE and ME concepts are integrated.

1) A comparison of the Comp Exam scores showed that students who took the integrated sequence performed as well on EE and DAQ questions as those who took separate courses. This suggests that students are understanding and retaining EE and DAQ concepts. This is especially remarkable given that the class time students spend discussing EE topics in the EE/DAQ I and EE/DAQ II sequence is approximately 30% less than the time spent in the original EE course. However, the content in the EE/DAQ I and EE/DAQ II sequence focuses on topics that are covered in the Comp Exam and topics and skills used in ME application. While the breadth of EE instruction may be less than in the original curriculum, the new curriculum provided a more targeted approach. Student reflections also support the finding that they are motivated in learning fundamental EE concepts when connected to ME content.
2) The new course sequence helped develop students' hands-on EE skills. Student RBCs showed their appreciation for hands-on learning, for the relevance of the EE material, and for the authenticity of lab exercises. The emphasis of hands-on skills is supported in part by the wider ME curriculum that engages students in doing engineering in regular labs. In the new sequence, students spend twice as much time in labs as in the old courses. Student reflections confirm their recognition of the importance and value of the lab time.
3) Student reflections support their understanding of how EE and ME concepts are integrated. They pointed to the linking of theory and practice, an importance connection noted in [14] and [15]. Many students commented on the connection between EE and ME concepts when working on the labs that pulled information from ME classes outside of the DAQ sequence. The tight integration of the EE and DAQ topics also help to establish these connections and aligns with the recommendations in [11].

Together, these three findings show that students learned EE and DAQ concepts and integrated them with ME.

B. RQ 2: How Did the Students Connect the Experience to Their Evolving Identity as Engineers?

The new curriculum and the culture of doing engineering aim to provide an institutional support for students to develop their engineering identity. As an essential part of the new curriculum, this new course sequence created an opportunity to do engineering in a rich way that provided fertile ground for developing engineering identities. Situated learning, like labs, provides opportunities for students to develop interests, skills, and confidence and see themselves as engineers. As supported by [29] and [30], all of these contribute to engineering identity formation especially when coupled with intentional, recursive reflection. Interest, skills, and confidence appeared in student RBCs, suggesting that the new course sequence contributes to students' evolving identity. This is particularly encouraging because this development occurred when over half of the course sequence was taught online. Even better results are expected when students are able to connect in person during labs.

C. RQ3: How Did Students Experience the Course Over the Two Quarters?

Because the RBC approach involved reflection exercises every other week, it provided a clear window into student experiences across the 20-week course and, thus, provided answers for the third research question. At the beginning of the term, students noted that they had never built circuits or were new to microcontrollers and coding. Toward the end of the term, students wrote about the progress they had made and their sense of accomplishment when they overcame obstacles, which is important in the developing their engineering identity, as reported in [28] and [29]. They also conveyed an understanding of engineering traits and what engineers do. Confidence continued to increase through the second term, and students reported being better able to discern what they needed to do to complete a given task. Students learned not only by doing engineering but also by reflecting on their learning experiences.

D. Improvements

While there is evidence of success, the findings also suggest several aspects to be improved in future offerings of the course sequence.

1) Student engagement with the RBCs decreased over time, falling to a low of 82% participation during the final quarter. Some of this decline could be attributed to the burnout all students experienced in the remote learning environment. However, some might also be attributable to fatigue with the RBC instrument itself or to a decrease in the perceived value of the exercise. Possible solutions include increasing the weighting of the grade associated with participation in the RBC or providing some variance in how the RBC is administered or in the questions that are asked. In addition to these administrative adjustments, it is important to explain to students how reflecting betters their learning and meaning-making.
2) The lab report was designed to provide evidence to assess ABET Student Outcomes 2 and 6 [21]. However, the quality of the lab reports was varied. Although the lab reports documented how students designed and

TABLE VI
SUMMARY OF COURSE CONTENT

Winter	EE	DAQ	Spring	EE	DAQ
Week 1	Voltage, Current, Power & Energy	Introduction to data collection and microcontroller.	Week 1	Inductors & RL Circuits	Timing, Polling, RTOS
Week 2	Basic Laws	Programming in C	Week 2	Sinusoids	Free RTOS, Counters &Timing
Week 3	Nodal analysis	Analog to Digital Converter & Pause Width Modulation	Week 3	Phasors	Frequency Content & Fourier Transforms
Week 4	Mesh analysis, Diodes & Transistors	Digital Input, Digital Output & Counters	Week 4	Impedance and Admittance	FFT
Week 5	Source Transformation	IoT	Week 5	Sinusoidal Steady-State Analysis	Frequency Response, Bode & Filtering
Week 6	Thevenin & Norton Equivalent Circuits	Exam	Week 6	Sinusoidal Steady-State Analysis	Exam
Week 7	Op Amps	IoT Continued- Web Page Basics	Week 7	Second Order Circuits	Antialiasing filters & Digital Filters
Week 8	Op Amp Applications	Measurement Uncertainty	Week 8	Second Order Circuits	Interrupts review. Quadrature Proportional Feedback
Week 9	Capacitors	Measurement Statistics	Week 9	Transistor Circuits	Sensors
Week 10	RC circuits	Review	Week 10	AC Power Analysis	Sensors

conducted their experiments, analyzed their data, and drew conclusions, they did not provide sufficient data for the researchers to systematically analyze students' performance related to the research questions. Even with an annotated outline for the lab report provided to EE/DAQ I students, lab reports still had a large range of quality. For EE/DAQ II, a simple example report was added as a reference for students. This did improve the overall report quality, but the quality was still inconsistent. In future offerings, a detailed example report at the start of EE/DAQ I that includes specific "check points" in each lab will be added to help guide students' reports.

3) The largest challenge was the pandemic and shift to remote instruction. While the hands-on labs were retained, students were unable to work with each other except in "Zoom rooms." Although remote collaboration is increasingly common, teams developing EE, ME, and teamwork skills may benefit from face time. Future labs will be held in a large classroom where teams of students can collaborate within their team and between teams. The impact of teamwork should be traced to assess ABET Student Outcome 5.

E. Limitations

It is important to note that this study has several limitations. First, this study aims to surface the connection between the features and intended outcomes of the newly designed course sequence so researchers can learn from it and improve on future iterations of the course sequence. From our research, the design of this course sequence is the first of its kind. It is important for the researchers to continue to iterate its design. Hence, the purpose of this study is not to compare this instructional design to others but to present an innovative approach that sparks new ideas among educators. Second, this study focuses on the formation of engineering identity related to students' experience in this newly designed course sequence conveyed through their RBCs. Overall identity changes result from their experience of the entire program. It is impossible to isolate the impact of each course and program facet from all of the factors students simultaneously experience that contribute to identity change. Therefore, the change of student identity based on this course sequence alone is not traced. However, through the RED projects over the past four years, measures of student identity, including the explicit engineering student identity scale (ESIS) [44], and the implicit association test (IAT) [45] were administered. The results show how the overall changes in the program affect student identity and will be reported in the future. Third, participants in this study include all students enrolled in these courses. As shown in Section III-B, the majority of participants are White males. Given the small number of students in other ethnic groups and genders, it is not feasible to analyze the Comp Exam and RBC data along demographic lines. Additionally, this cohort had several nontraditional students who are older in age. While this contributes to the older average age compared to other programs, the impact of age is also not studied due to the small sample size.

TABLE VII
PROMPTS FOR QUESTIONS 3–5 OF EACH RBC EXERCISE

	Question 3: start a reaction	**Question 4: add an explanation for the reaction**	**Question 5: provide an action to the reaction**
Winter DAQ I RBC 1	What in labs last two weeks was surprising, unexpected, or new?	Why do you think you had this reaction (i.e., your response to the prior questions)?	What is something about this thinking you could talk to your teammate about?
Winter DAQ I RBC 2	In labs last two weeks, think about what you enjoyed. What was it? Think about what was uncomfortable. What was it? Choose ONE or BOTH.	So what do you think that reaction means to you?	What is something you might want to try out to make it more enjoyable or less uncomfortable?
Winter DAQ I RBC 3	In labs last two weeks, think about what you enjoyed. What was it? Think about what was uncomfortable. What was it? Choose ONE or BOTH.	Is there anything you don't understand in this?	What is a small action you/we could take to change your reaction?
Winter DAQ I RBC 4	In labs last two weeks, think about what you were proud of. What was it? OR Think about what was unsettling. What was it? Choose ONE or BOTH.	Why do you think you had this reaction (i.e., your response to the prior questions)?	What is something you might tuck into the back of your mind to think about some more?
Spring DAQ II RBC 5	What in labs last couple of weeks was surprising, unexpected, or new?	Is there anything you don't understand in these labs? Is there anything making you feel confident about these labs?	What is something you might want to try out in a class to help you understand better? What is something you might want us to try out in class to help you feel more confident?
Spring DAQ II RBC 6	In labs last two weeks, think about what you enjoyed. What was it? OR Think about what was uncomfortable. What was it? Choose ONE or BOTH	So what do you think that reaction means to you?	What is something you might want to try out to make it more enjoyable or less uncomfortable?
Spring DAQ II RBC 7	In labs last two weeks, what part of the lab took longer than you expected? OR Think about what frustrated you. What was it? Choose ONE or BOTH.	Is there anything you don't understand in this?	What is a small action you/we could take to change your reaction?
Spring DAQ II RBC 8	In labs last two weeks, think about what you were proud of. What was it? OR Think about what was unsettling. What was it? Choose ONE or BOTH.	Why do you think you had this reaction (i.e., your response to the prior questions)?	What is something you might tuck into the back of your mind to think about some more?

VI. CONCLUSION

The ME Department at Seattle University is developing a culture of doing engineering that fosters engineering identities in part through new curricular experiences. One area that students, industry partners, and faculty all felt needed to be addressed was the disconnect between EE concepts and ME. In response, an innovative instructional approach was developed that integrated EE and ME concepts, emphasized hands-on labs, and incorporated reflection. Using a mix of qualitative and quantitative data, this article presented the details of this newly designed course sequence and links to the intended outcomes for this initial offering. Quantitative (Comp Exam) and qualitative (RBC) data showed that students learned, integrated, and applied EE and ME concepts and synthesized their experiences. RBCs also demonstrated the connection between students' experiences and their evolving engineering identity in the new course sequence. This is significant given that the RBCs simply asked about students' experiences rather than instructing students to consider the course content's integration and application or their identity growth. Findings from this study also provided directions for improvement of future offerings of this course sequence, including modifying reflection activities, enhancing digital notebooks, and tracing the influence of teamwork, to gain more insights on student learning and identity growth. Overall, the integrated EE/DAQ sequence was successful. The course allowed students to learn both EE and DAQ concepts in an integrated framework—connecting EE and ME concepts through open-ended real-world labs; it emphasized a hands-on learning experience; and it contributes to students evolving engineering identity through labs and reflection.

APPENDIX A

See Table VI.

APPENDIX B

See Table VII.

APPENDIX C

See Table VIII.

TABLE VIII
PARTICIPANT IDENTIFIERS WITH DEMOGRAPHICS

STUDENT ID	AGE	GENDER	RACE
1	38	M	ASIAN
2	22	M	ASIAN
3	21	M	ASIAN
4	22	F	HISPANIC
5	27	M	HISPANIC
6	21	M	HISPANIC
7	24	M	INTERNATIONAL
8	30	M	WHITE
9	22	M	INTERNATIONAL
10	23	F	WHITE
11	23	M	UNKNOWN
12	34	M	WHITE
13	21	M	ASIAN
14	22	F	ASIAN
15	22	M	WHITE
16	22	M	WHITE
17	22	M	INTERNATIONAL
18	22	M	WHITE
19	22	F	WHITE

REFERENCES

[1] Y.-L. Han, K. Cook, G. Mason, T. R. Shuman, and J. Turns, "Board 55: Engineering with engineers: Revolutionizing engineering education through industry immersion and a focus on identity," in *Proc. ASEE Annu. Conf. Expo.*, Salt Lake City, UT, USA, 2018, pp. 1–10, doi: 10.18260/1-2–30058.

[2] Y.-L. Han, K. Cook, G. Mason, T. R. Shuman, and J. Turns, "Board 31: Engineering with engineers: Revolutionizing a mechanical engineering department through industry immersion and a focus on identity," in *Proc. ASEE Annu. Conf. Expo.*, Tampa, FL, USA, 2019, 1–12, doi: 10.18260/1-2–32322.

[3] Y.-L. Han, K. Cook, G. Mason, T. R. Shuman, and J. Turns, "Engineering with engineers: Fostering engineering identity through industry immersion," in *Proc. ASEE Annu. Conf. Expo.*, 2020, pp. 1–14, doi: 10.18260/1-2–34566.

[4] C. Henderson, A. Beach, and N. Finkelstein, "Facilitating change in undergraduate STEM instructional practices: An analytic review of the literature," *J. Res. Sci. Teach.*, vol. 48, no. 8, pp. 952–984, Sep. 2011, doi: 10.1002/tea.20439.

[5] Q. Malik, P. Mishra, and M. Shanblatt, "Learning barriers in service courses: A mixed methods study," in *Proc. ASEE Annu. Conf. Expo.*, Jun. 2010, pp. 1–13, doi: 10.18260/1-2–17020.

[6] G. Crawford, J. A. Riofrio, and R. Melnyk, "Development of an introduction to circuits course and lab for mechanical engineering students via systematic design of instruction," in *Proc. ASEE Annu. Conf. Expo.*, Salt Lake City, UT, USA, 2018, pp. 1–26, doi: 10.18260/1-2–30327.

[7] "The Future of Engineering Workforce, Learning, and Skills." Video ASME. May 3, 2021. [Online Video]. Available: https://www.asme.org/topics-resources/content/video-the-future-of-engineering-workforce,-learning,-and-skills (Accessed: Jun. 28, 2021).

[8] A. M. Bisantz and V. L. Paquet, "Implementation and evaluation of a multi-course case study for framing laboratory experiments," *J. Eng. Educ.*, vol. 91, no. 3, pp. 299–307, Jul. 2002, doi: 10.1002/j.2168-9830.2002.tb00707.x.

[9] D. J. Olinger and J. C. Hermanson, "Integrated thermal-fluid experiments in WPI's discovery classroom," *J. Eng. Educ.*, vol. 91, no. 2, pp. 239–243, Apr. 2002, doi: 10.1002/j.2168-9830.2002.tb00697.x.

[10] A. M. Okamura, C. Richard, and M. R. Cutkosky, "Feeling is believing: Using a force-feedback joystick to teach dynamic systems," *J. Eng. Educ.*, vol. 91, no. 3, pp. 345–349, Jul. 2002, doi: 10.1002/j.2168-9830.2002.tb00713.x.

[11] N. S. Edward, "The role of laboratory work in engineering education: Student and staff perceptions," *Int. J. Electr. Eng. Educ.*, vol. 39, no. 1, pp. 11–19, Jan. 2002, doi: 10.7227/IJEEE.39.1.2.

[12] D. J. Magin and S. Kanapathipillai, "Engineering students' understanding of the role of experimentation," *Eur. J. Eng. Educ.*, vol. 25, no. 4, pp. 351–358, Jul. 2000, doi: 10.1080/03043790050200395.

[13] K. R. Salim, M. Puteh, and S. M. Daud, "Levels of practical skills in basic electronic laboratory: Students' perceptions," in *Proc. IEEE EDUCON*, 2011, pp. 231–235, doi: 10.1109/EDUCON.2011.5773142.

[14] L. Feisel and A. Rosa, "The role of the laboratory in undergraduate engineering education," *J. Eng. Educ.*, vol. 94, no. 1, pp. 121–130, Jan. 2005, doi: 10.1002/j.2168-9830.2005.tb00833.x.

[15] D. J. Moore and D. R. Voltmer, "Curriculum for an engineering renaissance," *IEEE Trans. Educ.*, vol. 46, no. 4, pp. 452–455, Nov. 2003, doi: 10.1109/TE.2003.818754.

[16] S. A. Ambrose, "Undergraduate engineering curriculum: The ultimate design challenge," *Bridge Linking Eng. Soc.*, vol. 43, no. 2, pp. 16–23. Jun. 2013, [Online]. Available: ww.nae.edu/File.aspx?id=88638

[17] J. Strobel, J. Wang, N. R. Weber, and M. Dyehouse, "The role of authenticity in design-based learning environments: The case of engineering education," *Comput. Educ.*, vol. 64, pp. 143–152, May 2013, doi: 10.1016/j.compedu.2012.11.026.

[18] K. Cook, Y.-L. Han, T. R. Shuman, and G. Mason, "Effects of integrating authentic engineering problem centered learning on student problem," *Int. J. Eng. Educ.*, vo. 33, no. 1, pp. 272–282, 2017.

[19] S. Bell and M. Horowitz, "Rethinking non-major circuits pedagogy for improved motivation," in *Proc. ASEE Annu. Conf. Expo.*, Salt Lake City, UT, USA, 2018, pp. 1–20, doi: 10.18260/1-2–30936.

[20] S. L. Rodriguez, E. E. Doran, R. E. Friedensen, E. Martinez-Podolsky, and P. S. Hengesteg, "Inclusion & marginalization: How perceptions of design thinking pedagogy influence computer, electrical, and software engineering identity," *Int. J. Math. Educ. Sci. Technol.*, vol. 8, no. 4, pp. 304–317, 2020, doi: 10.46328/ijemst.v8i4.952.

[21] "Criteria for Accrediting Engineering Programs 2019–2020." ABET. [Online] Available: https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2019-2020/ (Accessed: Mar. 31, 2020).

[22] A. Kolb and D. Kolb, "Experiential learning theory: A dynamic, holistic approach to management learning, education and development," in *The SAGE Handbook of Management Learning, Education and Development*, S. Armstrong and C. Fukami, Eds. London, U.K.: SAGE, 2009, pp. 42–68.

[23] J. Turns, B. Sattler, K. Yasuhara, J. Borgford-Parnell, and C. J. Atman, "Integrating reflection on experience into engineering education," in *Proc. ASEE Annu. Conf. Expo.*, Indianapolis, IN, USA, 2014, pp. 1–15.

[24] S. L. Ash and P. H. Clayton, "The articulated learning: An approach to reflection and assessment," *Innov. High. Educ.*, vol. 29, no. 2, pp. 137–154, 2004.

[25] J. Eyler and D. E. Giles, *Where's the Learning in Service-Learning?* San Francisco, CA, USA: Jossey-Bass, 1999.

[26] J. Eyler, "The power of experiential education," *Liberal Educ.*, vol. 95, no. 4, pp. 24–31, 2009.

[27] K. Tonso, "Enacting practices: Engineer identities in engineering education," in *Engineering Professionalism: Engineering Practices in Work and Education*, U. Jørgensen and S. Brodersen Eds. Rotterdam, The Netherlands: Sense Publ., 2016, pp. 85–104.

[28] A. Godwin, "The development of a measure of engineering identity," in *Proc. ASEE Annu. Conf. Expo.*, New Orleans, LA, USA, 2016, p. 16, doi: 10.18260/p.26122.

[29] J. Rohde *et al.*, "Design experiences, engineering identity, and belongingness in early career electrical and computer engineering students," *IEEE Trans. Educ.*, vol. 62, no. 3, pp. 165–172, Aug. 2019, doi: 10.1109/TE.2019.2913356.

[30] M. Eliot and J. Turns, "Constructing professional portfolios: Sense-making and professional identity development for engineering undergraduates," *J. Eng. Educ.*, vol. 100, no. 4, pp. 630–654, 2013, doi: 10.1002/j.2168-9830.2011.tb00030.x.

[31] R. M. Clark and S. J. Dickerson, "Assessing the impact of reflective activities in digital and analog electronics courses," *IEEE Trans. Educ.*, vol. 62, no. 2, pp. 141–148, Mar. 2019, doi: 10.1109/TE.2018.2885720.

[32] A. R. Carberry, T. S. Harding, P. J. Cunningham, K. R. Csavina, M. C. Ausman, and D. Lau, "Professional and personal use of reflection by engineering faculty, students, and practitioners," in *Proc. ASEE Annu. Conf. Expo.*, Salt Lake City, UT, USA, 2018, p. 16, doi: 10.18260/1-2–30896.

[33] "FE Exam." NCEES. [Online]. Available: https://ncees.org/engineering/fe/ (Accessed: Apr. 3, 2020).

[34] "STM32 Nucleo Boards." ST. [Online]. Available: https://www.st.com/en/evaluation-tools/stm32-nucleo-boards.html (Accessed: Jun. 26, 2021).

[35] A. Qurthobi, R. F. Iskandar, A. Krisnatal, and Weldzikarvina, "Design of capacitive sensor for water level measurement," in *Proc. J. Phys. Series 8th Int. Conf. Phys. Appl.*, vol. 776, Aug. 2016, Art. no. 12118.

[36] Y.-L. Han, K. Cook, G. Mason, T. R. Shuman, and J. Turns, "Integrating electrical engineering fundamentals with instrumentation and data acquisition in an undergraduate mechanical engineering curriculum," in *Proc. FIE Conf.*, Uppsala, Sweden, Oct. 2020, pp. 1–5, doi: 10.1109/FIE44824.2020.9274210.

[37] C. Burger. "Research Spotlight: Engineering Notebooks Make Learning More Engaging." Aug. 31, 2017. [Online] Available: https://blog.eie.org/research-spotlight-engineering-notebooks-make-learning-more-engaging (Accessed: Jun. 8, 2020).

[38] J. D. Hertel, C. M. Cunningham, and G. J. Kelly, "The roles of engineering notebooks in shaping elementary engineering student discourse and practice," *Int. J. Sci. Educ.*, vol. 39, no. 9, pp. 1194–1217, May 2017, doi: 10.1080/09500693.2017.1317864.

[39] Y. Han, J. M. Hamel, C. Strebinger, G. Mason, K. E. Cook, and T. R. Shuman, "Making the 'new reality' more real: Adjusting a hands-on curriculum for remote learning," in *Proc. ASEE Annu. Conf. Expo.*, 2021, pp. 1–6. [Online]. Available: https://strategy.asee.org/37450

[40] "Analog Discovery 2." Digilent. [Online]. Available: https://store.digilentinc.com/analog-discovery-2-100msps-usb-oscilloscope-logic-analyzer-and-variable-power-supply/ (Accessed: Jun. 27, 2021).

[41] *FE Reference Handbook 10.0.1*, Nat. Council Examiners Eng. Surveying, Greenville, SC, USA, 2020.

[42] S. Shiffman, A. A. Stone, and M. R. Hufford, "Ecological Momentary Assessment," *Annu. Rev. Clin. Psychol.*, vol. 4, pp. 1–32, Nov. 2008, doi: 10.1146/annurev.clinpsy.3.022806.091415.

[43] A. Minichiello and E. Hanks, "Becoming engineers in the middle years: Narrative writing as identity work in an undergraduate engineering science course," *Int. J. Eng. Educ.*, vo. 36, no. 5, pp. 1529–1548, 2020.

[44] K. E. Cook, Y.-L. Han, G. Mason, T. R. Shuman, and J. A. Turns, "Work-in-Progress: Engineering identity across the mechanical engineering major," in *Proc. ASEE Annu. Conf. Expo.*, Salt Lake City, UT, USA, 2018, p. 12, doi: 10.18260/1-2–32726.

[45] K. E. Cook, Y.-L. Han, G. Mason, T. R. Shuman, and J. Turns, "Implicit engineering identity in the mechanical engineering major," in *Proc. ASEE Annu. Conf. Expo.*, Tampa, FL, USA, 2019, p. 8, doi: 10.18260/1-2–29884.

Yen-Lin Han received the B.S. degree in material science and engineering from National Tsing Hua University, Hsinchu, Taiwan, in 1993, and the M.S. degree in electrical engineering and the Ph.D. degree in aerospace and mechanical engineering from the University of Southern California, Los Angeles, CA, USA, in 2006 and 2008, respectively.

She is currently an Associate Professor of Mechanical Engineering with Seattle University, Seattle, WA, USA. She also holds the patent for the continuous trace gas separator and several pending patents in autonomous vehicles and robotic testing apparatus. Her research interests include microscale molecular gas dynamics, micro fluidics, and heat transfer applications in MEMS and medical devices, as well as autonomous vehicles and robotics.

Dr. Han is the Co-Principal Investigator for the NSF Revolutionizing Engineering and Computer Science Departments Grant awarded to the Mechanical Engineering Department, Seattle University. She is a member of the American Society of Engineering Education and the American Society of Mechanical Engineers.

Jennifer Turns received the B.S. and M.S. degrees in systems engineering from the University of Virginia at Charlottesville, Charlottesville, VA, USA, in 1990, and the Ph.D. degree in industrial engineering from Georgia Tech, Atlanta, GA, USA, in 1998.

In 2000, she started as an Assistant Professor of Technical Communication with the University of Washington, Seattle, WA, USA. The department changed its name to Human Centered Design and Engineering in 2009, where she is currently a Professor and an Associate Chair. She publishes in such journals as the *Journal of Engineering Education and Design Studies*. Her research interests include reflection in higher and engineering education, innovation in engineering education, design education, and research through design.

Dr. Turns is currently the Co-Principal Investigator for the NSF Revolutionizing Engineering and Computer Science Departments Grant awarded to the Mechanical Engineering Department, Seattle University, to study how the department culture changes can foster students' engineering identity with the long-term goal of increasing the representation of women and minority in the field of engineering. She is a member of the American Society for Engineering Education.

Kathleen E. Cook received the B.M.E. degree in music and education from the University of Louisville at Louisville, Louisville, KY, USA, in 1988, and the Ph.D. degree in social and personality psychology from the University of Washington, Seattle, WA, USA, in 2002, with emphases in cognitive and educational psychology and a minor in quantitative methods.

In 2002, she started as an Assistant Professor of Psychology with Seattle University, Seattle, and is currently a Professor and a Chair. She publishes in engineering journals, such as the *ASME Journal of Mechanical Design*, *International Journal of Engineering Education*, and *Journal of Applied Engineering Science*. Her research interests include self and identity, person perception, and educational approaches in psychology, nursing, and STEM/engineering.

Dr. Cook is currently the Co-Principal Investigator for the NSF Revolutionizing Engineering and Computer Science Departments Grant awarded to the Mechanical Engineering Department, Seattle University. She is a member of the Society of Personality and Social Psychology and the Association for Psychological Science.

Gregory S. Mason received the B.S.M.E. degree from Gonzaga University, Spokane, WA, USA, in 1983, the M.S.M.E. degree in manufacturing automation from the Georgia Institute of Technology, Atlanta, GA, USA, in 1984, and the Ph.D. degree in mechanical engineering, specializing in multirate digital controls, from the University of Washington, Seattle, WA, USA, in 1992.

He worked with the Robotics Laboratory, Department of Defense, Keyport, WA, USA, for five years after receiving the M.S.M.E. degree. He is currently a Professor with the Department of Mechanical Engineering, Seattle University, Seattle. He is a Licensed Professional Engineer. His research interests are controls system and use of technology to enhance engineering education.

Dr. Mason is the Co-Principal Investigator for the NSF RED Grant. He is a member of the American Society of Engineering Education and the Society of Manufacturing Engineers.

Teodora Rutar Shuman was born in Belgrade, Yugoslavia. She received the Dipl.Ing. degree in mechanical engineering from Belgrade University, Belgrade, Serbia, in 1992, and the M.S. and Ph.D. degrees in mechanical engineering from the University of Washington, Seattle, WA, USA, in 1994 and 2000, respectively.

She joined the Mechanical Engineering Department, Seattle University, Seattle, in 2000 and is currently a Professor and a Department Chair. She is also an Affiliate Professor with the University of Washington. Her work is published in venues, including the IEEE TRANSACTIONS ON EDUCATION, *Journal of Engineering Education*, *Combustion and Flame*, *Chemical Engineering Journal*, and *Bioresource Technology*. Her research includes NOx formation in lean-premixed combustion, electromechanical systems for sustainable processing of microalgae, and numerous topics in engineering education.

Dr. Shuman is the Principal Investigator for the NSF RED grant. She is a member of the American Society of Engineering Education, American Society of Mechanical Engineers, and Algae Biomass Organization.