Introducing Circuits to Non-Majors for Self-Efficacy and Technical Literacy

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Abstract

Technical literacy is an essential skill given technology's impact on every aspect of modern society. *18-095: Getting Started in Electronics* is a technical elective course for non-engineering students developed to advance technical literacy through tinkering with electronics. *18-095* introduces the basic principles of electric circuit prototyping, debugging, and design. The course's target audience is undergraduates, serving students majoring in computer science, design, the liberal arts, and business, at a private R1 research institution. The class guides students through a series of laboratory exercises and design experiences to develop their confidence and ability in the domains of soldering, breadboard prototyping, circuit fundamentals, and microcontrollers. This paper evaluates the impact *18-095* has had over three semesters (Fall 2023, Spring 2024, Fall 2024), analyzing the development of student self-efficacy, identity, and sense of belonging, as measured across three surveys each semester (n = 71). Self-efficacy for circuit prototyping and design increased by a mean of 45.7 points between the pre-measure (mean = 37.6) and post-measure (mean = 83.2) on a 100-point scale, a significant increase. Despite the large increase in self-efficacy, increases in self-reported identity as a "maker" or "engineer" did not achieve significance, whereas a small but significant increase in sense of belonging was observed. Students' ability to successfully build a circuit with no assistance based on its schematic in a lab practical exercise did not correlate with student-reported self-efficacy, suggesting that students may factor in social support from peers as part of their ability to approach future electronics projects. This work provides insight into an understudied group in engineering education: non-majors in an elective course. This sort of outreach course is critical to developing broad, long-term technical literacy.

Introduction

Technical literacy is essential for modern careers and informed citizenship in the 21st century [1]. While many undergraduate programs require technical elective courses in science and engineering [1], [2], [3], [4], few studies have examined the long-term development of student attitudes, such as self-efficacy and identity, regarding engineering in non-major populations [4], [5]. Non-engineering graduates must be technically savvy in today's workplace. Therefore, students outside of the engineering disciplines should be able to develop technical skills without the traditional barriers of calculus and physics that gatekeep the engineering major at the university level. Our course *18-095: Getting Started in Electronics* draws students from the fine arts, humanities, computer sciences, and business disciplines, helping them improve their technical literacy and technical comprehension. The class is named in tribute to Forrest M. Mims III's legendary experiential text *Getting Started in Electronics* [6]. Lab exercises and circuits for

18-095 were adapted and modified from Mims' extended work [6], [7] and Charles Platt's modern successor *Make: Electronics* [8].

Non-major courses in most disciplines are targeted towards students who are not expected to become practitioners [9], [10]. These courses focus on developing translatable skills rather than teaching specific technical content [4]. *18-095* follows this strategic approach, de-emphasizing mathematics and circuit analysis in favor of developing practical hands-on skills [10], [11], [12]. Engaging in prototyping and debugging circuits builds the skills of critical thinking, problem-solving, and hypothesis testing. Design experiences give students the opportunity to identify a need, work within constraints to solve a problem, and communicate their results. We believe this course will teach students to engage with questions regarding society's use of technology, cultivate personal empowerment with respect to electronic artifacts, and help students become better-informed consumers and citizens.

A variety of experiences are incorporated into the class to provide students the opportunity to build their circuit prototyping and design skills. The technical assignments include eight guided laboratory assignments and two open-ended projects, each scaffolded by a proposal process, where students meet with teaching assistants to check in and get critical feedback on their design ideas. A *Lab Practicum* is administered as an authentic performance measure near the end of the course. Three reflection assignments are administered throughout the semester at week 2 (pre), week 9 (mid), and week 14 (post) to measure the development of student attitudes throughout the course. These reflection results are the data analyzed in this paper.

In addition to measuring students' self-efficacy, the reflection assignments also measure their identity both as a "maker" and "engineer" as well as their sense of belonging to the engineering discipline. If students are to engage meaningfully with technology after this course, a stronger sense of identity as an engineer or maker is a desirable outcome. Identity and sense of belonging have been tied to persistence with STEM subjects and long-term career success [13], [14]. A heightened sense of belonging may translate into more confidence taking roles adjacent to technical fields, working closely with practicing engineers.

The present study sought to test three research questions (RQs) about students' self-efficacy and sense of belonging.

Research Questions

RQ1: Does a non-major student's self-efficacy change after completing circuit labs and a circuit design project?

Self-efficacy is an individual's belief in their capability to complete tasks and achieve a planned outcome [15]. Higher self-efficacy is associated with positive outcomes in engineering education and career development, such as increased retention in STEM fields and decreased burnout in stressed student populations [13]. Potential sources of self-efficacy include mastery experiences (opportunities to successfully use a skill), vicarious experiences (watching someone else successfully do a task), verbal persuasion (receiving message of one's confidence in your ability to accomplish something), and physiological/affective state (feelings of anxiety or stress) [15].

We hypothesize that a course focused on developing the skills of soldering, interpreting schematics, building circuits on a breadboard, and designing microcontroller instrumentation will provide mastery experiences that build confidence and self-efficacy in the non-major population. For some of these students, this may be the only technical laboratory course they take in college.

RQ2: Does a student's identity as a "maker" or "engineer" or their sense of belonging change after completing circuit labs and a circuit design project?

It has become commonplace for engineering programs to weave design experiences throughout the curriculum, as early as in a first-year "cornerstone" design project [16], [17]. Since these experiences are viewed as essential for engineering students at the outset of their studies, exposing non-majors to these design experiences ought to build technical ability and literacy as well [18]. Engaging in these activities may also increase a student's identity as a maker or engineer.

We predict that an increase in identity as an engineer might result from working on an open-ended circuit design, given the importance of design projects in educating engineers. An alternative identity as a "maker" can be a gateway for further exploration in the engineering discipline for students who are not engineering majors [19].

RQ3: Does self-efficacy correlate with performance on a lab practical task?

Since self-efficacy and identity are self-reported attitudes, we want to test if these attitudes correlate with an authentic performance measure: a practical laboratory exam. We hypothesize that self-efficacy reported at the course midpoint will predict students' success or failure at a practical circuit-building lab exercise, with students with higher self-efficacy successfully completing the task at a higher rate than students with lower self-efficacy.

Methods

Instructional Design

This 14-week lab course is offered to up to 36 students per semester. A timeline showing the timing of the lab assignments, projects, and surveys is shown in Figure 1 below. The technical assignments include eight guided laboratory assignments, two open-ended projects scaffolded by a proposal and consultation with a TA mentor, and one laboratory practical exam. Undergraduate teaching assistants support the students in open lab hours and with targeted mentorship for their projects.

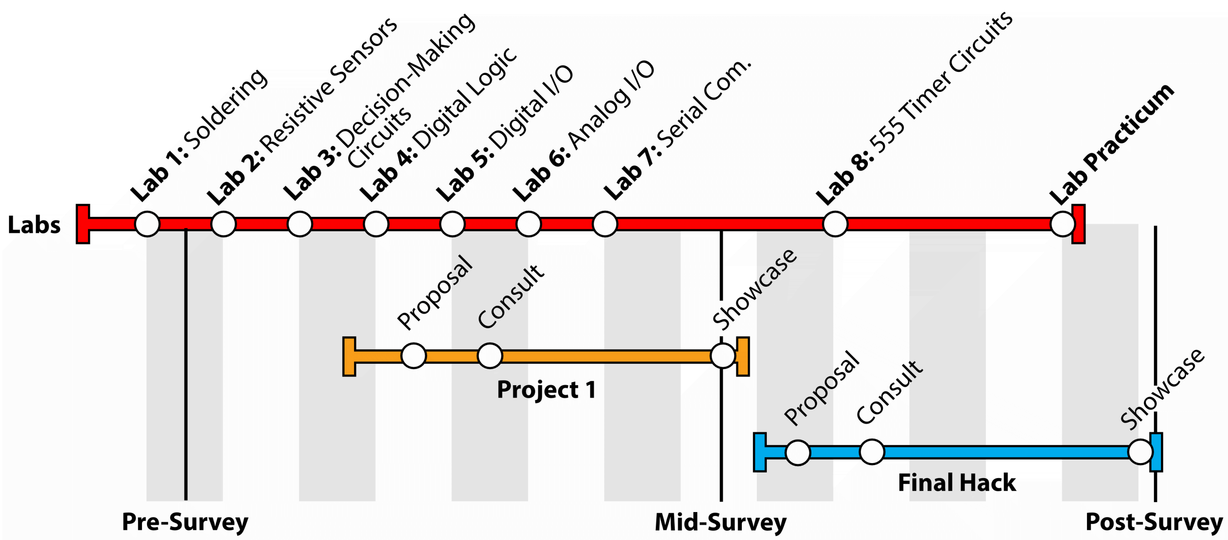

Figure 1: Timeline of *18-095: Getting Started in Electronics*, including lab assignments, design projects, and reflection surveys.

Weekly laboratory exercises supporting these skills are listed in Table 1 below. The fundamental practical skills developed by the class are the following:

- Soldering
- DC measurements
- Circuit prototyping on a breadboard
- Microcontroller interfacing

Each student receives a lab kit containing components and tools to build and test these circuits. The microcontroller chosen is a generic version of the Arduino Uno for its relative ease of use for newcomers and large volume of help resources available online.

Table 1: Weekly laboratory assignments and their relationship with the fundamental skills targeted by the class

Course Assignment *Circuits built*	**Skills Supported**
Lab 1: Soldering *Blinking LED PCB*	Soldering, DC measurements
Lab 2: Resistive Sensors *Photocell; thermistor; potentiometer*	Circuit prototyping, DC measurements
Lab 3: Decision-Making Circuits *Temperature-controlled fan; Night light*	Circuit prototyping, DC measurements
Lab 4: Digital Logic Control *Full adder; SR latch; 2-to-4 decoder*	Circuit prototyping
Lab 5: Digital I/O *7-segment display driver; countdown timer*	Microcontroller interfacing, circuit prototyping
Lab 6: Analog I/O *Light theremin; Joystick RGB LED controller*	Microcontroller interfacing, circuit prototyping
Lab 7: Serial Communication *I2C LCD Display; RGB NeoPixel Traffic Signal*	Microcontroller interfacing, soldering, circuit prototyping
Lab 8: 555 Timer Circuits *LED flashing circuit; Audio synthesizer*	Circuit prototyping, soldering

Partway through the semester, students are paired into groups of two to complete *Project 1*, the *Hamerschlag Hall Improvement Project*, intended to improve the experience for users of our campus' historic electrical engineering building. Students interview engineering students and propose a way to improve the campus space with a circuit-based project. A second project is more open-ended, allowing students to build a project of their choosing called a *Final Hack*. Students are given the option to complete the *Final Hack* independently or with a partner of their choice. Each project takes approximately 4 weeks from beginning to end: students submit a proposal, consult with a TA mentor to refine their ideas, and have approximately 2 weeks to build their prototypes during class and open lab hours. The results of each of these design experiences are exhibited to the campus community during public showcases.

Students are also administered a 30-minute *Lab Practicum* to benchmark their circuit prototyping and debugging skills with an authentic performance measure. Students are asked to build a resistor-based circuit on a breadboard from its schematic (build a circuit) and find errors in an incorrectly wired circuit provided on a breadboard (fix a circuit). This practical assessment can be found in the Appendix. We desire to gain an understanding of students' success (no mistakes) or failure (one or more mistakes) in the circuit-building task specifically, as this requires the synthesis of several skills: interpretation of a schematic, circuit prototyping, and debugging methodology.

Research Design

Three reflection assignments are completed throughout the semester, at week 2 (pre), week 9 (mid), and week 14 (post). Students complete all eight laboratory exercises and *Project 1* between the pre and mid surveys and the *Final Hack* and *Lab Practicum* between the mid and post surveys.

These reflection assignments ask students to respond to several open-response prompts, as well as complete these surveys:

- Self-efficacy for circuit tinkering (5 items) and circuit design (4 items) on a 100-point unipolar scale. This self-efficacy survey is adapted from extant engineering tinkering and design instruments [20], [21], [22].
- Sense of identity as a "maker," sense of identity as an "engineer," and sense of belonging in an engineering course (4 items each, 7-point Likert scale). Our belonging instrument is a shortened version of one developed by Walton and Cohen [23].

Participants' demographic information is collected using two open-ended questions: "What is your major or intended major?" and "What is your gender identity?" on the pre survey. A few open-response questions prompted students to reflect on the sources of their growth, such as "What experience(s) in this course have contributed to your confidence in building circuits?" and "What did you learn from the practicum experience?" on the post survey. Also on the post survey, students were asked to respond on a 7-point Likert scale to the item, "After taking this course, I'm more likely to incorporate electronics into my future creative or personal projects." The complete survey instrument can be found in the Appendix.

Results

Student demographics. Student demographics were pooled across Fall 2023, Spring 2024, and Fall 2024 semesters (Figure 2). All students who completed this survey question, regardless of their participation in the other surveys, are included in these data (n = 89). A majority of students (50%) came from a Computer Science discipline, such as machine learning, robotics, or computer science. The next largest student demographic was Fine Arts (20%), which included design and music majors. The third largest demographic was Engineering (10%), including biomedical engineering and materials science majors. The remaining 20% of students came from the sciences, information sciences, business, and the humanities.

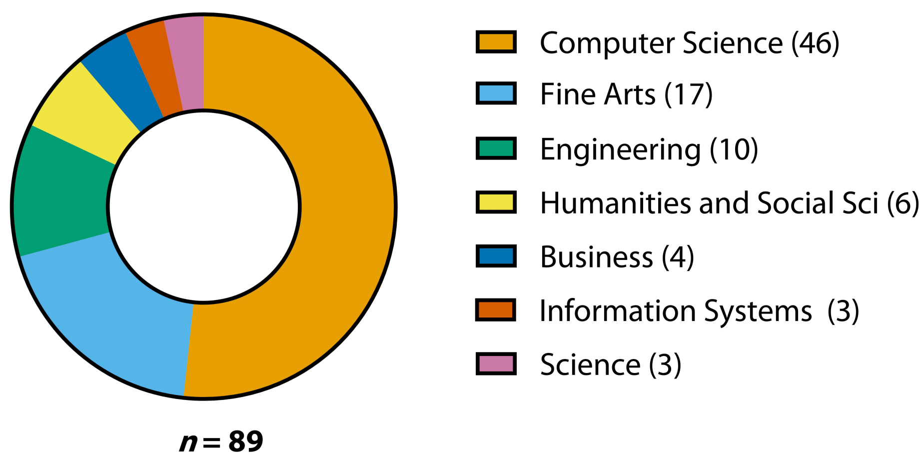

Figure 2: Number of students by college across three semesters (Fall 2023, Spring 2024, Fall 2024; *n* = 89 responses)

Gender demographics for the three semesters were 64% male, 30% female, and 6% identifying as another gender identity (*n* = 90). Students also came from different stages of their education. While most students (67%, *n* = 90) were in their third or fourth year, a few graduate students and first- or second-years also participated, evidencing the broad audience and range of experiences students brought to the class (Figure 3).

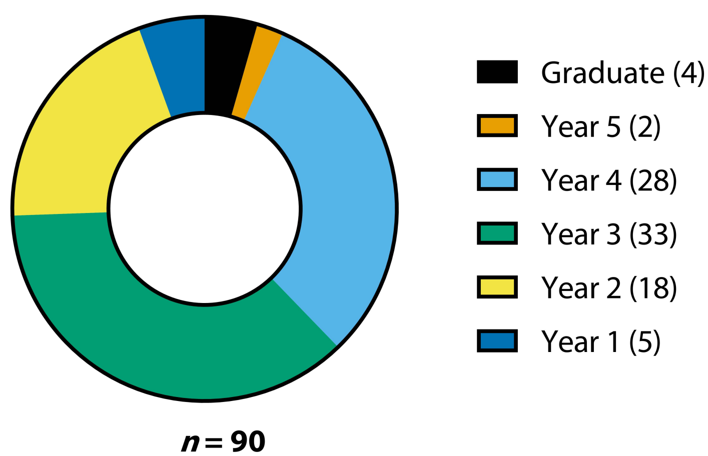

Figure 3: Number of students by class standing across all three semesters (Fall 2023, Spring 2024, Fall 2024; *n* = 90 responses)

Mastery experiences of building circuits were associated with a substantial increase in electronics self-efficacy. Data were pooled across the Fall 2023, Spring 2024, and Fall 2024 semesters, and only individuals who responded to all three surveys were included in this analysis (*n* = 71, Figure 4). Tinkering self-efficacy and design self-efficacy were combined into a single measure called circuit self-efficacy. Reported self-efficacy increased by a mean of 45.7 points between the pre survey (mean = 37.6) and post survey (mean = 83.2) on a 100-point scale (Table 2). Paired t-tests indicated there was a significant effect ($p < 0.05$) with large effect size (Cohen's $d > 0.8$) between pre/post ($t(70) = 17.84$, $p < 0.001$, Cohen's $d = +2.35$) and pre/mid surveys ($t(70) = 15.55$, $p < 0.001$, Cohen's $d = +1.90$), and a medium effect size (Cohen's $d > 0.5$) between mid/post ($t(70) = 7.08$, $p < 0.001$, Cohen's $d = +0.75$). Students exhibited a larger increase in self-efficacy in the first half of the course than in the second half.

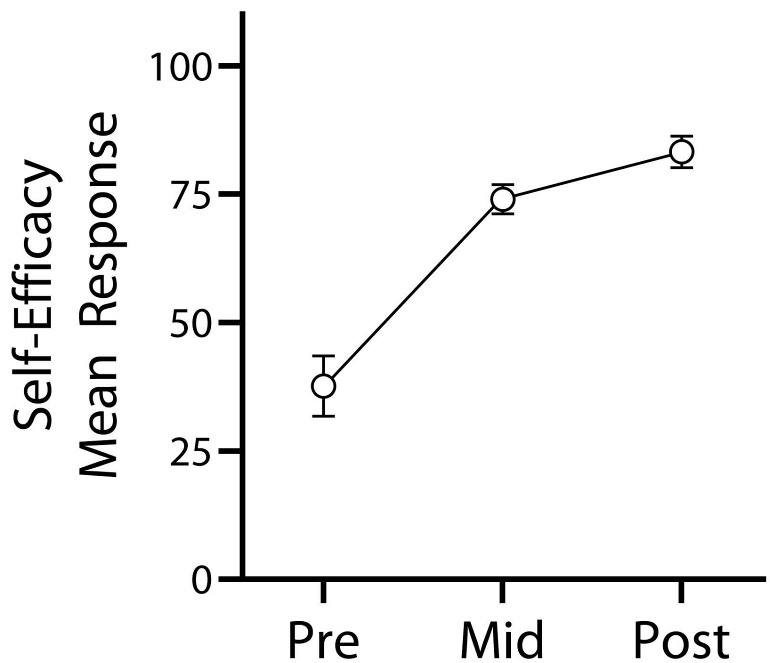

Figure 4: Development of circuit self-efficacy over course of semester (*n* = 71). The mean change in self-efficacy for circuit tinkering and design (combined into one measure) is +45.7 from pre to post on a 100-point scale. The change at each time point was statistically significant ($p < .001$). Error bars represent 95% confidence intervals.

Table 2: Summary statistics of change in circuit self-efficacy across semester. Pairwise comparisons were made between the three surveys with the paired t-test. All comparisons between time points were statistically significant ($p < 0.001$).

	Change in self-efficacy	**Cohen's *d***	***t*(70)**	***p***
Pre/Post	+45.7	+2.35	17.84	<.001
Pre/Mid	+36.5	+1.90	15.55	<.001
Mid/Post	+9.2	+0.75	7.08	<.001

Responses to “What experience(s) in this course have contributed to your confidence in building circuits?” were coded as matching one of the four traditional sources of self-efficacy as identified by Bandura: 1) mastery experiences, 2) vicarious experiences, 3) verbal persuasion, and 4) physiological/affective state [15]. Most students ($n = 64$, 91% of responses) identified mastery experiences of building circuits as the main source of self-efficacy. A smaller number ($n = 6$, 7% of responses) identified the impact of instructional or social support, from either a partner on one of the class projects or from a teaching assistant, which we coded as verbal persuasion in Bandura’s framework. There were zero responses coded as vicarious experience or physiological/affective state.

The weekly labs were mentioned most often as an impactful mastery experience. Here is a sample of responses:

Coded as mastery experiences:

> “I really enjoyed coming in every week to work on the labs. I felt like I was learning a lot, and got to witness how what I learned came into play. It also became easier throughout the semester to design complex circuits.”
>
> “Spending a lot of time breadboarding helped, and getting more hands-on experience with useful analog design elements like voltage dividers, potentiometers, and how to take advantage of the multimeter.”
>
> “Debugging and designing my own circuits definitely boosts my confidence.”

Coded as verbal persuasion:

> “Also, my TAs have helped me immensely; they validate my approaches and steer me in the right direction.”

Students did not experience a significant change in identity but did demonstrate an increased sense of belonging. There were small but nonsignificant increases in self-reported identity as a “maker” and as an “engineer,” confirmed by pairwise t-tests (see Figure 5 and Table 3, $p > 0.05$). The increase in self-efficacy that the class experienced did not concur with a significant change in identity for the class in aggregate. Yet, sense of belonging showed a significant increase ($p < 0.05$) with small effect size (Cohen’s $d > 0.2$) between pre/post ($t(70) = 3.81$, $p < 0.001$, Cohen’s $d = +0.45$) and mid/post ($t(70) = 2.92$, $p = 0.005$, Cohen’s $d = +0.35$). In contrast with self-efficacy, the increase in belonging was greater in the second half of the course than in the first half, while small increases in both identity measures did not achieve statistical significance.

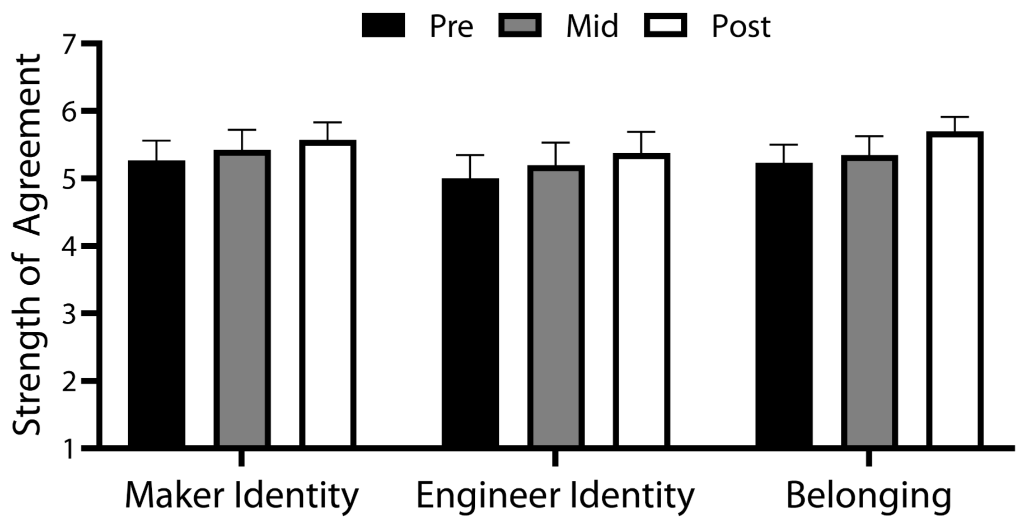

Figure 5: Maker Identity, Engineer Identity, and Belonging Results Summary. The y-axis represents the mean response on the 7-point Likert scale (1 = strongly disagree, 7 = strongly agree). The x-axis represents the type of identity students hold as reported in the class surveys. Neither identity as a "maker" or as an "engineer" significantly changed across the semester, but sense of belonging significantly increased from pre to post ($p < .001$) and mid to post ($p < .01$). Error bars represent 95% confidence intervals.

Table 3: Summary statistics of change in identity and belonging across semester. Pairwise comparisons are made between the three surveys with the paired *t*-test. Cohen's *d* and *p* values are reported. Rows with *p*-values reaching significance ($p < 0.05$) are highlighted.

Comparison		**Change (7-pt scale)**	**Cohen's *d***	***t*(70)**	***p***
Maker Identity	Pre/Mid	+0.16	+0.13	1.38	0.171
	Pre/Post	+0.30	+0.30	1.21	0.053
	Mid/Post	+0.15	+0.12	1.97	0.229
Engineer Identity	Pre/Mid	+0.20	+0.14	1.55	0.126
	Pre/Post	+0.38	+0.27	1.19	0.054
	Mid/Post	+0.18	+0.13	1.96	0.239
Belonging	Pre/Mid	+0.11	+0.10	1.16	0.250
	Pre/Post	+0.46	+0.45	3.81	<0.001
	Mid/Post	+0.35	+0.33	2.92	0.005

Identity did not come up often in the open-response surveys, but one student did explicitly mention the term “maker”:

> “I loved this class!!!! So fun. I love making things. I AM a maker”

Reported self-efficacy does not predict success on a lab practical exam. During the *Lab Practicum*, students were asked to 1) build a circuit given its schematic and 2) fix a circuit on a breadboard. Students had 15 minutes to complete each task. The circuit students built consisted of four resistors (see the Appendix). Fifty-six students (79% of the class) built the circuit without any mistakes. The remaining 21% of students built circuits containing at least one error.

Students were also provided with a breadboard and a malfunctioning LED circuit and were tasked to find the errors and restore its function. Over 95% of students succeeded in this task. Given the low variability in student performance, these results were not considered in this analysis.

We grouped the class based on students’ success or failure on the circuit-building task to see how self-efficacy just before the *Lab Practicum* may have differed between these groups. We performed logistic regression with the class and found a poor relationship between self-efficacy (on the mid-survey) and success or failure on the circuit task (Figure 6). Fit was evaluated by Tjur’s R-squared value, which is the absolute difference between the means of the probabilities of success and failure. This pseudo-R-squared measure was 0.023, indicating little separation between the two groups on the basis of self-efficacy.

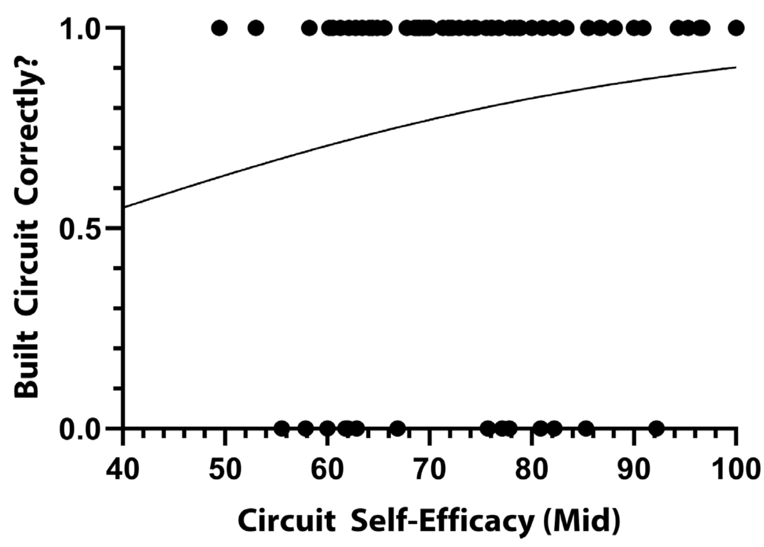

Figure 6: Logistic regression of success or failure in practical circuit-building task predicted by self-efficacy (*n* = 71). Student groups that succeeded and failed at the circuit build task reported similar self-efficacy at the midpoint of the class. Self-efficacy was a weak predictor of success on this task (Tjur’s R-squared value = 0.023).

Qualitative responses from students indicated stress caused by the *Lab Practicum*, despite their relatively high success rate. The experience also encouraged critical self-reflection, with the post survey asking, “What did you learn from the practicum experience?” Selected responses follow:

> “The lab practicum made me feel like I was actually doing something right when usually when [sic] I build circuits it feels like trial and error.”
>
> “I think just thinking through methodically the problem / I think just identifying the issues”
>
> “I learned that debugging the circuit was actually something I had done a lot during labs”
>
> “To be confident in myself”
>
> “I still have a slight gap between the theoretical and the practical”
>
> “I need more practice”

Discussion

Our course is one of many recent examples that builds technical skills, including hardware tinkering and design, for students outside of the traditional electrical engineering university track [10], [11], [24], [25]. Despite this focus, 10% of the students that took our class were engineering majors (mechanical, civil, or chemical engineering), and 50% were computer science majors. This may be because our course is our college’s only electrical circuits service class and fulfills a science and engineering elective requirement for computer science students. The class’s orientation towards practical use of sensors and microcontrollers attracted a few PhD and master’s students who wanted to learn how to build instrumentation for their research (about 5% of students). Our university’s industrial design program was another major constituency, and these students comprised the majority of those from the fine arts. These course demographics suggest that our approach allowing students to engage in guided design experiences draws students from a variety of disciplines and backgrounds, though students with some technical background still predominate.

While there have been numerous studies regarding self-efficacy in students pursuing engineering careers [13], [26], [26], [27], studies of technical development in non-engineering students are less common. Retz and Dickerson’s *Microcontrollers for Everyone* elective course for liberal arts majors is most closely aligned to our work, as the key experience was a final open-ended design project [11]. However, student attitudes toward engineering were not measured. Revelo et al. performed pioneering work studying long-term self-efficacy for students who took *ECE 101 - Exploring Digital Information Technology*, a technical literacy course [4], [5]. *ECE 101* was broader in focus than our course, split evenly between software and hardware; our class emphasizes electronics. Their class, like ours, culminated in an open-ended design project supported by TAs. The authors investigated the sources of self-efficacy through interviews and found that verbal persuasion and mastery experience were mentioned most often. Faculty and teaching assistants were key sources for verbal persuasion [4].

We previously reported measurements of self-efficacy and identity in the pilot semester of this course [28], but only five students participated in the study, and no pre-course survey was used to benchmark self-efficacy at the start of the semester. This made it difficult to ascertain the complete impact of the course on student self-efficacy and identity. Since then, this study has expanded to $n = 71$ students who have taken a complete pre, mid, and post survey, providing a more holistic picture of how self-efficacy and identity develop coincident with course experiences.

Our first objective was to determine the impact of the course on students' self-efficacy. Students' self-efficacy for circuit tinkering and design increased across the entire semester, supporting our hypothesis that these experiences would have a positive effect. The pre-to-post change from a mean of 37.6 to 83.2 on a 100-point scale was significant for our sample ($p < 0.001$, $n = 71$ students across three semesters). The increase of +45.7 on a 100-point scale had a large effect size (Cohen's $d = +2.35$). The bulk of this gain in self-efficacy occurred in the first 9 weeks of the course, which consisted of eight laboratory exercises and the first design experience, as the mid-survey represented an increase of +36.5, 80% of the total gain. The interventions in the latter part of the course, the second design experience (*Final Hack*) and *Lab Practicum*, coincided with a further +9.2 increase in self-efficacy between mid/post time points with a moderate effect size (Cohen's $d = +0.75$). The course's effect on self-efficacy was strong, consistent with its emphasis on developing practical skills.

Retz and Derickson's *Microcontrollers for Everyone* course [11] and electronics hardware-oriented massively open online courses (MOOCs) that delivered similar hands-on experiences at scale [24], [25] demonstrated the effectiveness of the project-based learning approach at building competence in electrical hardware. Project-based learning presents students with mastery experiences, which are one of the four sources of self-efficacy identified by Bandura, and the most relevant to a lab-oriented course. Our practicum, labs, and design projects were designed as mastery experiences to build student self-efficacy. It is not surprising that responses to the question "What experience(s) in this course have contributed to your confidence in building circuits?" overwhelmingly (over 90%) mentioned direct experiences building circuits! The variety of interventions employed, including week-long laboratory assignments, extended design experiences, and a debugging practical exam, all seemingly contributed positively to student self-efficacy. However, because our study lacked a control group, we cannot definitively say that these increases were due *solely* to factors related directly to the course. For example, students may have been involved in club projects or hardware hackathons during the semester.

We suggest that others who wish to adapt our approach at their institutions consider how to incorporate a wide variety of mastery experiences in their courses, starting with small laboratory exercises and working towards a guided design project. Scaling this class to a larger number of students can follow the flipped classroom format popularized by MOOCs, where video modules introduce fundamental concepts, so class time becomes a series of guided laboratory exercises with TAs available to help students. The instructor becomes more of a facilitator and manager of a TA mentorship team in this model. Little value is lost by reducing in-person lecture time, as most of the active, productive learning comes from engaging in mastery experiences. It is vital to have TAs that are committed to providing an inclusive classroom climate, understanding that students will achieve different levels of mastery. A growth mindset is emphasized to students and teaching staff alike, and collaboration on projects is encouraged. This peer learning model scales up well, leveraging the expertise of students and TAs together to build a supportive and motivating learning community.

Our second objective was to determine the impact of the course on students' identity and sense of belonging. While identity as both a "maker" and "engineer" saw marginally significant gains over the course of the class, sense of belonging in an engineering course increased from 5.23 to 5.70 on a 7-point scale, a small but significant increase ($p < 0.001$, Cohen's $d = +0.45$). Further analysis showed that there was not a significant increase in belonging until the post-survey (from pre/mid; $p = 0.250$, Cohen's $d = +0.10$), with a small and significant increase from mid/post ($p = 0.005$, Cohen's $d = +0.33$). These results suggest that the activities in the latter half of the course, consisting of the *Lab Practicum* and the *Final Hack* design project, may have contributed the most to the development of belonging, or that it takes non-major students weeks to build up their belonging in a novel discipline. We believe that the authentic measure of the *Lab Practicum* was impactful because it was a high-stress testing situation (the pressure to perform well was mentioned in numerous surveys) that most students successfully navigated. Definitively attributing the growth in belonging to the practicum, however, requires comparison to a control group, which we did not have in the present study. We speculate that the *Final Hack*, being a second attempt at a design experience, may have also had an impact on post belonging given design's importance to the engineering discipline [16], [18].

Our third objective was to attempt to benchmark student attitudes about self-efficacy to an authentic performance measure: the *Lab Practicum*. Success or failure on this practical examination was not accurately estimated from mid-term self-efficacy, confirming that self-efficacy is not always an accurate measure of students' actual ability. We speculate that the *Lab Practicum* was timed and performed in an artificially isolated environment, while all other assignments were collaborative and open-ended in nature. Students may factor in social support when assessing their ability to succeed in circuit-building tasks, which was not available in the controlled environment of the *Lab Practicum*. Changing testing conditions to allow controlled TA support or a less stringent time limit may result in exam performance more correlated to self-efficacy. Remarkably, 75% of students built a circuit from a schematic with zero mistakes, and over 90% could fix a non-functional circuit, despite their lack of formal training before this class.

Understanding the lasting impact of our course on its intended audience will help to optimize its instructional design. When asked their level of agreement with the statement "After taking this course, I'm more likely to incorporate electronics into my future creative or personal projects," students' mean response was 6.14 ± 0.86 on a 7-point Likert scale. This is a promising sentiment, so we propose that a longitudinal study of students after they leave the course will contribute to our understanding of the longevity of any positive outcomes. Students may engage with technology differently after taking the course and identifying these attitudes will be informative. We plan to expand our study by following up with students in interviews focused on understanding how, if at all, they are applying the knowledge and skills developed in this course over the long term and if their self-efficacy for these skills has maintained. This will build on work by Revelo et al., which found that non-engineering students who took *ECE 101* had notable long-term outcomes, with students applying their newfound skills in personal projects [4], [5].

We reaffirm that there is value in everybody learning how technology works, given its massive impact on our daily lives. By working on open-ended design projects, students will experience a creative relationship with technology rather than one of uncritical consumption. Coming from diverse disciplinary backgrounds, they will be better equipped with tools for interacting with the technology-laden workplace, and these experiences may contribute to an increased sense of belonging and agency in this environment. Engaging with circuit debugging and design develops critical thinking, experimentation, and problem-solving skills translatable to any career. *18-095: Getting Started in Electronics*, demonstrates an effective way to build technical literacy to a broad audience in a manner that is personally meaningful, validated over three semesters of repeated success. While our approach targeted non-majors, making more space for creativity and design experiences in engineering curricula should have similar positive impacts on student self-efficacy and belonging. Engineering educators from all disciplines can broaden their impact by providing technical training to non-major students. *It is imperative to do so* – society needs more people who are willing to engage with the technology that increasingly controls our lives.

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Appendix

Self-Efficacy Instrument

Scale = 0 (completely uncertain) to 100 (completely certain)

Instructions: Please respond to the following statements regarding your level of certainty that you can perform the different activities. If you aren't sure, just go with your first instinct. There are no right or wrong answers!	
Tinkering self-efficacy (5 items, Pre/Mid/Post)	I can work with circuits.
	I can build circuits.
	I can recognize changes needed for a circuit to work.
	I can modify circuits to adjust their behavior.
	I can use tools to fix circuits.
Design self-efficacy (4 items, Pre/Mid/Post)	I can identify tasks that circuits can accomplish.
	I can develop a circuit to achieve a desired outcome.
	I can test that my circuit design works.
	I can assess the value of my circuit design.

Identity/Sense of Belonging Instrument

Scale = 7-point Likert (7 = Strongly Agree, 1 = Strongly Disagree, with neutral point (4) of neither disagree or agree)

Instructions: Please respond to the following statements regarding your level of agreement or disagreement with the following statements. If you aren't sure, just go with your first instinct. There are no right or wrong answers!	
Maker ID (4 items, Pre/Mid/Post)	I am a "maker."
	I can relate to "makers."
	I have a lot in common with "makers."
	"Makers" share my personal interests.
Engineer ID (4 items, Pre/Mid/Post)	I am an engineer.
	I can relate to engineers.
	I have a lot in common with engineers.
	Engineers share my personal interests.
Sense of Belonging (4 items, Pre/Mid/Post)	I feel like I belong in an engineering class.
	I fit in well with engineering students.
	I feel comfortable with engineering students.
	I feel like an outsider in an engineering class.*

***reverse coded**

Additional Questions

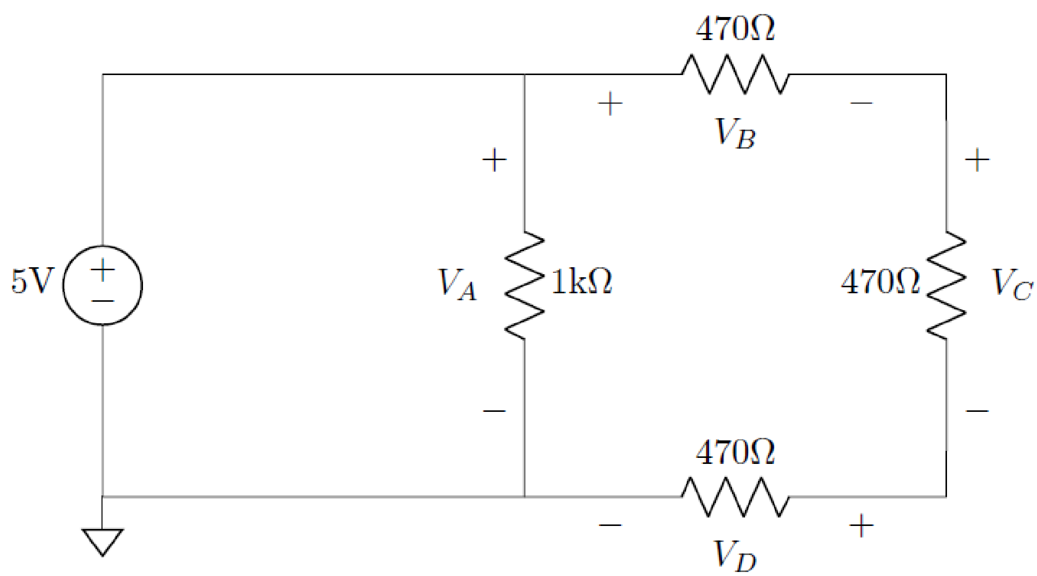
Demographics (Pre only)	What is your major or intended major? [open-ended response]
	What is your gender identity? [open-ended response]
Sources of self-efficacy (Mid/Post only)	What experience(s) in this course have contributed to your confidence in building circuits? [open-ended response]

Reflecting on the *Final Hack* (Post only)	In your opinion, how successful was your final hack? [0 = completely unsuccessful, 100 = completely successful]
	How do you define "success" in this project? [open-ended]
	What was the most interesting thing you learned this semester?
Reflecting on the *Lab Practicum* (Post only)	Which of the two practicum tasks did you find to be more challenging? ['build a circuit' or 'fix a circuit']
	How much did the practicum tasks impact your overall confidence in this course's material?
	What was challenging about the practicum tasks?
	What did you learn from the practicum experience?

Lab Practicum

Task 1: Build a Circuit

Carefully examine the circuit below.



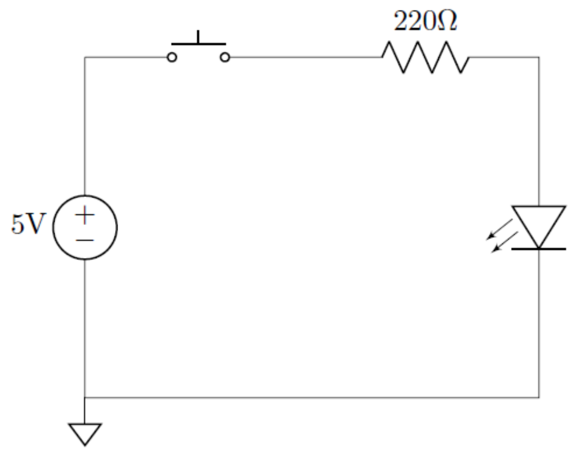
Given the materials provided to you, please assemble this circuit on the breadboard. Make sure that you are using the right components.

Power the circuit, then measure the voltages V_A, V_B, V_C, and V_D as labeled on the circuit schematic.

Do you believe these measurements are correct? Use what you know about circuits to justify the voltages that you measured.

Task 2: Fix a Circuit

Carefully examine the circuit below. When powered, the LED will turn on when the button is pressed, otherwise the LED is off.



Your TA has provided you with an implementation of this circuit that has several errors. Your task is to use the tools provided to find the errors and fix the circuit.

- Use your multimeter to make observations
- You may ask for new components if you believe they need to be replaced
- Any part of the circuit could be an issue, so be prepared to test anything.

Any time you are certain that you have found an error, please write a description of that error in the space below.

Errors were:

- *LED leads were shorted by insertion in the same breadboard row*
- *Pushbutton was wired incorrectly, to be always connected*
- *Wire connecting 5V supply to the circuit was not stripped on one end, so electrical contact was not being made to the supply voltage*