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Design Curriculum in Introductory Circuits Laboratory Assignments and the Influence on Innovation Self-Efficacy

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Abstract

This paper examines the impact of integrated design elements in a second-year introductory circuits course on students' innovation self-efficacy (ISE). Building upon a pilot study from Spring 2024, this research focuses on the implementation of updated laboratory assignments in one section of the course while maintaining the original curriculum in a parallel section. The updated curriculum emphasizes experiential learning through active learning engagement, simulation exercises, open-ended design challenges, and reflection. This allows students to navigate the full design process, from conceptualization to testing and evaluation.

Results from the ISE measurement instrument show significant increases in six of eight ISE factors exclusively in the research group. Reflective responses support these results and highlight that active and experiential learning with integrated design elements can be augmented by leveraging technology, leading to a challenging and yet fulfilling and meaningful learning experience.

Introduction

Engineering education is undergoing a critical shift to integrate experiential and design-based learning into traditionally analytical curricula [1–3]. Although first-year engineering courses and senior capstone projects often emphasize creativity and innovation, second- and third-year courses frequently lack design-oriented experiences [4]. Increases in student confidence within the first year then decrease throughout the second- and third-year only too be re-developed at the end of a degree [5]. This approach fails to utilize the momentum that students develop in their first year, and limits students' exposure to critical skills in iterative design, real-world problem solving, and computational tools, which are essential for their development as professional engineers [1]. Addressing this gap, the introductory linear circuits course (ECE 101) at the university implementing this intervention has been redesigned to incorporate design-focused laboratory modules, bridging theoretical concepts with practical application [6].

This study builds on a Spring 2024 pilot initiative, where the redesigned laboratories introduced students to tools such as Simulation Program with Integrated Circuit Emphasis (SPICE) simulations to accompany hands-on circuit building, and iterative evaluation of design solutions. The initial results of the pilot indicated promising gains in student confidence and competence in design tasks [6]. Specifically, the pilot demonstrated a significant improvement in confidence levels for students' use of simulation tools (mean increase from 2.9 to 4.3 on a 5-point Likert scale, $p = 0.0002$) and matrix problem-solving (mean increase from 3.0 to 4.1, $p = 0.0041$) [6], when compared with students from previous cohorts. To rigorously assess the impact of these changes, a controlled study was conducted in the Fall 2024 semester. Two concurrent sections of ECE 101 were evaluated—one implementing the new design curriculum and the other retaining the traditional format. The study focuses on ISE, a critical construct in engineering education that reflects students' confidence in their ability to ideate, design, and implement solutions [7].

Methods

Study Design

This study employs a controlled design to evaluate the impact of integrating design-oriented laboratory exercises into a second-year introductory linear circuits course. Two concurrent sections of the course were utilized: one section retained the traditional laboratory curriculum, while the other section implemented redesigned labs.

Study Population

Course participants included 119 students, with 52 in the control group and 67 in the research group. Identifiable information was not collected. Students could choose to participate in the pre-semester survey, the post-semester survey, or both. Students who chose to participate in the surveys provided demographic information, shown in Figure 1 and Table 1.

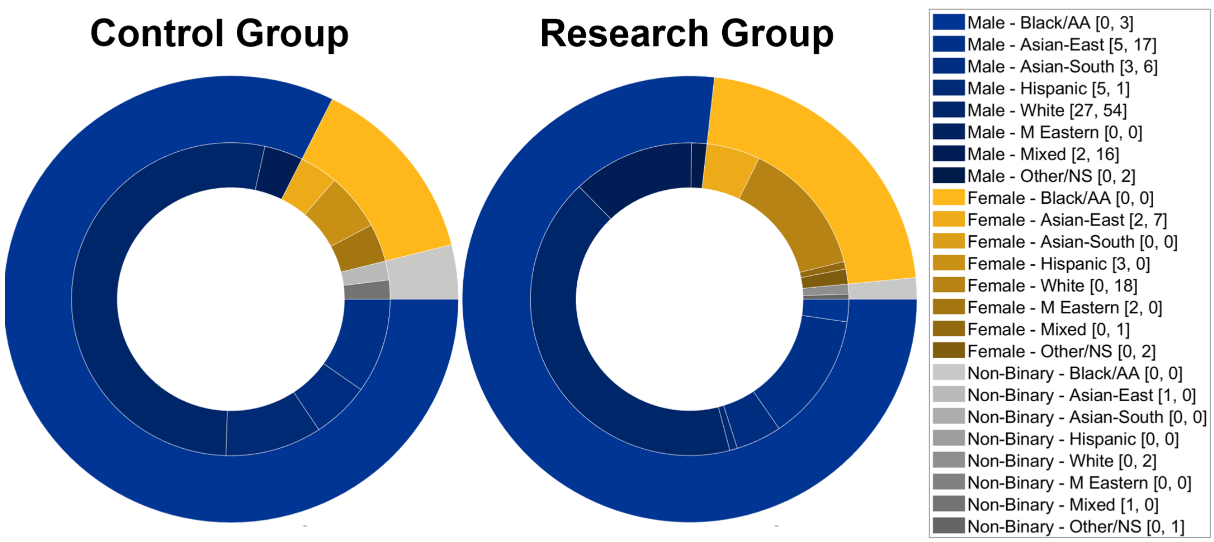

Figure 1: Demographics aggregated by group

Table 1: Study Demographics; reported as pre-control, post-control, pre-research, post-research

Ethnicity	Female	Male	Non-Binary/Other	Total
Black/African American	00-00-00-00	00-00-01-02	00-00-00-00	00-00-01-02
White	00-00-09-09	10-17-25-29	00-00-01-01	10-17-35-39
Asian - East/General	01-01-03-04	04-01-08-09	00-01-00-00	05-03-11-13
Asian - South	00-00-00-00	01-02-04-02	00-00-00-00	01-02-04-02
Hispanic/ Latinx	02-01-00-00	03-02-00-01	00-00-00-00	05-03-00-01
Middle Eastern	01-01-00-00	00-00-00-00	00-00-00-00	01-01-00-00
Mixed	00-00-00-01	01-01-08-08	00-01-00-00	01-02-08-09
Other/Not Specified	00-00-01-01	00-00-01-01	00-00-01-00	00-00-03-02
Overall Total	04-03-13-15	19-23-47-52	00-02-02-01	23-28-62-68

Laboratory Redesign

The original laboratory assignments included traditional computation by hand followed by circuit building and testing. The redesigned curriculum introduced structured computational exercises (aided by MATLAB computational tools), beginner-friendly and comprehensively scaffolded SPICE-based simulation activities in LTspice, and open-ended design challenges aimed at mimicking real-world engineering practices. Within the research group, each of twelve lab assignments followed a consistent progression (see Figure 2): students began with a mathematical evaluation and circuit layout, proceeded to simulate and verify the circuit using LTspice, and then followed up with physical circuit building, testing, and evaluation. Students were expected to communicate consistently throughout the process through the composition of a lab document, and iterate whenever they encountered different results than expected.

Open-ended design problems—such as optimizing the performance of an LED driving circuit under specific constraints for component availability, power, current, and voltage—were included in many of the labs and encouraged creative problem-solving and iterative refinement. Key updates also included the separation of “pre-lab” and “in-lab” components to emphasize preparation and stimulate deeper engagement during lab sessions.

In addition to design exercises integrated into the twelve labs, the fifth lab of the semester was an entirely new, open-ended, experiential design experience where students had the opportunity to design their own sensing circuit. This lab provided students with the opportunity to independently conceptualize, build, and refine a circuit design to meet specified constraints, mimicking real-world engineering tasks.

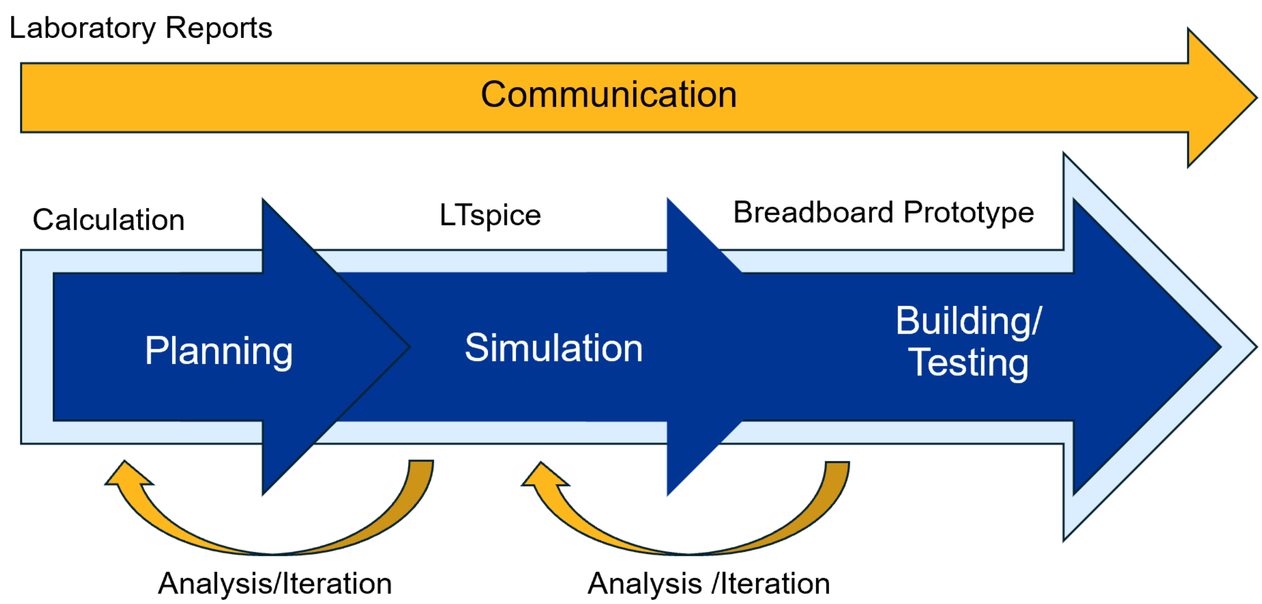

Figure 2: The iterative lab progression framework emphasizes planning, simulation, and building/testing phases, supported by analysis and communication.

Data Collection

Quantitative Data

The ISE measurement tool developed by Carberry, Gerber, and Martin was utilized to collect self-reported quantitative data at both the beginning and end of the course [7]. This instrument consists of 29 items that comprise eight factors as shown in Table 2. Please refer to Appendix A for the full measurement instrument. Exploratory factor analysis for this instrument showed factor loadings ranging from 0.715 to 0.899, with reliabilities indicated by Cronbach's Alpha values between 0.743 and 0.864 [7].

Table 2: Composition of Factors by Item

Factor	**Item No.**
Creativity	6, 12, 26
Exploration	1, 8, 18, 29
Iteration	9, 22, 27
Implementation	7, 13, 21, 24
Communication	16, 17, 23
Resourcefulness	3, 14, 15, 19, 20, 28
Synthesis	2, 10, 25
Vision	4, 5, 11

Qualitative Data

To ensure a true experiential learning experience, a reflection prompt was designed to accompany Lab 5 with the intention of eliciting metacognitive engagement by encouraging students to articulate their challenges, iterative processes, and growth during the exercise.

> Reflection Prompt: "Please reflect on your experience in this lab. Example questions you could answer here are: If you found this lab challenging, what about it was difficult for you? If you enjoyed this lab, what made it an enjoyable experience for you? Throughout this lab, if you had to iterate multiple times and change your design after simulation or actual testing, what was the experience like for you? What led you to an operational design?"

Structured reflection, as demonstrated by Singh et al., scaffolds metacognitive practices, enabling students to critically analyze their learning strategies and experiences [8]. Although the scaffold provided in this study is less rigid than that recommended by Singh et al., it is intentionally provided to guide students through reflecting on their design learning experiences. Reflective writing has been shown to enhance students' ability to connect hands-on tasks with broader learning objectives, and the researchers believe this could lead to the fostering of ISE when paired with a reflection about an engineering design challenge [9]. The reflection question provided students 10 participation points for completion out of 100 total points for the lab.

Data Analysis

Quantitative Data Analysis

Shapiro-Wilk tests were used to assess the normality of data distributions [10].

In the control group, all factors significantly departed from normality at the beginning of the semester, with the largest deviations in Exploration ($W = .860$, $p < .001$), Communication ($W = .888$, $p < .001$), and Synthesis ($W = .891$, $p < .001$). By the end of the semester, four factors remained significantly non-normal ($p < .05$).

In the research group, the pre-intervention cohort showed no significant deviations from normality, with Iteration ($W = .966$, $p = .083$) being the least normal but still acceptable. Following the intervention, six of eight factors exhibited significant non-normality, with Iteration again showing the largest deviation ($W = .925$, $p < .001$).

Given these violations of normality assumptions, survey responses were analyzed using the Mann-Whitney U test to compare ISE scores between groups [11].

Qualitative Data Analysis

Inductive thematic coding was applied to student reflections from the open-ended design-based lab (Lab 5) [12]. Open-ended reflections were selected for qualitative analysis because they provide richer insight into students' experiences and perceptions of the design process compared to closed-form survey responses. The thematic codes captured both technical and experiential dimensions of student learning.

Researchers identified three major themes and seven associated codes. Two of these codes were further broken down into sub-codes to capture additional nuance in student responses. Each reflection could receive multiple code assignments, allowing for complex or multidimensional reflections to be appropriately characterized.

In total, 100 codes were applied across 32 group reflections. Coding was independently performed by two researchers, achieving an initial inter-rater reliability of 77%. Following independent coding, consensus was reached through collaborative discussion without the need for mediation or third-party adjudication. This consensus process ensured that code applications accurately reflected student intent while maintaining consistency across the dataset.

Due to the comprehensive nature of the reflections, codes were further classified into four types: positive, negative, neutral, and productive difficulty. Positive and negative types were assigned when reflections were exclusively favorable or unfavorable, respectively. Neutral reflections typically provided factual descriptions without evaluative judgment. Productive difficulty was assigned when a reflection described a challenge that ultimately contributed to a deeper understanding or skill development, emphasizing growth through iterative design processes. Each code was assigned exclusively to one response type based on the predominant tone and content of the reflection.

All codes, definitions, and theme groupings are summarized in Table 3.

Table 3: Themes, codes, and definitions

Code	**Definition**
Theme One: Cognitive and Technical Challenges	
Challenges with New Concepts	Reflects difficulties with understanding and applying unfamiliar technical concepts introduced during the lab, such as photoresistors, comparators, pull-up networks, and practical component handling.
Challenges with Previously Learned Concepts	Reflects challenges with applying prior knowledge that students were expected to know, such as resistors, voltage dividers, LED driving, and interpreting datasheets and component specifications.
Theme Two: Bridging Theory and Practice	
Simulation Benefits	Highlights the impact of using LTspice or other simulation tools to validate and refine circuit designs before physical implementation.
Practical Application	Captures student perceptions of transitioning from theoretical designs (mathematical and/or simulation-based) to real-world circuit behavior, including discrepancies and troubleshooting during physical builds.
Theme Three: Experiential Design	
Iteration	Highlights persistence and learning through multiple cycles of redesign and testing to improve circuit designs.
Achievement/ Enjoyment	Captures moments of pride and fulfillment when achieving a functional circuit design or successfully completing the lab. Also considers the fun of the process and/or the end result.
Autonomy	Discusses the impact of autonomous design, including dissatisfaction with unclear, vague, or insufficient instructions provided for the lab.

Results

Quantitative Results

The ISE instrument revealed significant improvements in self-efficacy scores only for students in the research group (see Table 4 and Figure 3), with no significant change in the ISE of students in the control group. Table 4 provides detailed findings from the Mann-Whitney U tests performed. In the table, *Mdn* is the median value of the group, *n* is the number of subjects in the group, *U* is the Mann-Whitney statistic, *Z* is the value assuming U is normally distributed, *p* is the statistical significance, and *r* is the effect size, i.e., how strong the difference is between two groups. The largest improvements were observed for the research group in communication between the pre- (*Mdn* = 57.50, *n* = 62) and post-intervention scores (*Mdn* = 74.83, *n* = 68), being significant to $p < .001$, with a near medium effect size *r* = .290, followed by improvements in creativity between the pre- (*Mdn* = 62.50, *n* = 62) and post-intervention scores (*Mdn* = 74.17, *n* = 68), being significant to *p* = .002, with a small effect size *r* = .267. Perhaps unsurprisingly, the three items from the instrument with statistical significance $p < .001$ corresponded to the two factors with the largest changes. Item #12, part of the creativity factor, revealed a significant increase in confidence between the pre- (*Mdn* = 59.00, *n* = 62) and post-intervention scores (*Mdn* = 75.00, *n*

= 68), being significant to $p < .001$, with a medium effect size $r = .318$. Items #17 and #23, both part of the communication factor, showed a significant increase in confidence between pre- (*Mdn* = 53.19 & *Mdn* = 54.17, $n = 62$) and post-intervention scores (*Mdn* = 76.72 & *Mdn* = 75.83, $n = 68$), with $p < .001$, with a medium effect size $r = .312$, and $p < .001$, with a medium effect size $r = .312$, respectively.

Table 4: ISE Survey Factor Statistics for Research Group

		Mdn	*n*	*U*	*Z*	*p*	*r*
Creativity	Pre	62.50	62	1455	-3.046	.002	.267
	Post	74.17	68				
Exploration	Pre	74.13	62	1842	-1.242	.215	.109
	Post	78.00	68				
Iteration	Pre	67.50	62	1539	-2.653	.008	.233
	Post	76.17	68				
Implementation	Pre	68.75	62	1504	-2.816	.005	.247
	Post	77.50	68				
Communication	Pre	57.50	62	1399	-3.305	<.001	.290
	Post	74.83	68				
Resourcefulness	Pre	69.83	62	1691	-1.944	.052	.171
	Post	77.83	68				
Synthesis	Pre	67.67	62	1485	-2.907	.003	.255
	Post	78.00	68				
Vision	Pre	72.67	62	1644	-2.163	.030	.190
	Post	77.33	68				

While no differences were found to be significant between the early semester and late semester cohorts for the control group, there were some interesting findings. The traditional cohort showed the largest increases in creativity and resourcefulness, with the median of each factor increasing by 2.67 and 2.08, respectively. The control group also showed decreases in exploration, implementation, communication, and vision, with the median value for exploration decreasing by 5.00 from 82.38 to 77.38. No statistical significance was shown for any results in the control group, highlighting the limited impact of non-design-focused labs on ISE.

Qualitative Results

There were 32 reflections from Lab 5, and they provided qualitative insights into the curriculum's impact. Figure 4 includes the distribution of codes by type.

The Achievement/Enjoyment code had the greatest number of instances by far, with most student reflections expressing a sense of accomplishment and/or the enjoyment of the design process. The researchers made note of references to the enjoyment of the *process* versus the enjoyment of the *end result*, and found that there were 13 instances of the process versus 8 instances of the end result being the source of enjoyment and/or pride (some responses indicated both). Overall, it seems that students were engaged with the process, though many also appreciated feeling accomplished at the conclusion of the lab experience.

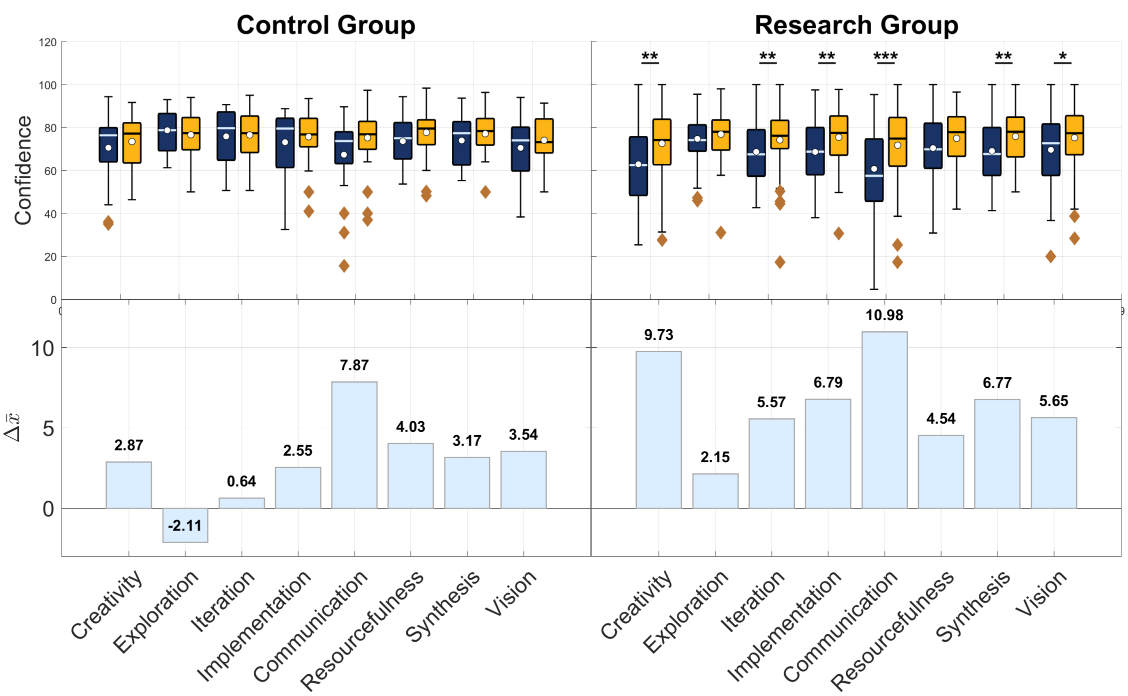

Figure 3: Comparison of pre- and post-scores for Control and Research groups. The y-axis shows median (horizontal lines) and mean (white circles) values. Outliers are shown as bronze diamonds. Statistical significance (p-values) is marked by asterisks: * ($p < 0.05$), ** ($p < 0.01$), *** ($p < 0.001$). The bar charts indicate mean changes across groups.

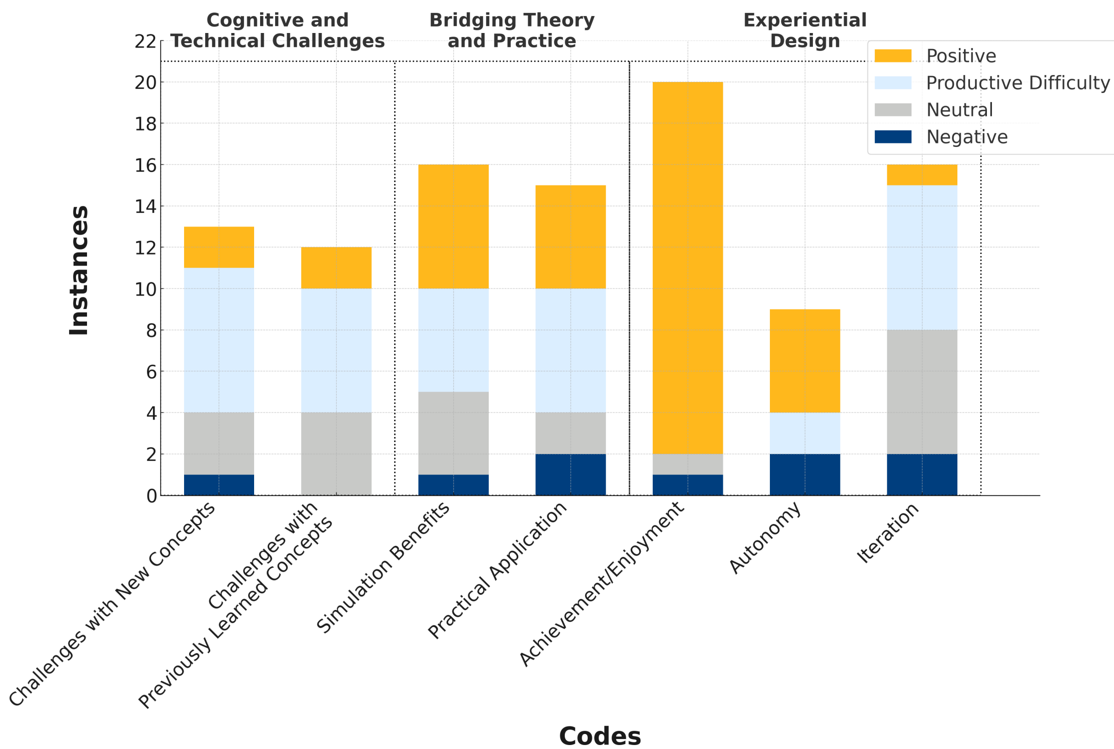

Figure 4: Distribution of responses across identified codes and types.

In addition, the researchers made note of the instances of iteration for *optimization* versus *trial-and-error* and found that, overall, students indicated that they did more trial-and-error than design optimization (10 instances versus 6 instances).

The most prominent overlap of codes is shown in Figure 5. The largest overlap was seen between iteration and practical application, with achievement/enjoyment overlaps being present in 13/24 of the most frequent code overlaps.

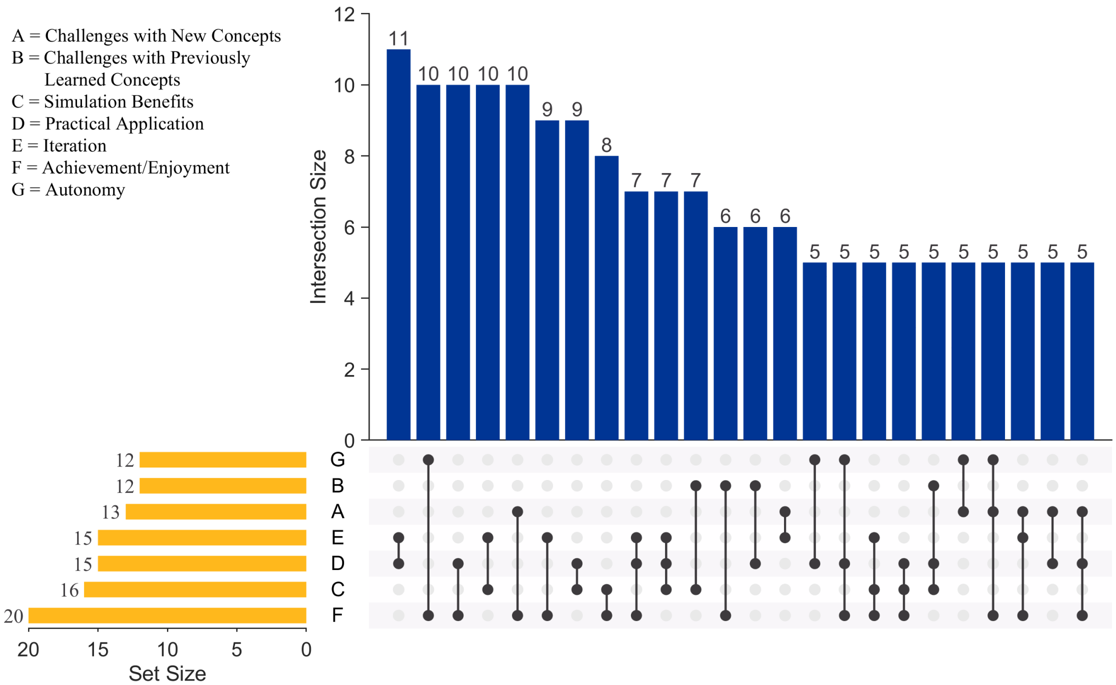

Figure 5: Code Intersections

Student Reflections

Student reflections revealed a strong level of engagement, often touching on metacognitive themes that illustrated how students made sense of both the learning process and the challenges they encountered. By engaging in the open-ended, hands-on tasks, students demonstrated an ability to navigate moments of productive difficulty, often showing signs of improved critical thinking skills such as troubleshooting, iteration, and collaboration. Below, we present selected examples of student reflections, categorized by theme. These examples showcase the diversity of experiences, from grappling with new concepts to leveraging simulations for design optimization, and underscore the transformative impact these lab exercises may have on students' confidence and skill development.

It is important to acknowledge that while these reflections suggest meaningful growth resulting from the design-based lab experience, no equivalent reflective data were collected from the control group. As a result, we cannot draw direct comparisons or attribute observed changes exclusively to the intervention.

Challenges with New Concepts (Productive Difficulty):

"At the start, we did face some challenges. The lab required a lot of data analysis—interpreting datasheets for new components, thoroughly understanding the lab report, and getting acquainted with fresh concepts. This initial phase felt a bit overwhelming because there was a steep learning curve, and we needed time to absorb all the new information. Despite the initial difficulties, we found it incredibly satisfying that our circuit worked on the first try! It was gratifying to see the effort we put into reading and understanding the technical data pay off in the form of a functional design! Overall, the lab gave us a sense of accomplishment, especially as it combined both the challenges of theoretical learning and the excitement of practical application—which we have been strengthening the past 8 weeks."

Challenges with Previously Learned Concepts (Productive Difficulty):

"I did enjoy the challenge of this lab. Most of it wasn't too difficult, I found that calculating the proper resistances for every individual section of the circuit very easy, but combining that with the current, power, and everything else in the entire rest of the circuit, the design process involved a lot of trial-and-error... The reason why I had to alter my design was because with such small amounts of current, the red, green, and blue LEDs were all extremely dim."

Practical Application (Productive Difficulty):

"We found the LTSpice portion of the lab quite interesting, especially when simulating the circuit behavior. However, we faced a significant hurdle when the actual circuit did not work for multiple hours, even though the LTSpice simulation showed everything functioning correctly. This led to a lot of time being spent on troubleshooting issues that weren't apparent in the simulation, adding an extra layer of complexity to the lab. Ultimately, these challenges guided us toward finding an operational design through persistence and testing."

Simulation Benefits (Positive):

"The reason why I did not need multiple iterations was because of my extensive calculations and LTspice simulations to ensure that every part of the circuit was getting proper voltage, nothing was getting too much current, and that the total power from both sources combined was safely under 250mW. ... I'm not ashamed to admit that LTspice has definitely grown on me, and that I do enjoy designing/testing circuits with it. Although I do know all the proper calculations to theoretically build this circuit on paper, without LTspice, I most likely would have destroyed multiple LEDs (probably two or three minimum)."

Iteration (Productive Difficulty):

"This was undoubtedly a difficult lab. We were both pretty comfortable with breadboards and building operational circuits in that respect, but the spice simulations were hard and we ultimately had to resort to a lot of trial and error to get resistor values that worked.

We had to iterate countless times through the design, probably to a fault. If we had to do this lab again, we agreed that we'd work harder to obtain a better analytical solution, instead of trying a bunch of different resistors in the circuit and seeing which ones led to expected behavior.
It's sometimes easy to get carried away in the "lab" part of the lab, instead of relying on the mathematical models that we use in engineering, which can often lead you to a right answer more quickly than brute force trial and error techniques."

Achievement/Enjoyment (Positive):

"I challenged myself to minimize the number of resistors/components required for a functional design. I eventually decided to approach driving the signal LEDs with digital LOW signal, and it was a fun challenge to experiment with the comparator behavior to accommodate that goal. I found the process of designing and settling on component values relaxing. Having hands-on experience with voltage division - specifically, designing a voltage divider ladder - seemed to help some of those ideas cement as intuition."

Autonomy (Positive):

"Something that was new was the novel challenge of designing our own circuit as opposed to being given exact expectations as to what we should make. The design and brainstorming phase was hard on account of our team not having much experience with the creative freedom, but fun when we figured out what we wanted to do and how to put it all together."

These reflections underscore the multifaceted learning experiences fostered by the lab. By providing opportunities for open-ended exploration and encouraging autonomy in problem-solving, the lab challenged students to balance theoretical analysis with practical application. The emphasis on iterative design and hands-on engagement enabled students to develop a deeper understanding of circuit design and troubleshooting. Moreover, the reflections reveal a sense of accomplishment and growth, as students moved beyond initial frustrations to achieve meaningful results.

Negative Reflections

Most students valued the challenges posed by the lab, reflecting on how the difficulties enhanced their learning and problem-solving skills. However, a small number of students expressed frustration, perceiving the challenges as excessive or unproductive. These negative reflections, while rare, provide valuable insights into areas where the lab experience could be improved.

Notably, the Iteration category included more negative responses overall than positive responses. The researchers believe this was due in part to the way the lab was initially framed.

Iteration (Negative):

"Conceptually speaking, this lab is supposed to be really cool because shining the light on the photoresistor and the outputs receiving different voltages sounds like an interesting concept, but because of the variability between photoresistors, and the

immense trial and error this lab required, we were never able to get the correct resistor values, and probably did not have the correct build configuration to complete it."

This quote suggests that students struggled to conceptually understand the photoresistor. While individual components are reliable, variability between components arises from material fabrication rather than photon adsorption. The photoresistor was introduced with an explanation of its variability to emphasize the importance of measuring resistance limits in both full- and low-light conditions for informed design. However, this explanation may not have sufficiently conveyed the fundamental operation of the photoresistor, potentially leaving students with misconceptions about component variability.

Another group commented negatively about Practical Application.

Practical Application (Negative):

"The greatest difficulty came with implementing the design on our breadboard. Our circuit was not working correctly initially, causing concern to grow regarding a possibly incorrect design. After hours of troubleshooting, however, we realized that the problems we were facing were due to faulty comparator chips. This was especially frustrating since there wasn't necessarily any gain in terms of circuit knowledge, rather increased distrust in the functionality of components provided."

Due to high manufacturing standards and quality control of Texas Instruments components, the likelihood of encountering a defect is roughly 10–50 ppm $(0.001\%–0.005\%)$, and more likely to be at the lower end of this range. While the researchers recognize that it's possible one of the chips was defective, the likelihood of encountering more than one defective chip out of the roughly 35 supplied to the students in the course is so low that the researchers believe it was faulty operation and/or handling that may have caused damage to the chip. Because this group achieved a working design at the conclusion of the lab, the researchers believe they encountered challenges that stretched their understanding and capabilities until they were able to properly handle the component. This kind of error could be mitigated in the future by the teaching team by sourcing more robust components and/or ensuring that proper operation is clearly communicated.

Discussion

The integration of design-oriented elements in the introductory circuits course resulted in significant improvements in the ISE of students. These findings highlight the value of experiential learning coupled with technological tools to bridge theoretical and practical aspects of engineering education. Specifically, the emphasis on simulation tools such as LTspice and iterative design processes fostered critical skills in troubleshooting and creativity.

Most of the students positively reflected on their experiences, with many expressing enjoyment derived from the process of designing and troubleshooting circuits. Most students appreciated the hands-on nature of the labs, and the reflection data revealed a greater focus on the process rather than the final results, demonstrating an intrinsic engagement with the design challenges.

Negative reflections were most pronounced in the Iteration category, where students struggled with trial-and-error processes. This highlights the need for clearer instructional scaffolding to help students distinguish between productive iteration and unstructured experimentation.

Students widely recognized the benefits of simulation tools in improving their understanding of circuit design. LTspice, in particular, was credited for enabling efficient testing and reducing errors in physical builds. The positive reception suggests that expanding the integration of simulation exercises could further enhance students' confidence and autonomy.

The open-ended nature of the labs exposed students to ambiguity in problem-solving, a skill critical for addressing global engineering challenges [13]. While some students struggled with poorly defined objectives, this ambiguity encouraged others to develop innovative solutions and collaborate effectively. These findings underscore the potential of such labs to cultivate globally competent engineers capable of navigating complex and interdisciplinary challenges.

Despite the success of the redesigned curriculum, areas for improvement remain. For example, a more robust introduction to theoretical concepts and clearer guidance on iterative design could mitigate frustration and foster a more structured approach to problem-solving. In addition, further refinement of instructions and alignment of expectations could enhance the overall learning experience.

Limitations

While this study was designed to minimize bias by using concurrent sections and validated instruments, several limitations should be acknowledged. One primary limitation is the single-institution context, which may restrict the generalizability of the findings to other educational settings with different student demographics, resources, or institutional priorities. Expanding the study to multiple institutions, including those with varying levels of research activity, geographic diversity, and student population sizes, could provide a broader perspective on the impact of the redesigned curriculum.

Another limitation lies in the potential differences in instructor delivery between sections. Despite efforts to standardize teaching materials and instructions, variations in teaching style, experience, or emphasis could influence student outcomes.

Additionally, the study's reliance on self-reported measures of innovation self-efficacy introduces the potential for bias, such as social desirability or overestimation of abilities. Incorporating objective assessments, such as direct evaluations of student work or performance on standardized design challenges, could provide a more holistic view of the curriculum's impact.

While demographic data were collected, no statistically significant differences in outcomes were observed for underrepresented groups in STEM. However, the study did not explicitly explore how the redesigned curriculum might differentially affect these groups or address barriers they may face in engaging with design-oriented activities. Future research should intentionally examine how such interventions support or challenge students from underrepresented backgrounds, considering factors such as access to resources, prior exposure to design-based learning, and potential biases in group dynamics. Tailored strategies, such as mentorship programs or targeted instructional support, could be explored to ensure equitable benefits of the curriculum for all students.

Finally, the study focused on a single course, limiting its ability to capture long-term effects of the redesigned curriculum on students' innovation self-efficacy. Future research should consider longitudinal studies that track students' progress over multiple courses or semesters, providing insights into the durability and cumulative effects of design-focused learning experiences.

Addressing these limitations through expanded scope, more rigorous methodologies, and intentional consideration of diverse student populations will strengthen the robustness of future studies and allow for more comprehensive evaluation of the impact of integrating design elements into engineering education.

Conclusion

This study demonstrates that integrating design-focused laboratory exercises in a second-year introductory circuits course significantly improves students' innovation self-efficacy, particularly in creativity and communication. By emphasizing hands-on design, simulation tools, and reflective practices, the redesigned curriculum bridges the gap between theoretical coursework and real-world engineering applications.

The results highlight the transformative potential of experiential learning, as students not only develop technical competence but also cultivate critical soft skills such as resilience, adaptability, and collaboration. While challenges with iteration and ambiguity revealed areas for refinement, these difficulties also presented opportunities for growth, encouraging students to embrace the iterative nature of engineering design.

Future efforts should prioritize the scaling and adaptation of this design-oriented curriculum to diverse educational settings, including institutions with varying resources, student demographics, and disciplinary focuses. A multi-institutional collaboration could enable broader validation of the results, revealing insights into the curriculum's adaptability and potential for wider impact. Additionally, interdisciplinary applications of this approach could be explored, integrating design-focused activities into other STEM fields such as environmental science, biomedical engineering, or computer science, to cultivate innovation self-efficacy across a broader range of technical disciplines.

To address identified challenges, enhancements in theoretical support should focus on providing students with stronger foundational knowledge before engaging in complex design tasks. This could include pre-lab instructional videos, interactive tutorials on component behavior, or scaffolded worksheets that guide students through critical problem-solving steps. Furthermore, the framing of lab activities should be refined to better balance open-ended exploration with structured guidance. For example, incorporating "checkpoints" during the iterative design process could help students identify productive iteration versus unstructured trial-and-error, reducing frustration and improving outcomes.

Finally, the incorporation of more advanced simulation tools and opportunities for cross-institutional student collaboration could extend the benefits of the curriculum. For instance, cloud-based simulation platforms could enable students to work on complex design projects collaboratively, regardless of geographical location, fostering both technical competence and global teamwork skills.

By addressing these challenges and scaling this approach thoughtfully, engineering educators can empower students to develop not only technical expertise but also the creativity, adaptability, and collaborative mindset needed to tackle the multifaceted challenges of the modern world.

Institutional Review Board Exempt Study Considerations

The study, titled "Influence of Design Curriculum on Innovation Self-Efficacy," was reviewed and deemed exempt under the 2018 Common Rule 45 CFR 46.104(d) by the University of Pittsburgh Institutional Review Board (IRB). The exemption, granted on August 15, 2024, falls under category (1) for research conducted in established or commonly accepted educational settings. Limited IRB review was conducted as required to ensure compliance with ethical research standards.

This exemption is registered under STUDY24070107 and does not have an expiration date. The study will remain active until formally closed by the principal investigator. All activities were conducted in accordance with University of Pittsburgh policies, including adherence to the principles of responsible research conduct. Documentation of the exemption is retained for reference.

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Appendix A

Innovation Self-efficacy (ISE) Survey

Directions: Rate your degree of confidence that you can do each of the activities listed below on a scale from 0 (not at all confident) to 100 (extremely confident).

1. Understand the needs of people by listening to their stories.
2. Find connections between different fields of knowledge.
3. Seek out information from other disciplines to inform my own.
4. Identify opportunities for new products and/or processes.
5. Question practices that others think are satisfactory.
6. Come up with imaginative solutions.
7. Make risky choices to explore a new idea.
8. Consider the viewpoints of others/stakeholders.
9. Evaluate the success of a new idea.
10. Apply lessons from similar situations to a current problem of interest.
11. Envision how things can be better
12. Do things in an original way.
13. Set clear goals for a project.
14. Troubleshoot problems.
15. Keep informed about new ideas (products, services, processes, etc.) in my field.
16. Communicate ideas clearly to others.
17. Provide compelling stories to share ideas.
18. Learn by observing how things in the world work.
19. Solve most problems if I invest the necessary effort.
20. Be resourceful when handling an unforeseen situation.
21. Suggest new ways to achieve goals or objectives.
22. Test new ideas and approaches to a problem.
23. Share what I have learned in an engaging and realistic way.
24. Make a decision based on available evidence and opinions.
25. Relate seemingly unrelated ideas to each other.
26. Think of new and creative ideas.
27. Model a new idea or solution.
28. Find new uses for existing methods or tools.
29. Explore and visualize how things work.