# WIP: Complementary Teaching Modes to Promote Design Self-Efficacy


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***Abstract*—This work-in-progress (WIP), innovative-practice paper describes the piloting of laboratory experiments that emulate real-world engineering design practices during the instruction of a sophomore-level introductory circuits course. Results reflect positively on design self-efficacy and suggest promise for future work.**

**Introductory electronic circuits courses have historically been taught within an analytical framework. Recent design-based pedagogical changes, i.e., the incorporation of makerspaces, simulations, and design-oriented assignments, to Electrical and Computer Engineering (ECE) curricula have shown the benefits of multi-modal approaches to instruction. The research suggests that student motivation, satisfaction, and performance are enhanced through the application of design-based learning challenges. The authors believe that active and experiential learning opportunities can be coupled with computational tools and traditional instruction to provide a range of frameworks that serve different types of learners.**

**As a part of this study, students spent three hours per week in a makerspace where they completed twelve re-designed laboratory assignments with integrated simulation exercises and design challenges. Students who completed the course before and after implementing these changes were surveyed to gauge the influence that the lab changes have on their self-efficacy with course material and circuit design. Student responses to Likert-scale questions, tested with the Wilcoxon Signed Rank Sums test, show significant improvements in student confidence with simulation and computational tools and with utilizing computer translational and scalable matrix-solving techniques for linear circuits. In addition, while students expressed the difficulty of working on open-ended, independent learning challenges, their reflection responses also indicated the value of the experience.**

**This pilot study serves as a basis for further investigation into how different modalities may complement one another and lead to independent concept application and design self-efficacy in young engineers.**



***Index Terms*—design, experiential learning, multi-modal approaches, self-efficacy, simulation**


## I. Introduction

Professional engineering practice requires a comprehensive amalgamation of fundamental knowledge and skills, along with a sense of identity within engineering. Historically, however, engineering curriculum has focused primarily on the development of technical knowledge over deeply integrated learning experiences that fundamentally prepare engineering students to develop into engineering professionals [1].

One method of addressing this is the application of design-oriented curriculum units within engineering education. Early analyses of the benefits of design-oriented assignments within a makerspace environment suggest that they increase innovation, self-efficacy, and feelings of belonging to the engineering community [2]. In addition, the incorporation of a project-based and design-oriented curriculum has been shown to aid in the development of problem-solving and investigation skills and additionally benefits students by providing opportunities for hands-on and technical experience [3].

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There is also evidence that design-oriented learning has effects that extend beyond the course in which they are applied [4].

While there has been a concentrated effort to increase design-based learning experiences for first-year and final-year engineers, second and third-year engineering students at many universities are missing out on these crucial learning experiences [5], [6]. In addition, the combination of real and virtual experimentation (i.e., simulation coupled with hands-on work) to teach circuits concepts has been shown to lead students to a greater conceptual understanding than real experimentation alone [7], [8]. It is clear that early and consistent integration of design-oriented assignments and simulation exercises within the engineering curriculum has the potential to create the types of learning experiences that engineering students require to develop into effective professionals. This study seeks to expand this work and apply it directly to a second-year introductory circuits course.

## II. Methods

The research questions that guided the study design are RQ1: Does a multi-modal curricular approach promote design self-efficacy within an introductory circuits course for second-year engineering students? RQ2: How is student perception of their learning influenced when multi-modal elements are incorporated into their learning experience?

Twelve lab assignments were reviewed in detail. Changes were first proposed and then deliberated on. The final changes included the following.

- All labs were modified to include a Simulation Program with Integrated Circuit Emphasis (SPICE) exercise using the freely available LTSpice program. These exercises increased in complexity to comprehensively teach students to utilize the full functionality of the software. Overall, this aims to increase students' understanding of modern design practices applicable to discrete and integrated electronics.
- All labs were modified to move students through the full design process: mathematical evaluation and layout, simulation and verification, building, testing, and finally, evaluation and characterization.
- Design exercises were integrated into several labs. For example, as a part of the second lab, students were asked to reference a datasheet and design a passive circuit to provide the proper voltage and current to a Kingbright blue LED.
- Computational tools were introduced or reinforced to solidify a computer-aided design methodology. For example, MATLAB's symbolic solver was introduced with matrix analysis techniques.

Likert-scale survey questions were developed as a measure of student confidence in each of four modal categories: technology (Q1), engineering design (Q2), traditional computation (Q3), and communication (Q4). One multiple-choice and one reflection question were chosen to address each research question (RQ1: Q6 & Q8 ; RQ2: Q5 & Q7). Refer to Tab. I for the survey questions by type. Multiple-choice responses for Q6 are shown in Tab. II.

TABLE I
Survey Questions with Response Frequency by Group

| Type | Question | Past Student | Current Student |
|---|---|---|---|
| Likert-scale | Q1: Upon completion of ECE 0101 I was comfortable using simulation and/or computational tools to aid in a comprehensive solution to a linear circuit | 22 | 21 |
| | Q2: Upon completion of ECE 0101 I was able to design an optimal passive network to connect sources and loads with a specific practical application in mind | | |
| | Q3: Upon completion of ECE 0101 I was comfortable transforming a circuit into an inverse matrix problem to solve for parameters of interest | | |
| | Q4: Upon completion of ECE 0101 I was able to communicate about analytical, simulation, and experimental results to an appropriate audience | | |
| Multiple-choice | Q5: How long did it usually take you/your team to complete the labs? a) Less than the standard lab period b) The standard lab period c) More than the standard lab period | 22 | 21 |
| | Q6: What resources were the most valuable to your learning in the class? | | |
| Reflection | Q7: How did the labs impact your learning? | 16 | 20 |
| | Q8: Were there concepts from this course that were challenging to understand at first? What helped you to understand them? | 13 | 18 |

TABLE II
LEARNING MODES BY FREQUENCY

| Learning Mode | Frequency |
|---|---|
| Laboratory Experiments | 8 |
| Computational Tools | 1 |
| Simulation Tools | 2 |
| Professor Office Hours | 3 |
| TA Office Hours | 6 |
| Other: Online resources | 2 |
| Other: Homework | 2 |
| Other: Practice Problems | 8 |

Surveys were sent to past students through email and 42 responses were collected. The same survey was administered to current students through QR codes in the laboratory space at the conclusion of the semester, with a total of 22 received responses . The response frequency, by question type, is also shown in Tab. I.

Responses of the two student groups to Q1-Q5 were analyzed for statistical significance using the Wilcoxon signed-rank test [9]. Each response was assigned a value from 1 ("strongly disagree") to 5 ("strongly agree") or 1 ("less time") to 3 ("more time").

The responses to Q7 were coded through a multi-step pattern thematic analysis process with one instance of mediation [10]. The responses to Q8 and Q6 were evaluated, and the frequency of mention of different learning modes was tallied.

The fifth lab was an experiential lab that required students to learn independently. Students were asked to choose their own methods for communicating about circuit design and simulation and then either present a functioning circuit in person or include a video recording with their lab report. They were then asked to reflect on their experience.

## III. QUANTITATIVE RESULTS

Statistics of the Likert-scale categorical mean data showing increases in all confidence level means are shown in Fig. 1. Results of Q5 showed an increase from a mean of 1.9 to 2.4.

Statistical Analysis showed that the difference between the two groups' responses to Q2 and Q4 was not statistically significant. However, there was a significant difference found between the two groups' responses to Q1, Q3, and Q5, with $p$ values of 0.0002, 0.0041, and 0.0160 for the normal approximation and 0.0002, 0.0040, and 0.0155 for the chi-squared approximation.

## IV. QUALITATIVE RESULTS

The reflective responses to Q7 belonged to three themes. Table III shows the resulting themes and Fig. 2 the frequency of responses that belonged to each theme and/or sub-theme.

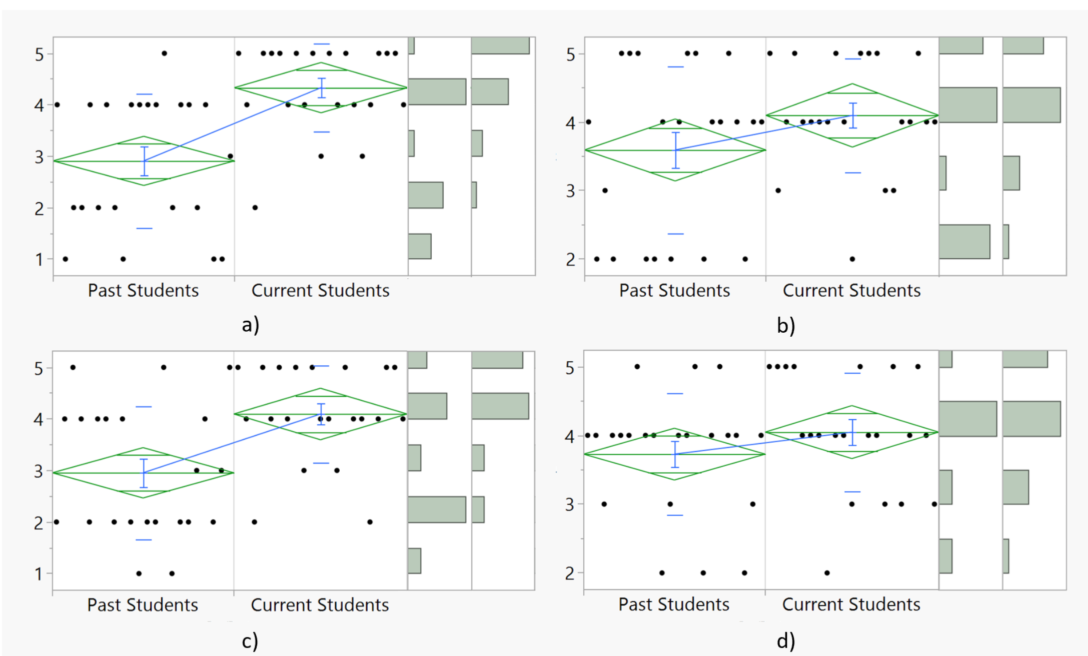


Fig. 1. One way analysis of Likert-scale responses to Q1-Q4 (a-d). Each plot displays the point spread, mean diamond, mean error bars, and standard deviation lines. Histograms showing the frequency of responses are shown to the right for each question.

Both groups felt the labs helped them solidify their knowledge. For instance, a past student wrote, “[E]xplaining the properties that I saw, solidified the content for me,” whereas a current student wrote, “They were good at forcing me to crystallize my ideas.”

The frequency of positive responses generally increased; two sub-themes (“Equipment” in “Experience” and “Practice” in “Comprehension”) showed a decrease in the number of positive responses. Several past students felt the labs were an equipment introduction and practice with course material. Current students expressed capability with electrical tools in conjunction with a more comprehensive understanding. For example, where a past student’s response to how the labs impacted their learning was “Introduced to lab equipment to be used in the future,” a current student wrote:

> *The labs definitely helped me understand how to build and troubleshoot circuits, as well as how they are used in the real world. I would not have learned any of this without the labs, since the lecture doesn’t have any hands on content.*

Student responses to Q8 were analyzed by counting mentions of educational modes. These were cross-referenced with the modes given as multiple-choice response answers to Q6, and the resulting frequency of responses can be found in Tab. II. The most frequent modes that students referred to as aiding their understanding of challenging concepts were “Laboratory Experiments,” “Practice Problems,” and “TA Office Hours.”

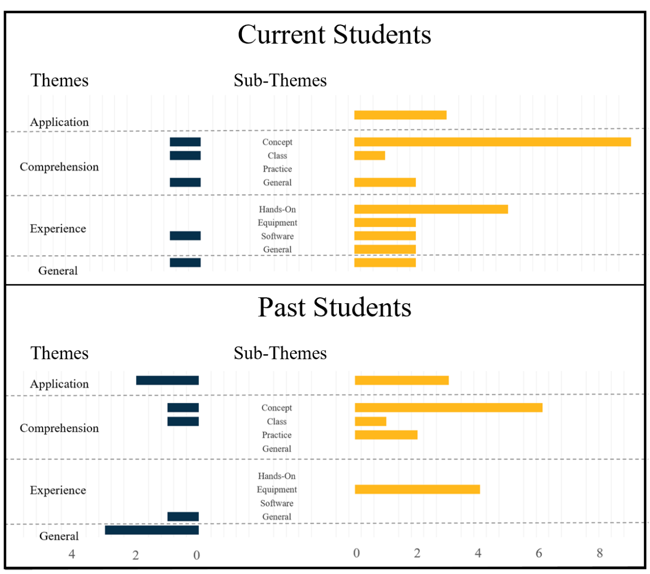


Fig. 2. Frequency of Q7 responses before and after the lab re-design

TABLE III
THEMES OF Q7

| Theme | Sub-Theme | Definition |
|---|---|---|
| Experience | Equipment | Student gained skills utilizing laboratory equipment |
| | Hands-on | Student gained experience in building circuits in a hands-on environment |
| | Software | Student gained software skills that aided in circuit design and/or understanding |
| Comprehension | Practice | Student gained additional practice with course material |
| | Coursework | Physical circuit interaction aided in course-related concept comprehension for the student |
| | Concepts | Student was able to see real-world applications of lecture material |
| Application | Real-world | Student was able to see real-world applications of lecture material |

TABLE IV
THEMES OF EXPERIENTIAL REFLECTION QUESTION

| Theme | Definition |
|---|---|
| Value | The lab was valuable and/or rewarding. Reflection response included references to wonder/fun/curiosity, hands-on experience, application of knowledge, etc. |
| Concepts | The concepts were abstract and/or confusing. Alternatively, there was a disconnect between the lecture and lab material. |
| Time | The assignments did/did not require a significant amount of time; time was a significant factor for success |
| Reflection | Reflection response included a self-reflection/ team-reflection about capabilities (i.e. “I/we could/could not design this on my/our own”); may also include references to “other” (i.e., “compared to others…”. |

Reflection responses for the experiential design-based lab were coded according to the themes in Tab. IV. The two most frequent themes expressed by students in their reflections were the difficulty of making connections between concepts (“Concepts - Negative”) and the value they obtained by facing and completing a significant challenge (“Value”). These two sentiments were often expressed in tandem. Student reflections that expressed negativity regarding the difficulty of understanding concepts and/or making the proper connections were, in all but one case, coupled with positive reflections regarding the value of the experience and/or the rewarding nature of the completion of the lab.

The "Reflection" theme encapsulates student responses where they addressed their own abilities. These reflections could be positive or negative. For example, one student reflected by writing, "I felt that I needed assistance multiple times along the way to run through the lab... I feel that I could not run through this lab completely on my own without helpful hints here and there" where another wrote:

> *Overall, this lab was very informative in showing how to account for different power requirements, especially when looking at how to power the LEDs correctly, and how to account for multiple voltage requirements... The project overall was quite fun to do, as it was a simple concept that could be applied in a way that was feasible for beginner circuit designers.*

## V. Discussion

Reflection responses by current students emphasized the difficulty of making connections between concepts. While the researchers recognize that grappling with conceptual understanding encourages a heuristic learning style, they also believe students should always have the tools required to make the proper connections. It is clear that a balance must be found where students have the resources they require and yet are given challenges that stretch their capabilities and encourage them to grow.

## VI. Conclusion

Quantitative results indicate greater student confidence with circuit design tools. Qualitative results indicate both confidence and capability. The researchers tentatively conclude, regarding RQ1, that the multi-modal approach to teaching introductory circuits with an aim to develop self-efficacious engineers is effective. In addition, regarding RQ2, the multi-modal approach to teaching an introductory engineering course appears to lead to improvements in student perception of their learning within all modal categories, with significance shown in the use of technology and traditional computation.

## VII. Future Work

While the preliminary results of this pilot study are promising, they are only indicative of the potential for the incorporation of these elements within the curriculum. They may be impacted by small sample sizes, lack of a controlled study, or biases. The research team would like to address this by running the study again with a control group and a larger sample size ($n > 40$). Additionally, the researchers aim to quantitatively analyze performance between the two groups and measure innovation self-efficacy with a tool developed by Adam Carberry to couple numerical performance data and confidence perception and more comprehensively evaluate the influence on design self-efficacy.


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