WIP: Developing Entrepreneurial Mindset Habits in circuits curriculum

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WIP: Cultivating Selected Entrepreneurial Mindset Habits in an Electronic Circuits Lab

Abstract

This work-in progress study investigates the effectiveness of integration of hands-on activities and guided reflection [1–3] during Fall 2025 semester in an electronic circuits lab. The aim of the work is to develop selected elements of the KEEN Entrepreneurial Mindset (EM) among engineering students [4]. Within the broader 3C's framework of Curiosity, Connections, and Creating Value, this work focuses on a subset of specific habits namely - embracing ambiguity in design, stakeholder focus, and systems thinking. In order to meet the above learning objectives, students engaged in a series of activities that developed key skills by analyzing technically strong but commercially unsuccessful products to propose customer-focused improvements, making iterative design decisions under incomplete information, and examining how individual modules integrate into a complete power converter while balancing system-level cost and performance trade-offs. Preliminary qualitative analysis suggests that these interventions were effective in encouraging student engagement with aspects of EM thinking,

1 Introduction

Problem-based learning (PBL) is a learner centered, well-established active learning approach in engineering education. Prior studies demonstrate that PBL enhances students' problem-solving abilities, promotes integration of knowledge across disciplinary boundaries, and increases motivation by situating learning within real-world contexts [5, 6]. Building on this foundation, entrepreneurial mindset frameworks emphasize the development of cognitive habits that shape how engineers think, make decisions, and create value in complex, real-world contexts.

While strong problem-solving skills are foundational for engineering practice, technological and product innovation additionally require ways of thinking that enable engineers to frame ambiguous problems, connect technical decisions to stakeholder needs, and identify opportunities for value creation. The EM framework emphasizes development of cognitive habits that shape how engineers think, make decisions, and create value in complex, real-world contexts [7]. Furthermore the framework can be intentionally incorporated into a variety of established learning methodologies to emphasize EM development. The benefits of EM enhanced curriculum are well documented, including several examples illustrating the integration of EM into PBL [8–10]. Prior studies have also demonstrated that deliberate integration of EM into engineering coursework helps students cultivate core EM habits [11–13].

Engineering laboratory courses inherently provide opportunities for problem-based learning through iterative design, experimentation, and evaluation of real systems. This context also creates a strong platform for integrating entrepreneurial mindset development by requiring students to make informed decision, evaluate trade-offs, navigate ambiguity, and connect technical decisions to real-world impact. In this work we describe curricular changes implemented within a five-week module of a junior-level electronic circuits lab (ECE 343) aimed at incorporating certain elements of the KEEN EM framework. Preliminary assessment indicates that deliberate intergation of EM elements into lab activities can help students develop an appreciation of EM framework. The following section gives a brief description of the electronic circuits course offered in the department of Electrical and Computer Engineering at the University of Illinois, Urbana-Champaign, providing relevant context for the subsequent discussion.

2 Lab Description

ECE 343 is an introductory electronic circuits laboratory and the first hands-on course in the electronic circuits sequence. The course is organized into six modules that progressively develop students' understanding of circuit design, analysis, and implementation.

Lab 3 of the course focuses on the end-to-end design and evaluation of an AC–DC power conversion system. In earlier iterations, the lab emphasized technical correctness through highly guided procedures and predefined design parameters, limiting opportunities for independent design decision-making. Students primarily followed prescribed steps to arrive at a working solution. To address these limitations, Lab 3 was redesigned to provide a more authentic design experience that integrates entrepreneurial mindset principles through open-ended decision-making and reflection exercises, while maintaining technical rigor.

Prior to the redesign, the laboratory defined learning objectives that emphasized technical correctness and problem-solving skills, while also encouraging connections to related coursework (e.g., voltage dividers in the first year class Introduction to Electronic Circuits (ECE 110)). Students were introduced to the design of an AC–DC power supply with a linear feedback regulator through a two-phase problem statement. In Phase 1, students designed a Zener diode–based voltage regulator to meet specified voltage regulation, ripple, and load requirements. In Phase 2, feedback was introduced to achieve a regulated $10\ \mathrm{V}$ output capable of supplying approximately $100\ \mathrm{mA}$ current.

While earlier the objectives emphasized technical rigor, the redesign sought to broaden students' perspective without diminishing the original learning goals. These changes are elaborated in the following section, which details the design, implementation, and rationale for each modification.

3 Lab Changes

To emphasize the importance of a broader engineering perspective aligned with the EM framework, the learning objectives were expanded to include elements based on the framework. It should be noted that, during this semester, the instructional and assessment emphasis was placed on a selected subset of EM habits. The specific habits targeted in this work are listed below:

1. **Experimentation** - Test and reiterate ideas and approaches to refine methods (Curiosity).
2. **Embracing ambiguity** - Develop comfort with uncertainty and decision-making when there is limited information. (Curiosity).
3. **Systems Thinking** - Recognize the interdependencies in systems and identify leverage points (Connections).
4. **Customer focus/Stake-holder interests** - Frame efforts in terms of the customer's actual needs (Create Value).

To this end, the following modifications were introduced:

- **Design under ambiguity:** Design information was released in stages, requiring iterative decision-making under incomplete information.
- **Systems thinking:** Students examined interactions among power supply subsystems, considering system-level cost and performance trade-offs. Students also considered broader ecosystem interdependencies.
- **Customer focus/Stake-holder interests:** Students analyzed technically strong but commercially unsuccessful products and proposed design modifications to improve market viability.

To help students appreciate the relevance of these new objectives at the outset of the lab, a think–pair–share activity was incorporated at the beginning of the module. The structure and rationale for this activity, along with the other changes introduced in the redesign, are discussed in the following sections.

3.1 Activity: Study of a Failed Product

As part of the redesigned laboratory module, this activity is designed to extend learning beyond technical implementation by engaging students in aspects of real-world engineering decision-making. The activity emphasizes the role of constraints that are often outside an engineer's direct control and highlights the need to make informed decisions despite incomplete or evolving information. The structure and the prompt for the activity is shown in Fig. 1 below.

Think-Pair-Share : Failed Product

Some engineering products were technically brilliant but still failed in the marketplace. Why? Often, non-technical factors such as cost, customer needs, or regulations made the difference. Pick one product (past or recent) that you admired but never purchased. If you cannot think of a personal example, research and identify a product that failed despite strong engineering.

Your Task (Individual Work):

- **Partner 1:** Research the *technical side*. Very briefly describe the engineering innovation in the failed product. What made it a marvel from a design perspective?
- **Partner 2:** Research the *non-technical side*. Identify why the product failed in the marketplace. Consider economics, safety, competition, customer needs, or regulations.

Pair Discussion: Share your findings with your partner. Together, create a short bulleted summary that connects the *technical strengths* and the *non-technical reasons for failure*.

Share (Joint Output):

1. One key lesson engineers can learn from this failure.
2. A brief statement of who researched the technical side and who researched the non-technical side.
3. **Reflection:**
   Propose one change that might have improved this product's outcome. For example, could a different target market, pricing strategy, safety feature, or design modification have increased its chances of success? Explain why you think your proposed change could have made a difference.

Figure 1: Think-Pair-Share - Study of failed study.

3.2 Lab Problem Statement

After the think–pair–share activity, students engaged with the power supply design task through a scenario-based problem statement that cast them as engineering interns, providing a familiar and motivating context while embedding real-world constraints, stakeholder priorities, and practical decision-making—contrasting with the more abstract framing used in earlier versions of the lab. As shown in Fig. 2, the design specifications were intentionally presented in stages to expose students to design under conditions of ambiguity. Additionally, the inclusion of a "proof of concept" requirement in the problem statement was deliberate, encouraging students to, later on, consider issues of scale within a realistic product-development context.

Featherlite Medical

Mr. McDuck has decided he is tired of just counting gold coins. He is setting up a new company - Featherlite Medical, Inc. His first product: An **infusion pump** for hospitals. But being Mr. McDuck, he insists on one thing:

" It better be cheap! Every extra **penny** spent on diodes or unnecessary components is on one less penny in the vault!"

You and your partner have just been hired as engineering interns and your job is to design a "proof of concept" **power supply** that converts $120\ V$ **AC from the wall** into $10\ V$ **DC** capable of supplying $\approx 100mA$ current for pump's control circuit.

Figure 2: Lab Problem Statement

3.3 Ambiguity in Design

The primary components of a power supply include the transformer, rectifier, filter, and regulator. To expose students to ambiguity in design, they begin by investigating and comparing three basic diode-based rectifier configurations while working in pairs. Using guiding questions, students evaluate each rectifier in terms of component count and cost, output voltage characteristics, and the relative smoothness of the resulting DC waveform. Students also examine how the choice of rectifier influences the design of subsequent stages of the power supply, thereby exposing students to consideration of trade-offs and system-level implications rather than treating the rectifier as an isolated circuit element. The prompt is shown in Fig. 3.

Our Challenge

Your task is to investigate and compare three basic diode based rectifier configurations. For each rectifier type, work with your partner to compare advantages and disadvantages of the rectifier types.

Guiding Questions:

1. How many diodes are needed? (Each diode costs $0.05)
2. How smooth is the output voltage (ranking is enough)?
3. Impact of choosing each rectifier on the following module of the power supply. (How does design of the following module change).

Figure 3: Introduction to design ambguity using rectifier options.

As part of the think–pair–share activity, students compared rectifier configurations and ultimately made a recommendation on which rectifier to use based on cost and the quality of the DC output. In doing so, students observed that while the half-wave rectifier is the least expensive option, it also produces the poorest average DC output. Students were encouraged to recognize that there is no single “right” or “wrong” recommendation and that the emphasis is on making and justifying a defensible design choice. The full-wave rectifier offers improved performance at a modest increase in cost, whereas the bridge rectifier is the most expensive configuration. This progression is intentional and is designed to create the impression that the bridge rectifier might be unnecessary, thereby setting up a meaningful design trade-off for subsequent stages of the lab. Students summarize their findings in the format shown in Fig. 4 below.

Recommendation

1. List the rectifier types with advantages and disadvantages of each based on the criteria listed above.
2. Which rectifier design do you recommend for McDuck Medical Devices?
3. Justify your answer considering:
   - Cost (remember, Mr. McDuck likes things to be cheap!)
   - Performance and safety (patients come first)
   - Scalability (hundreds of pumps)
   - While Mr. McDuck counts coins, the engineers believe in technical soundness. Convince them of your choice by comparing the average value of input voltage to the rectifier and the average value of half-wave and full wave rectified output. The average value, $< V >$, of voltage $V(t)$ is given by,

$$< V >= \frac{1}{T}\int_{0}^{T} v(t)dt.$$

4. Your recommendation with justification. Is there a clear winner? If not, what information will help you pick a clear winner.

Figure 4: Prompt: encouraging students to provide rectifier recommendations.

3.4 System Implications, Opportunity Recognition, Final rectifier choice

The choice of rectifier has direct implications for two other modules in the power supply: the transformer and the capacitor filter. Specifically, a full-wave rectifier requires a center-tapped transformer, while a half-wave rectifier requires a larger filter capacitor to achieve acceptable ripple performance. To establish the importance of a transformer, a think–pair–share activity is introduced at this stage; the activity prompt is shown in Fig. 5.

Safety Pivot Question

Suppose you directly connect your chosen rectifier circuit to **120V AC mains**. **Is this safe? Why or why not?**
Guiding Reflection:

- Why is a transformer often added before the rectifier?
- What role does isolation play in protecting patients and devices?
- How does the transformer fit into the block diagram below?

AC Source $\longrightarrow$ Rectifier $\longrightarrow$ Filter $\longrightarrow$ Regulator

Figure 5: Prompt: Transformer study and safety considerations to establish the need for a transformer.

Once the need for a transformer is established, additional "information," shown in Fig. 6, is provided to students. This information introduces the availability of standard off-the-shelf transformers, which effectively eliminates the full-wave rectifier option that initially appeared attractive based on cost and performance considerations.

New Information (Think–Pair–Share)

McDuck Medical Devices has just purchased a company that manufactures **standard 120 V / 25 V (RMS) transformers**.

Figure 6: New Information on easy access to standard transformers.

Students work with their partners to revisit the rectifier selection in light of newly available information about standard, low-cost transformers. They reconsider the earlier diode cost trade-offs and evaluate whether access to off-the-shelf transformer options alters their initial rectifier choice, potentially making the bridge rectifier a viable option, particularly when higher average DC output and improved ripple performance are required.. Students then formulate a recommendation to the project stakeholder, Mr. McDuck, identifying the most appropriate rectifier configuration—or acknowledging multiple viable options if no clear winner emerges. Students justify their choice based on a set of considerations addressing cost, performance, and scalability.

A suggestion is now made (Fig. 7) proposing that the transformer could be rewound to include a center tap, thereby enabling the use of a full-wave rectifier. Students are then asked to evaluate the feasibility of this suggestion, particularly in the context of a commercial product—recognizing that while such an approach might be acceptable for a proof-of-concept design, it may present significant challenges for large-scale manufacturing.

Justify your choice! (Think–Pair–Share)

Mr. McDuck, always looking for extra savings, now asks:
"Can't we just rewind existing transformers instead of buying new ones and eliminate the most expensive rectifier completely?"
Discuss with your partner:

- Safety
- Scalability

Figure 7: Exploring the option of rewinding a transformer

Students are asked to provide a brief explanation discussing whether rewinding a transformer is viable solution. Students then update their rectifier recommendation, identifying whether a clear choice has emerged or if multiple options still remain. If there is no clear winner, students are asked to articulate what additional information would be needed to make a final decision.

At this stage, two rectifier options remain under consideration: the half-wave and the bridge rectifier. Students now focus on design of filter capacitor. The necessary technical background is provided to help students compute capacitor values needed for each rectifier choice. The final piece of information introduced is the cost of the filter capacitors, which ultimately becomes the determining factor in selecting the rectifier configuration.

4 Assessment Approach and Preliminary Findings

This section describes the assessment methodology used to evaluate the effectiveness of the curricular changes in achieving the intended learning objectives. Three sources of evidence were used to support the preliminary assessment: student lab manuals, written reflection exercises, and focus group interviews. Although the redesign was intended to support several learning objectives, the preliminary analysis reported here concentrates on three specific dimensions: designing under ambiguity, stakeholder interests, and systems thinking. Forty two students students provided informed consent for their anonymized reflections and lab manuals to be used in this study. Focus group interviews were conducted with five students during the first semester of implementation. Preliminary analysis of fifteen reflections was done and all the lab manuals were looked at. Additional reflections, and focus group interviews are currently being analyzed, with expanded data collection planned for subsequent semesters. In addition, a survey instrument based on [14] was administered to the full class. Survey results are pendng and will be reported in future work.

4.1 Reflection and student manuals

The thematic findings reported in this section are derived from analysis of student written reflection exercises and selected artifacts from lab manuals; results from focus group interviews are presented separately in the next subsection. The preliminary insights from student reflections and lab manuals related to the three focal themes are summarized below.

1. **Designing under ambiguity:** This subsection examines evidence of students' engagement with design under ambiguity, guided by the reflection prompts summarized in Table 1.

Table 1: Reflection prompts and evidence sought in student responses - Design Ambiguity.

Reflection Prompt Focus	**Evidence Sought in Student Responses**
Evolution of rectifier choice as new information was introduced	Revisions to initial design decisions, justification for changing or maintaining choices as constraints and data emerged
Decision-making with incomplete or staged information	Expressions of uncertainty, adaptability, confidence calibration, and comfort with making provisional decisions
Real-world decision-making under uncertainty	Recognition that engineering decisions are often made before all information is available and must be revisited as new information emerges

Student reflections and lab artifacts show that rectifier choices evolved as new information was revealed. Most students initially selected the full-wave rectifier due to its lower ripple voltage, viewing the added diode (compared to half-wave rectifier) cost as an acceptable trade-off, while a few groups selected the bridge rectifier early but reported low confidence in that choice. Most students missed that the higher ripple of the half-wave rectifier could be addressed through filter capacitor design. As information about transformer availability and system-level costs emerged, groups revised their decisions and shifted toward a bridge rectifier. Overall, students recognized they might have to be responsive to emerging constraints and refine their choices as information became available. Some examples are included below.

> *Each step gave us new data, and I had to rethink my earlier choices more than once. It felt like a realistic process—starting with a rough idea, learning more, and adjusting the design. I learned that being flexible and practical is just as important as getting the math right.*

> *Is the higher efficiency of a bridge rectifier worth an extra* 0.10 *per unit when producing 10 million units? Is the cost of rewinding a transformer really that simple in terms of getting a lower cost? Going through this part of the exercise profoundly increased my appreciation for decision making under uncertainty.*

> *"We didn't feel very confident in our early decisions because we made the earlier decisions when less information was available to us and then adapted our decisions as we learned more about what we should be optimizing or what resources we already have available to us. We didn't end up changing our early choice but rather solidified our confidence in our choice as the lab went on."*

> *"...after capacitor cost information was introduced, ranging from less than a dollar for small capacitors to several dollars for large capacitors, I had to change my priorities."*

2. **Stakeholder Interests:** While stakeholder interest and systems thinking are reported as different categories, some overlap is expected. In this analysis, stakeholder interest captures who is affected by design decisions, whereas systems thinking captures students' recognition of how these considerations interact across the system. The reflection prompts and themes related to this category examined in student work is shown in table 2.

Table 2: Reflection prompts and evidence sought in student responses - Stakeholder interests

Reflection Prompt Focus	**Evidence Sought in Student Responses**
Non-technical reasons for product failure	References to cost, customer needs, regulations, competition
Engineers' responsibilities beyond technical correctness	Mindset shifts toward balancing technical performance with real-world constraints and stakeholder needs
Early-stage design questioning	Identification of stakeholder-driven questions posed early in future projects

Students described several stakeholder-centered mindset shifts, including greater attention to cost, user friendliness, marketing strategies, and societal impact. Across reflections, they emphasized the importance of asking early whether a product truly meets customer needs and delivers value, rather than prioritizing technical novelty alone. Cost emerged as the most commonly identified factor, along with less visible influences that indirectly affect cost, such as regulatory requirements. Students also noted ease of use, scalability, manufacturability, privacy concerns, competition, and failure to adapt to user or market needs. Representative student excerpts are presented below.

> *A good engineer is someone who can create a working product that attends to user experience and fulfills the needs of the creators.*

> *It's also important to keep in mind that while you can add a feature and make your product more technologically impressive, it doesn't mean you should. For example, the Google Glass added cameras which sparked backlash due to privacy concerns.*

> *.....I think the main shift in mindset from this lab had to do with my main approach to problem solving... Before, we would solve a problem, ask if the solution properly solves what we're asked, and move on. ... Knowing how to solve a given problem is great of course but ensuring that any solution you find is the most desirable to the end user's situation and cost constraints it equally as important.*

> *Now going into future projects, I'm going to be asking myself questions like "How would this fit into people's lives?", "Would this product be affordable or would it have a market for it?", or "How can I make this product useful for society?".*

> *Intel's Optane memory as an example of technically impressive products that failed... Adding onto this, one constraint I did not initially consider in this activity was the absolute and non-negotiable power of regulations and how they factor into costs.*

3. **Systems Thinking:** In the first offering of the redesigned lab, students encountered both technical and broader ecosystem interdependencies. Technical interdependencies were illustrated through the coupling between rectifier choice, transformer configuration, and filter capacitor sizing, where decisions in one subsystem directly affected others. A key leverage point was introduced via the availability of low-cost **standard** transformers, which reshaped feasible rectifier options and system-level trade-offs under stakeholder-imposed cost constraints.

   As mentioned earlier, interdependencies at the broader system level were highlighted through the case study of technically strong products that failed in the marketplace, emphasizing how external factors shape engineering outcomes. Table 3 below summarizes the indicators used in student responses to establish appreciation for systems thinking.

Table 3: Indicators used to identify systems thinking in student reflections

Systems Thinking	**Indicators in Student Responses**
Recognition of interdependencies and leverage points	Identification of how decisions in one subsystem (e.g., rectifier choice) affected others (e.g., transformer requirements, capacitor sizing), and recognition of leverage points such as standard component availability
Anticipation of broader ramifications	Consideration of downstream effects on cost, manufacturability, scalability, sustainability, stakeholders, or the broader product ecosystem beyond immediate technical performance

Several reflections explicitly articulated a systems perspective, recognizing that technical performance must align with infrastructure, manufacturability, sustainability, and market context. One student noted a shift from focusing on making a design work to considering how it fits within a larger ecosystem, highlighting the interdependencies that shape engineering outcomes. Another student described how they finalized the design once the information on availability of transformers was provided. An example of how scale can affect costs is also included below.

> *In my future project, I would ask: What infrastructures does this product require? What is the marketing strategy? Is this product sustainable and manufacturable? These questions will help me to avoid a huge failure like the hydrogen car example. This lab shifted my mindset from "How do I make it work?" to "How will this fit into the larger ecosystem?" Pairing technical achievement with customer need is crucial. Therefore, a good engineer blends technical achievement with a contextual awarenes*

> *My first choice was the center-tapped full-wave rectifier because it required only two diodes and produced a smoother output than the half-wave configuration. But when it was realized that the 120 V/25 V transformers are readily available and inexpensive, the design shifted to the fullwave bridge rectifier.*

> *It goes to show how every decision an engineer makes has consequences, and tradeoffs must be evaluated at every step, even if it's a few components that add $0.10 to the cost. Because when that scales over 1,000,000 devices, that's an extra $100,000 that must be spent for manufacturing.*

4.2 Focus group interviews

Two focus group interviews were conducted with five students who completed Lab 3 during the Fall semester 2025 and volunteered to participate in the interviews. Interviews were audio-recorded with Zoom and then transcribed. The interview audio and transcripts were imported into MAXQDA 2025, a qualitative research software program used to organize, manage, and analyze the interview data.

The interview data collection and analysis are ongoing. One qualitative researcher coded the data from two interviews using open coding beyond the three proposed dimensions first to capture emerging perspectives (Citation). Then, she has been analyzing the interview data iteratively, focusing on the three specific dimensions: designing under ambiguity, stakeholder interests, and system thinking to evaluate the effectiveness of Lab 3 design to improve students' EM mindset.

The preliminary analysis shows participants' positive learning experiences in dealing with ambiguity in the design process, understanding the interconnectedness among elements and their mutual influences, and becoming more aware of the importance of the non-technical aspects involved in the design process. First, participants became more mindful of the importance of understanding customers' needs and wants.

> *... if you're only thinking just about the technical aspects, you kind of forget about what the consumer may need, or what the consumer may want, or what the consumer may have, right? Just going back to the accessibility kind of point, I feel like when you know that something's not accessible to the consumer, you're not really designing a good product. Yes, as engineers, we are the people that are responsible for designing the technical components, yes. But, we also might need to consider what the consumer is saying..*
>
> *Sometimes the issue is that the technically good product is very good, but there's just no use for it in daily life. Like we can use technology to make a lot of things that are very, very good. But if someone cannot justify using it in daily life or cannot justify the price that it's for daily life, then it's really not meaningful.*

Furthermore, it is worth noting that the participants viewed the customer-centric mindset as an advantage for their future careers, differentiating themselves from other engineers who focus only on technical aspects of the design.

> *... if I am running a company, you know, I would be better to have an engineer who's willing to communicate back and forth... [It would] be better to have an engineer who can communicate with the business side and actually think about is it going to be profitable or something like that. ... but I feel like it's going to be a plus if engineers are able to think such way and then it'll make those like back and forth way easier, much faster if you want to in a company situation..*

Second, participants perceived ambiguity in the design process as a learning opportunity to seek out additional necessary information on their own and to experiment with their hypotheses using the available information and resources.

> *...But I feel like the limited information was an overall benefit. Because you're given such little information, you yourself have to look for it. And when you're looking for it, you're more likely to obviously understand it and know the differences and the details between these two different rectifiers...*

> *... you go in with an initial vision of how something's gonna work. And then usually once you learn a little bit more, you realize, oh, this doesn't work the way I thought it did. This isn't available to me. It's too prohibitive, you know...*

It is interesting to note that participants repeatedly mentioned that designing with limited information is positive and natural, perceiving that this would be similar to the work in the real world.

> *...I think that was a perfect way to show how actual, real life engineering works, because most of the times you get some information and then you get more information, which will completely change your entire project by the end of it. So, I think that was one very important aspect that they tried to teach us through this...*

> *"...[Having limitations] would lead you to think more of like an engineer, because that's like how the real world is, right?*

Lastly, participants demonstrated an understanding that changes in one condition would affect the designs and limitations.

> *...I think, it was good because we noticed, oh, there's a lot of power that's being lost if you just put a resistor first. Or you put a Zener diode. And you realize that because at first, I was confused as to why do we even need to use a DC to DC converter. It's DC. Can't you just use a resistor to just reduce the voltage? But when we do, we ... really lose a lot of power, and it's really inefficient. And I think that was really good at least explaining why we have the DC to DC. Right?*

Furthermore, participants' responses indicate that they can understand the limitations of elements in relation to the given contexts, including design objectives and resources.

> *...You get to see where each of these different configurations can be used for. Like the DC to DC, like the buck converter that the professor was talking about, that is probably the most efficient DC to DC converter. But that doesn't mean that it should be used for everything. ... A buck converter is kind of expensive. So, if it's like a really inexpensive small solution or a small project [with limited budgets], you could just use a regular resistor or a Zener diode.*

5 Limitations and Future Plan

The findings above are preliminary; therefore, it is crucial to note some limitations when interpreting them. First, the focus group interview data used for this preliminary analysis is limited to only two interviews. The team planned to conduct five interviews with 25 students who signed up to participate; therefore, more focus group interviews remain to be completed. Second, not all students' post-lab reflections have been reviewed. The reflection analysis presented in this paper is preliminary in nature, drawing on a subset of the collected reflection data and conducted by a single researcher. To strengthen the rigor of future analyses, two researchers will independently examine the full set of reflections and subsequently compare their thematic interpretations, resolving any discrepancies through discussion and consensus.

Additionally, the researchers will review selected reflections to check whether they align with the findings from the focus group interviews and to identify any other unique findings. Lastly, the students were interviewed a few weeks after completing the lab 3 activity; therefore, some participants' memories were not as clear as others'. To remind them of the lab experiences, the interviewer checked whether participants remembered their learning activities, then described what they were asked to do to complete the lab 3 activity. To capture students' vivid learning experiences and smooth the interview process, the team plans to schedule the focus group interviews one week after the lab is completed.

6 Conclusion

This work-in-progress paper describes instructional interventions implemented in a junior-level electronic circuits laboratory during the Fall 2025 semester. The interventions specifically targeted three aspects of the KEEN EM framework: designing under ambiguity, customer and stakeholder interests, and systems thinking. Preliminary qualitative analysis suggests that these interventions were effective in encouraging student engagement with aspects of EM thinking, consistent with findings from prior published work. Future work will include offering the revised lab in Spring 2026, expanding data collection, conducting deeper qualitative analyses, and developing and administering surveys to quantitatively assess the impact of these curricular changes.

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