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(WIP) Using Design Choices to Engage an Entrepreneurial Mindset

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Abstract

Engineering design involves making design choices. In an introductory circuit analysis class that has a final team design project, the student teams were given a design objective and were provided with multiple modules that could be combined to meet the given design objective. The students were told in the design proposal that they were given more modules than were necessary to complete the design project. The purpose of providing extra modules was to allow the students to make their own connections on combining the modules (with some modifications to specific circuit elements) to meet the stated design goal. In their final report, the students were asked to explain their connections of the modules by rationalizing their design choices. The final reports from the first semester this change was implemented were used as the metric for determining the students' engagement with an Entrepreneurial Mindset (EM). The final reports indicate that students were able to see how different sub-circuits can connect to create a more complex system level design. When analyzing the final reports, it was also discovered that by experimenting with the modules, the students were able to discover a novel solution to the design problem. This experimentation improved their understanding of system level design, and resulted in the students engaging with the "Curiosity" and "Connections" of the EM.

Introduction

Engineers are asked to take their scientific knowledge and apply it to design problems. An Entrepreneurial Mindset (EM) based approach incorporating 3C's - Connections, Curiosity, Creating Value, are an effective way to enable students to go beyond problem solving, and develop an engineering design mindset[1]. The connections aspect of the 3C's involves connecting theory learned previously in the class to a new application in the design project and understand how elements of an ecosystem are connected[2,3]. The curiosity aspect involves investigating trends, challenging assumptions, and examining data that supports unpopular solutions[4].

Reflections are a well known mechanism to improve student learning and exam scores[5,6]. Chen and Jacques[7] correlated student improvement on exams to the quality of their reflections on missed exam problems in an introductory photonics course. Chen et. al.[8] implemented reflections in an introductory course and a senior level ECE courses, and saw in both that higher quality reflections correlated to increased performance on similar problems.

We use reflections in the form of rationalizing their design choices in an end of semester final design project. The design objectives were selected so that there were multiple different ways to achieve

Criteria	Rating Scale			weight	Score
	3	2	1 or 0		
Design	The report clearly outlines the requirements, science, and equations behind the choice of values used for circuit components and their arrangement in the solution.	The report attempts to follow guidelines provided by the course documents, but there are errors that show the design constraints were poorly understood and applied.	Circuits were constructed, but the report gives little or no consideration to the choices made.	× 40=	/120

Figure 1: Design portion of grading rubric for the final project. Different point values are given based on how well the students explain their design choices using experimental data.

them and the students were told that there were multiple ways to meet the design requirements. The final project also includes a final report and video. As part of the final report for the design project, students are asked to rationalize why they selected a specific way of achieving their design objectives. The have to use experimental data to justify their choices and show that their design achieves the design objectives. Through using their connections and curiosity, the students were able to find a unique method for achieving the design requirements that had not been considered by the course staff.

Methods

ECE 110, an introductory circuits class at the University of Illinois Urbana-champaign, has a lab component of the course. The lab contains a final design project which utilizes the skills learned in the lab throughout the semester. The goal of the design project is for students to connect what they have learned in lab and in lecture in a new context to a real world problem.

To make the design easier, and provide a space for students quickly explore different designs, the students are asked to break their design into different modules that can be put together to meet the overall design requirements. The students are also given multiple different circuits that they can use in their modules, and are told that the course staff provided them with more methods to complete the final project than were needed. It is then up to the student groups to decide how they want to meet the design requirements in their final project.

The final design project also includes a final report. In that report, students are asked to explain their design choices and justify why they made those design choices to complete the project requirements. The justifications should include measurements, graphs, tables, etc. showing that their chosen method meets the design objectives. The portion of the final project rubric on design is given in Figure 1; different point values are awarded based on how well the students explain and rationalize their design choices using experimental data. The goal is to let students see that there are many ways to complete a given design task and learn how to justify their choices.

In one semester, the students were asked to build a simplified version of ”The Clapper ©”, a popular product that allows devices (usually lights) to be turned on and off by sound, i.e. clapping. The given design requirements were that the circuit must:

1. register a loud clap
2. the loud clap should trigger the circuit to turn on an LED

3. the LED must remain on until another clap is registered by the circuit

To achieve these goals, the students were provided with the following modules:

1. a microphone and amplifier
2. a peak detector
3. a timed reaction
4. a comparator
5. a bipolar junction transistor (BJT) latch

Example circuits from each module are given in Figures 2-6.

The students were not provided with any hints on how to combine these different modules to meet their design requirements, but were told that they might not need all of the modules to complete their design requirements. The students were also given approximately 3 weeks of lab time dedicated solely to working on the final project.

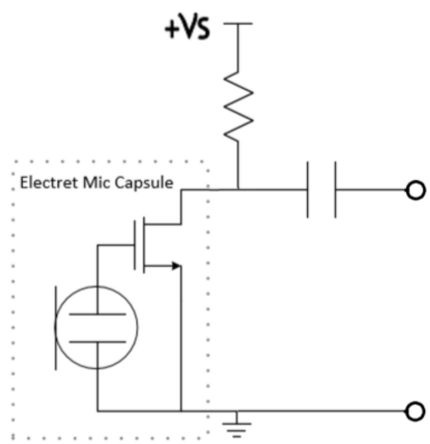

Figure 2: Microphone circuit given in the microphone module.

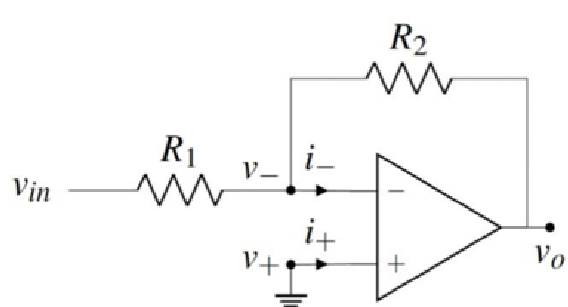

Figure 3: Inverting amplifier circuit given in the amplifier module.

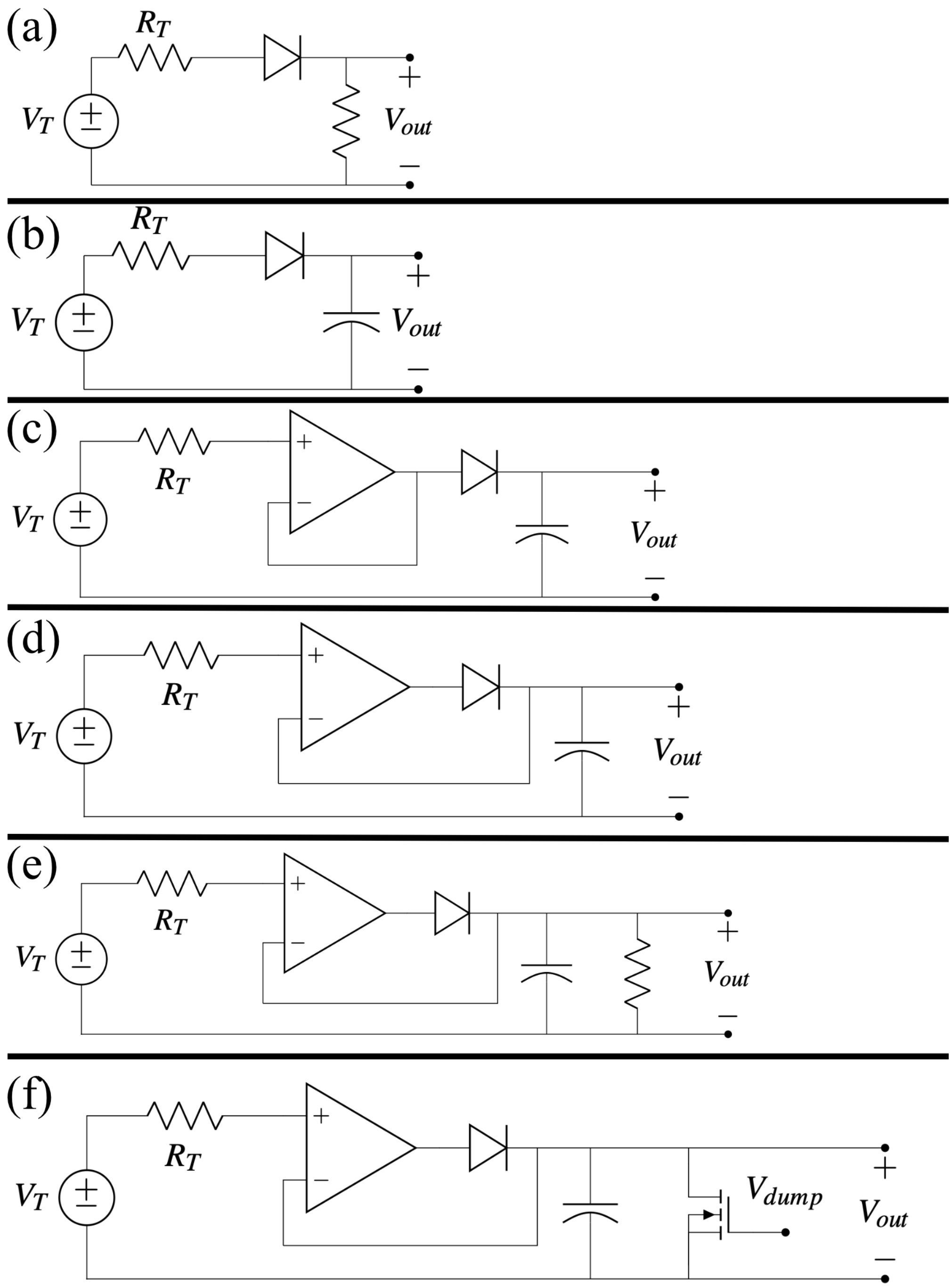

Figure 4: Family of peak detectors given in the peak detector module.

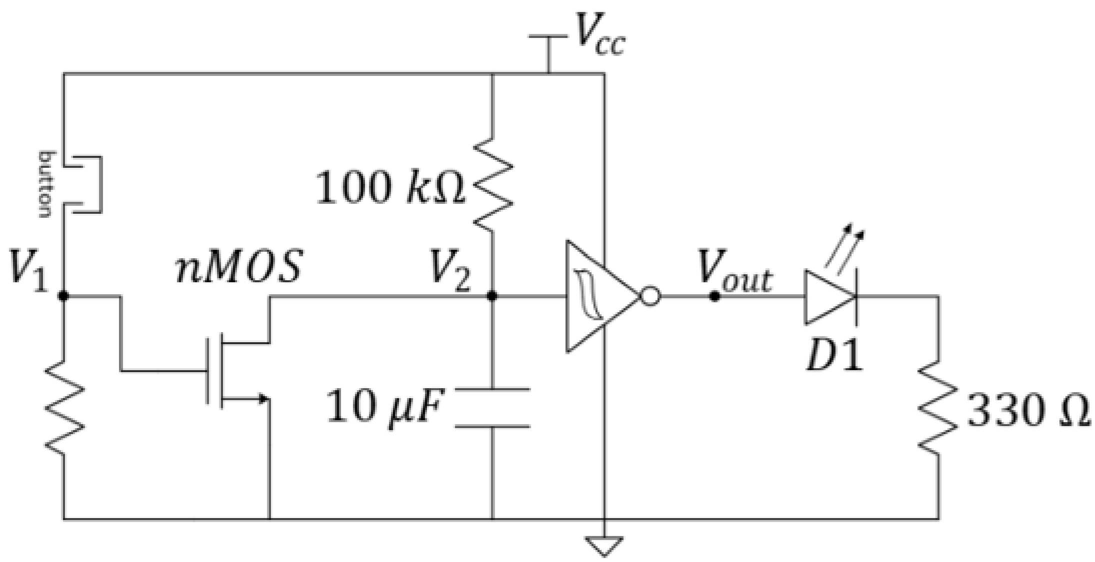

Figure 5: Timed reaction circuit given in the timed reaction module.

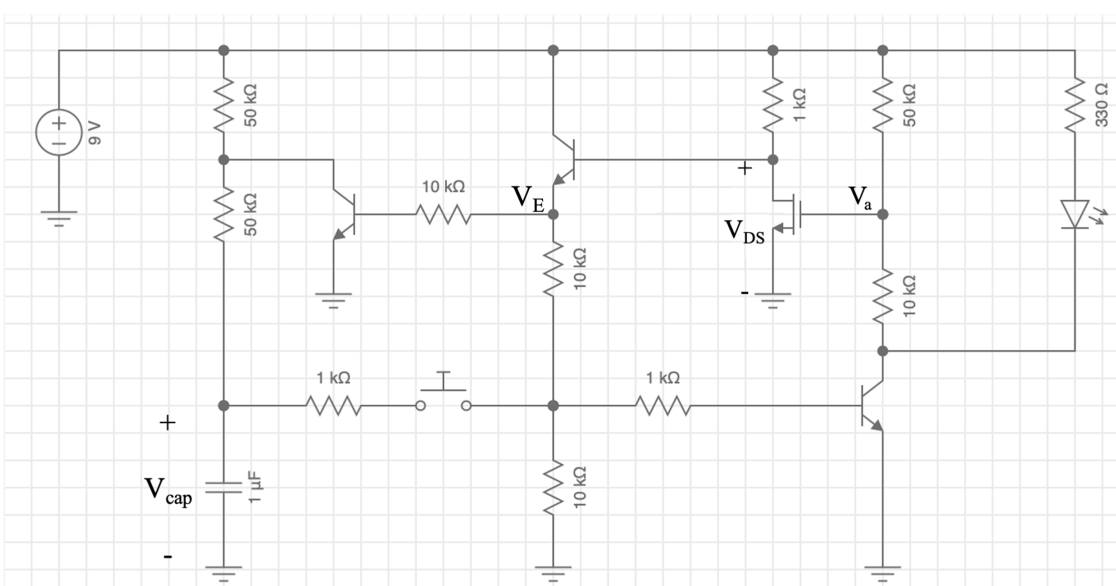

Figure 6: BJT latch circuit given in the BJT latch module.

During the prototyping phase of the design project, the course staff used 4 different modules:

1. the microphone and amplifier
2. the peak detector
3. the comparator
4. the BJT latch

The output from the microphone and amplifier was fed into the peak detector, which charged and discharged a 1000 μF capacitor. The capacitor voltage was fed into the comparator, which was used to determine the noise level of the clap. A louder clap would result in a larger capacitor voltage, and if the voltage was above a certain threshold, the comparator would turn on an nMOS MOSFET in the BJT latch, turning on the LED.

Results

25 reports were collected **with students' consent**, and then were imported into MAXQDA (version 26.0), a qualitative research software program used to organize, manage, and analyze the students' reports. One qualitative researcher analyzed the students' reports using the open coding method[9] to examine how students explored different design options and justified their design choices. During the initial cycle, they identified patterns in students' understanding and articulation of their design choices and learning experiences, which will be discussed in detail below. Currently, the analysis is ongoing iteratively with the thematic coding method[9] to examine further other emerging patterns.

The preliminary findings of the analysis show that students were able to formulate hypotheses and test them to achieve the desired behavior. The following are taken from the students' final reports:

> "We initially considered using a peak detector to smooth and extend the duration of the amplifed microphone signal. This would have been a good idea if the clapping sound was very brief. However, after using the oscilloscope to display the amplifer output, we observed that the amplifed signal was already strong and spiky enough to cross the comparator threshold without additional smoothing. Unfortunately, introducing the peak detector added unnecessary delay, reducing the reliability of the overall system."

> "From our testing we determined that only three components of the given 6 were necessary, these being the Microphone, amplifier, and BJT latch. It was obvious to our group that the microphone would be necessary to get an input signal for our "clapper", but through testing and measuring voltage differences we noticed that the output voltage was much too small and wouldn't work well with any of the other modules, so we determined that a voltage amplifier (OP AMP) would be necessary for our circuit to work properly."

> "Our initial approach was to switch the button from the BJT Latch circuit to a single MOSFET, however due to the existence of body diodes, the desired behavior could not be accomplished by a single MOSFET. We first discovered this when we found

> a negative voltage drop at the Source when the input shifts from high to low at the Gate. Therefore, we needed to find a way to offset the impact of body diodes in the MOSFET."

Furthermore, the students identified another effective method to meet the design requirements that the course staff had not demonstrated. For example, students discovered through their experimentation that they could take the output directly from the microphone and amplifier and connect it to the BJT latch to turn on the LED. Some students explored even further what they learned in hypothetical situations and for future improvements. The following are taken from the students' final reports:

> "Although we eventually succeeded in using a Back-to-back MOSFET, through peer review and from TAs we learned that some other teams succeeded with the one MOSFET configuration. The fact that the one MOSFET configuration works in different configurations creates a further interesting question that is worth future research. That is, why is this phenomenon happening, and would there be a more consistent way of integrating the entire circuit?"

> "While the final design met our goals, we also saw room for improvement. For example, adding a comparator could make the distinction between a clap and background noise more precise, making the circuit less sensitive to background noise."

> "One improvement we would do in the future is using an Arduino Nano to help handle the clap detection logic more precisely. With a microcontroller, we could program in features like a debounce timer or even detect clap patterns like double clap. This would give more control over how the LED responds to different clapping patterns and types of input. We could also fine-tune the resistor and capacitor values in both the latch and amplifier modules to get more consistent and predictable behavior, especially when it comes to timing and signal strength. Moving the final build off the breadboard and onto a stronger type of board (like a perf board) would help us reduce the chance of loose connections and make everything look cleaner. Also, adding decoupling capacitors near the op-amp and microphone would help smooth out voltage spikes."

Besides students' learning through experimentation, the preliminary findings show that students were able to connect and apply what they have learned from the previous class to this lab activity. From the students' final reports:

> "This project challenged our team to apply the analog circuit concepts we learned in ECE 110 to develop a modular, sound activated lighting system – basically a modern version of The Clapper."

> "Throughout this project, we were able to really understand our ECE 110 concepts, such as BJT latch dynamics, op-amp biasing, and MOSFET switching."

Limitations and Future Work

The findings reported in this paper are preliminary; therefore, the results presented here represent initial insights rather than conclusions and may be refined as additional data are analyzed. The same setup, with a different final project, was used in a subsequent semester to see if the trends observed here hold for a different design project. Secondly, these findings are based solely on students' written reflections. No supplementary data sources were collected to examine the lab learning experience during the semester. Consequently, the robustness of these findings is relatively constrained.

Student reports for a subsequent semester that re-used the same design setup, with different design objectives, have been collected. However, that data has not yet been analyzed, so no major trends can yet be observed.

Conclusion

This work in progress paper discusses initial insists gained from a design project where multiple different designs could be used to meet the design objectives. The students connected what they learned in previous labs and the lecture to different ways they could meet the design objectives. The students were able to form hypotheses about the modules based on their previous knowledge and tested them in the lab. Through their experimentation, the students found a novel design that met the design objectives that the course staff has not considered. The insights gained here through the EM 3 C's will be compared to results from a subsequent semester with different design objectives to see how the EM helps students create rationalized engineering designs.

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