Paper ID #50342

”Fun With Electronics”: An Endeavor to Increase Curiosity in the Design and Implementation of Practical Electronic Circuits While Incorporating Enjoyment via a Project-Based Laboratory Course.

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Abstract

Past research has demonstrated that project-based exercises allow students to build valuable skills, and retain knowledge, which will help them navigate and excel in industry after graduation. Many courses incorporate small projects to keep the courses interesting while reducing the burden of executing extensive projects. Unfortunately, such endeavors, even though valuable, fall short in developing skills needed for the industry and knowledge retention. Fun With Electronics is a 3-credit hour, project-based undergraduate Electrical and Computer Engineering (ECE) laboratory course designed to cultivate hands-on skills, creativity, and entrepreneurial thinking through electronics. Students complete seven project sets, each containing multiple circuits that explore switching, sensing, timing, and signal processing. The course culminates in real-world applications such as water-level alarms, Knight Rider-style light LED animations, AC power detectors, music-reactive lighting, and dimmer systems. The Missouri University of Science and Technology's (S&T) Electrical and Computer Engineering (ECE) Cooperative Engineering Program (CEP) serves as a testbed for the implementation of this course, which was recently molded to incorporate Entrepreneurship Mindset Learning (EML) elements, using AI-assisted contrarian design and test, to create a Project-Based Entrepreneurship Learning (PBEL) course. Student work and feedback shows a positive and enjoyable learning experience.

Keywords

Electrical and Computer Engineering, Project-Based Instruction, Entrepreneurship Mindset Learning, AI, Project-Based Entrepreneurship Learning.

Introduction

Course projects allow students to gain valuable engineering design and analysis skills that aim to prepare them for their chosen career path [1-8]. Past research has repeatedly demonstrated the need for active project-based learning, which involves significant hands-on projects for deeper learning and knowledge retention [1-2, 5-6]. A framework, to implement project-based learning for multiple and sequential upper-level courses in the S&T's Bachelor of Science (BS) Electrical Engineering (EE) undergraduate degree program, was used to create and implement several project-based courses [6]. This paper describes the course implementation of one such project-based course: "Fun With Electronics" (FWE), which is a 3-credit hour, project-based undergraduate Electrical and Computer Engineering (ECE) laboratory course designed to cultivate hands-on skills, creativity, and entrepreneurial thinking through electronics. This laboratory course is currently taught via EE 4099: Undergraduate Research, which can satisfy either elective E or a free-elective BS EE degree requirement [9-10].

Course Placement Within the Electronics Curriculum Sequence: FWE occupies a flexible position within the program's electronics curriculum as shown in Figure 1 [9-10]. Students may enroll after completing Introduction to Electronic Devices or after Electronics 1, the latter being a subsequent course in the standard sequence.

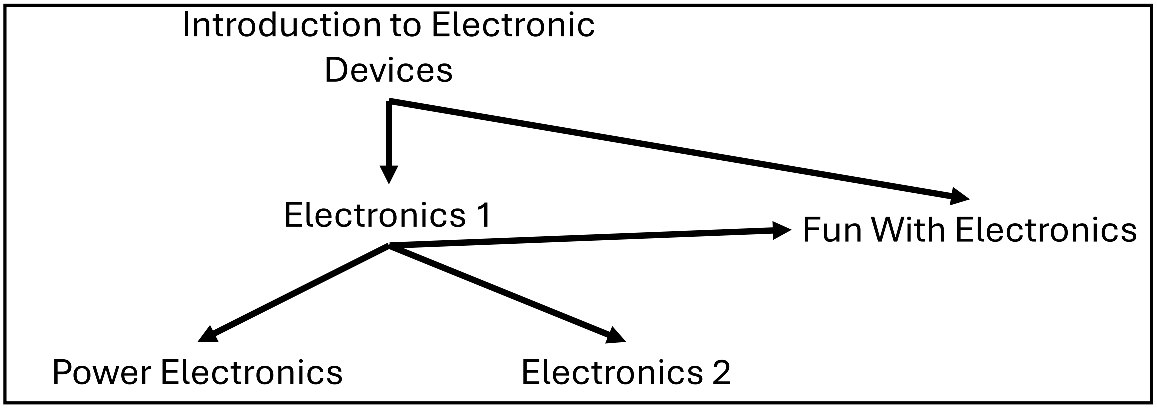

Figure 1: Course sequence structure for electronics curriculum and the location of FWE

This structure allows the course to serve both as an enriching follow-on to foundational topics and as an applied supplement for students with more advanced preparation. Typically, junior or senior ECE students enroll in this course.

Broad Course Framework

Course Recruitment: To ensure that students understand the intensive course expectations, students are regularly informed, before the start of the semester, about rigorous project-based courses assessments that will be a great learning experience but will be time consuming and challenging. This regular communication will ensure that only those students enroll in a project-based course who are truly interested in learning via hands-on projects. One drawback to this process is the resulting low enrollment numbers in rigorous project-based courses.

Broad course learning objectives include:
- Apply core electronics principles to design and build functional circuits.
- Integrate sensors, transistors, and timing components to create responsive systems.
- Use AI tools to assist in ideation, troubleshooting, and reflection.
- Explore real-world applications and iterate designs for performance and value.

Note: The above-mentioned course learning objectives include the recently incorporated EML components.

Broad course learning outcomes include:
- Demonstrate proficiency in circuit construction, testing, and documentation.
- Analyze circuit behavior using measurement tools and simulations.
- Communicate technical insights through structured reports and video presentations.
- Exhibit entrepreneurial mindset through curiosity, creativity, and value creation.

Note: The above-mentioned course learning objectives include the recently incorporated EML components.

Pedagogical rationale: Project-Based Learning (PBL) is grounded in the principle that students learn most effectively when they actively construct knowledge through authentic, open-ended tasks. Providing students with a foundational starting point, such as a basic circuit schematic, and challenging them to extend, enhance, or adapt it to meet open-ended requirements supports both creativity and deeper conceptual understanding [1, 4-5]. In project-based courses, students engage in complex, real-world problems that require them to integrate conceptual understanding with practical application. This approach shifts learning from passive reception to active investigation, encouraging deeper cognitive processing, sustained inquiry, and iterative refinement of ideas. PBL environments also promote essential professional skills, including teamwork, communication, resourcefulness, and problem framing that traditional lecture-driven formats typically cannot cultivate as effectively. Because engineering practice demands the ability to design, analyze, troubleshoot, and justify decisions under realistic constraints, project-based courses provide a pedagogically aligned mechanism for helping students bridge theory and practice. Moreover, by allowing students to assume ownership of their work and make meaningful choices about design pathways, PBL increases motivation, persistence, and self-efficacy while reinforcing a growth-oriented mindset. Within the broader curriculum, these courses create a natural context for integrating technical knowledge with creativity, ethical awareness, and lifelong learning habits, making them a critical component of modern engineering education.

Course Structure and Experiments

The 3-credit hour laboratory course consists of 7 sets of hardware projects/experiments. Prior to Fall Semester (FS) 2025, the experiments didn't incorporate extensive EML components. Although EML principles were embedded within earlier iterations of the course, they were not explicitly emphasized or framed as intentional learning outcomes. This section will discuss experiment tasks, rationalize the choice of experiments and provide links to typical executed student artifacts. For each project experiment, students are required to calculate the values of components, based on prerequisite study, build and test the hardware on breadboard, and log the observations, challenges faced, and solutions created. They are required to demonstrate the built and tested hardware circuits via videos created and showcased on their YouTube channel. The creators of all linked videos, in this paper, have granted permission for their video content to be showcased in this paper. Additionally, all cited YouTube videos are publicly accessible and available for viewing by anyone.

Note: The descriptions below do not include circuit diagrams. The reader is encouraged to watch the demonstration videos which show the give circuit diagrams and variations explored. Moreover, the videos mentioned in this section do not discuss the AI-assisted contrarian EML additions implemented starting FS 2025. These are discussed in the subsequent section.

Note: All linked YouTube videos valid as of February 11, 2026

Project 1: Basic switching of a small signal NPN and PNP BJT: This project delves into experimenting with different ways to switch a BJT including using a simple voltage divider, with fixed resistors and Light Dependent Resistor (LDR), Push-Button (PB), hand-touch, water, and delayed switching using an RC circuit. While basic BJT switching is covered in prerequisite courses, this experiment aspires to increase curiosity and explore different methods of switching a BJT for interesting subsequent practical applications. Students are given basic circuit diagrams of the desired switching circuit. Typical student artifacts include:

- Prior to FS 2025:
  - Transistor Switching Sample 1
  - Transistor Switching Sample 2
  - Transistor Switching Sample 3
- FS 2025:
  - Transistor Switching Sample 4
  - Transistor Switching Sample 5
  - Transistor Switching Sample 6
  - Transistor Switching Sample 7

Project 2: Astable Vibrator: This project delves into experimenting with an astable oscillator created using a pair of discrete BJTs, RC components for timing and LEDs for a light show. This circuit was chosen because other types of oscillator circuits are covered in other courses including Introduction to Electronic Devices (using 555 timer) and Electronics 2 (Hartley, Colpitts and OpAmp-based). Students are required to figure out the working of the two-stage oscillator circuit by taking oscilloscope measurements. Then, students are asked to extend the design to a 3-stage oscillator circuit and including RGB LEDs to create an interesting light show. Students are given basic circuit diagrams of the desired oscillator circuit. Typical student artifacts include:

- Prior to FS 2025:
  - Astable Vibrator Sample 1
  - Astable Vibrator Sample 2
  - Astable Vibrator Sample 3
- FS 2025:
  - Astable Vibrator Sample 4
  - Astable Vibrator Sample 5
  - Astable Vibrator Sample 6

Project 3: Water Level Indicator and Pump Controller Hacks!: This project delves into three switching circuits to create a low-cost application hack involving water level indication and pump control. In the first circuit students use BJT switching, using water, to create a 4-5 water level indicator circuit. The second circuit concentrates on using the 555-timer to create an automatic water pump controller. Students are given basic circuit diagrams of the desired switching circuit. The third circuit was a challenge circuit to see if students can combine the first two circuits to create an interesting multi-application low-cost circuit. Typical student artifacts include:

- Prior to FS 2025:
  - WLI and PCH Sample 1
  - WLI and PCH Sample 2
  - WLI and PCH Sample 3
- FS 2025:
  - WLI and PCH Sample 4
  - WLI and PCH Sample 5
  - WLI and PCH Sample 6

Project 4: Additional Transistor Switching: This project delves into the following interesting circuits:

- Expansion of a project 1 circuit, which required the BJT to switch using hand touch. In this extension, the goal was to expand the circuit to make the LED brighter. Students had to recall a circuit learnt in Introduction to Electronic Devices to accomplish this task. The circuit was not provided. Only the description was provided.
- BJT switching using a Normally Closed (NC) pushbutton switch. The circuit was provided.
- Expansion of a project 1 circuit, which required the BJT to switch using an LDR. The goal was to use ambient light to switch the BJT and turn on the LED. But now, make the LED face the LDR so that when the LED is on and the ambient light is turned off the LED is still on because it is facing the LDR, which is in turn receiving stimuli to keep the LED on. The circuit was provided.
- Strobe light generator. This circuit was tricky to create. Not many students had success with this circuit using discrete BJTs. Some students got it to work using an IC-based BJT.
- Quick turn on but slow turn off switch. This circuit was assigned to be a prequel to project 5. The goal was to quickly turn on the LED. But, when the power is disconnected, the LED slowly fades off. Several circuits were provided. Some worked and some didn't. Students were encouraged to create their own versions of the circuit based on the working description.

Typical student artifacts include:

- Prior to FS 2025:
  - Hand Touch Sample 1
  - Hand Touch Sample 2
  - Optical Latch Sample 1
  - Optical Latch Sample 2
  - Delayed Fade Off Sample 1
  - Delayed Fade Off Sample 2
  - NC Transistor Switch Sample 1
- FS 2025:
  - Hand Touch Sample 3
  - NC Transistor Switch Sample 2
  - Optical Latch Sample 3
  - Delayed Fade Off Sample 3

Project 5: Knight Rider (KITT) Lights: Being a fan of the 1980s show, this project has been a dream to implement, which combines the fading circuit implemented in project 4, a decade counter, and a 555 timer, to provide a clocking circuit, to create the famous KITT lights. Students were provided with the basic setup and some description on how to set up the counter. The rest of the design and implementation was left to the students to foster creativity. Typical student artifacts include:

- Prior to FS 2025:
  - KITT Lights Sample 1
  - KITT Lights Sample 2
  - KITT Lights Sample 3
  - KITT Lights Sample 4
- FS 2025:

- KITT Lights Sample 5
- KITT Lights Sample 6

Project 6: Assorted Applications: This project delves into the following interesting circuits:

- AC mains power detector: The goal of this circuit was to detect the single-phase mains power and light up an LED and a buzzer. Students were given a basic circuit image describing the idea, and the implementation specifics were left to students.
- Audio/Visual remote-control signal detector circuit. In this project, students were required to detect the IR signal being transmitted by a TV remote-control unit using a TSOP IR detector and a transistor switch. Students were required to measure the detected signal on the oscilloscope and describe the pattern for different button presses on the remote-control unit. The circuit was provided.
- Dimmer circuit-phase 1: The goal of this circuit was to generate a varying DC output voltage based on hand touch. This circuit would be the first stage of a high wattage dimmer circuit. The circuit was provided.
- Running a 2-pin RGB LED circuit using the mains voltage without a step-down voltage transformer and a simple half wave rectification. The circuit was provided.

Typical student artifacts include:

- Prior to FS 2025:
  - Power Detector Sample 1
  - Power Detector Sample 2
  - Remote Control Signal Detector Sample 1
  - Remote Control Signal Detector Sample 2
  - Dimmer Circuit P1 Sample 1
  - Dimmer Circuit P1 Sample 2
  - 2-pin RGB LED Sample 1
  - 2-pin RGB LED Sample 2
  - 2-pin RGB LED Application: Bonus design!
- FS 2025:
  - Power Detector Sample 3
  - Remote Control Signal Detector Sample 3
  - Dimmer P1 Sample 3
  - 2-pin RGB LED Sample 3

Project 7: Assorted Applications: This project delves into the following interesting circuits:

- Continuity tester for passive components such as resistors, capacitors, inductors, and diodes. The circuit was provided, and students were required to test the different components using the circuit.
- Joule Thief circuit which allows one to turn on an LED using a supply with a voltage less than the turn on voltage of the LED. This project exposed students to an interesting application of a toroid. The basic circuit setup was provided. Students had to figure out the turns needed to get the LED to work using a 1.5 V supply voltage.
- Dimmer circuit-phase 2. Using the varying DC voltage generated using the dimmer circuit-phase 1 circuit, the goal was to convert this DC voltage into a PWM wave and then drive a MOSFET, which in turn would drive a high wattage bulb. Students explore PWM wave

generation in Electronics 2 and Power Electronics. This project is ideal for students who are not planning to take either Electronics 2 or Power Electronics to get a basic idea of PWM signal generation using a comparator circuit.

- Music reactive LEDs: There were two circuits assigned for this section:
  - Simple music reactive LEDs. Students explore the connection of a microphone to a switching circuit and see if LEDs can react to music impacting the microphone surface. The circuit was provided.
  - Music reactive LED bar. Students explore creating an LED bar that reacts to amplitude changes in an incoming audio signal. The circuit was provided.
- A simple voltage divider circuit test. This experiment was recommended by a retired electrical engineer. Students build a simple voltage divider circuit and test its operation at different frequencies to understand the limitation of testing equipment and observing the effect of stray components in measurements.

Typical student artifacts include:

- Prior to FS 2025:
  - Continuity Tester Sample 1
  - Continuity Tester Sample 2
  - Joule Thief Sample 1
  - Joule Thief Sample 2
  - Dimmer P2 Sample 1
  - Dimmer P2 Sample 2
  - Music LED Sample 1
  - Music LED Sample 2
  - LED Bar Sample 1
  - LED Bar Sample 2
- FS 2025:
  - Continuity Tester Sample 2
  - Dimmer P2 Sample 3
  - Music LED Sample 3
  - Voltage Divider Test Sample 1

Evolution Towards KEEN PBEL Implementation

Starting FS 2025, with the AI-assisted contrarian circuit design and test, FWE has started to emphasize the 3Cs of EML practice in most of the assigned project circuits, thereby, deeply aligning with the KEEN Framework [11]:

- Curiosity: Students explore circuit behavior, ask “what if” questions, and use AI tools to investigate alternatives.
- Connections: Projects link electronics to broader systems (e.g., streetlight control, remote sensing, interactive lighting), encouraging interdisciplinary thinking.
- Creating Value: Students design circuits with real-world utility, such as continuity testers, dimmers, and music-reactive LED bars, fostering entrepreneurial insight.

While the above-mentioned student artifacts, for FS 2025, showcase the basic project circuits as done before FS 2025, additional AI-assisted contrarian design and test components have been incorporated. Typical project description screenshots and student artifacts, for the different main projects, include:

- Project 1:
  - Prompt AI to generate a circuit for street light control. Figure 2 shows the project description to allow for AI-assisted contrarian design and thinking.

1) A voltage divider:
   i. (5 points) Choose a suitable voltage divider to turn on the LED
   ii. (5 points) Replace R with an LDR (photoresistor) and see if you can turn on the LED. Measure the resistance of the LDR in dark and light conditions before creating and testing the circuit
   iii. (5 points) For 1ii) interchange the LDR (R) with the resistor connected from VCC to B and observe the effect on the transistor switching.
   iv. (15 points) Reflection and AI task:
      a. Curiosity: Based on the circuit created for 1ii) and 1iii), which circuit can be used to create a streetlight control circuit? Note that the transistor usually controls a relay, which in turn turns on the streetlight.
      b. Connections: Ask an AI tool to generate a circuit for streetlight control circuit, using an LDR and the transistor and test it? Did you get the desired circuit in the first prompt, or did you have to modify your prompts to get the desired circuit? Draw conclusions on the effectiveness of the AI tool to create the control circuit.

Figure 2: Part of project 1 description emphasizing EML components. Parts 1i,ii,iii), implemented prior to FS 2025, included implicit EML components. Part 1iv), added starting FS 2025, emphasize EML curiosity and connections.

  Street Light AI Sample
  - Prompt AI to generator a circuit with delayed turn on: Delayed Turn On AI Sample

- Project 2: Prompt AI to generate an astable vibrator using discrete transistors. Figure 3 shows the project description to allow for AI-assisted contrarian design and thinking.

3. Reflection and AI task:
   a. (15 points) Curiosity: Prompt an AI tool to create an astable vibrator circuit using discrete transistors. Comment on the AI results? Were the suggested circuits easy or more complicated than the ones created in this project? Did you get the desired circuit in the first prompt, or did you have to modify your prompts to get the desired circuit? Draw conclusions on the effectiveness of the AI tool to create the control circuit.
   b. (15 points) Connections: Ask an AI tool to generate a list of applications that uses an astable vibrator using discrete transistors other than the application created in this project. Based on the search results, comment on the circuit's role in a bigger system. Search for some applications in which such a circuit would be useful.

Figure 3: Part of project 2 description emphasizing EML components.

Astable Vibrator AI Sample

- Project 3: Prompt AI to generate the water level indicator circuit along with additional research questions on applications and creating value as a low-cost alternative. Figure 4 shows the project description to allow for AI-assisted contrarian design and thinking.

2. Reflection and AI task:
    a. (15 points) Curiosity: Prompt an AI tool to create a water level meter using transistors, resistors, battery and LEDs only. Comment on the AI results? Were the suggested circuits easy or more complicated than the ones created in this project? Did you get the desired circuit in the first prompt, or did you have to modify your prompts to get the desired circuit? What kind of battery did AI suggest for this application? Draw conclusions on the effectiveness of the AI tool to create the control circuit.
    b. (15 points) Connections: Ask an AI tool to generate a list of applications that use circuit 1. Based on the search results, comment on the circuit's role in a bigger system. Search for some applications in which such a circuit would be useful.
    c. (15 points) Creating value: Ask AI to generate a list of similar systems (high tech and low tech), along with associated costs, that are available commercially for this application. Perform a comparative study, using AI, to create value for an end user who may not be able to afford a more expensive system. Can this hack prove to be a viable low-cost solution?

Figure 4: Part of project 3 description emphasizing EML components.

WLI AI Sample

- Project 4: Prompt AI to generate a circuit using a discrete transistor for quick turn on but delayed turn off switching circuit. Figure 5 shows the project description to allow for AI-assisted contrarian design and thinking.

a. Reflection and AI task:
    i. (15 points) Curiosity: Prompt AI to generate a circuit that turns on quickly but has a delayed turn off. Test the circuit suggested by AI. Did you get the desired circuit in the first prompt, or did you have to modify your prompts to get the desired circuit? Was the suggested circuit like the one created in 1a) Reflect on AI's ability to generate circuits for this application.
    ii. (15 points) Connections: Ask an AI tool to generate a list of applications that use circuit 5. Based on the search results, comment on the circuit's role in a bigger system. Search for some applications in which such a circuit would be useful.

Figure 5: Part of project 4 description emphasizing EML components.

Delayed Turn Off AI Sample

- Project 5: Prompt AI to create the KITT light show interfacing circuit and additional AI-based research. Figure 6 shows the project description to allow for AI-assisted contrarian design and thinking.

> AI*: Prompt AI to create an interfacing circuit, as discussed above, which will be placed in between the 4017 and the fading circuit. Note, the goal here is to take the logic 'I' output, of CD 4017, and switch on the fading circuit (apply power to the circuit as done in circuit 5 of project 4). You may have to generate multiple successive prompts to obtain a working circuit. Test all the circuits, including the ones above, for ONE CD 4017 output and finalize your interfacing circuit. Reflection: Did AI provide a good and working circuit, which was easy to implement? Did you choose this circuit as your interfacing circuit? Comment on AI's ability to design this circuit.
>
> Project Reflection:
>
> - Curiosity: Based on the proposed design, were you curious about alternate designs for the KITT lights system. Prompt AI to see what solutions it can offer for the design of the KITT lights system. Comment on the results obtained by discussing the pros and cons of your built system and the AI suggested system.
> - Connections: Prompt AI to research similar circuits used in other applications. Are these circuits part of bigger systems? Based on AI-based research, comment on the "Out of the box" thinking to come up with a design circuit based on lower-level electronics/digital logic courses knowledge.
> - Creating Value: Since KITT lights were created in the 80s show, Knight Rider, based on your AI research above, comment on the usefulness and role of low-tech circuits (compared to today), created long ago, in today's high-tech culture. Is there room for low-tech circuits today?

Figure 6: Part of project 5 description emphasizing EML components.

[KITT Interface AI Sample]

- Project 6: Prompt AI to generate an AC power detector circuit using a discrete transistor. Figure 7 shows the project description to allow for AI-assisted contrarian design and thinking.

> b. Reflection and AI task:
>
> i. (15 points) Curiosity: Prompt AI to generate a circuit that can be used to detect AC power like the ones tested above and is used as a safety device at home. Test the circuit suggested by AI. Did you get the desired circuit in the first prompt, or did you have to modify your prompts to get the desired circuit? Was the suggested circuit like the one created in 1a) Reflect on AI's ability to generate circuits for this application.
>
> ii. (15 points) Creating value: Ask an AI tool to generate a list of applications that use circuit 1. Based on the search results, comment on the circuit's role in creating value for consumers and electricians.

Figure 7: Part of project 6 description emphasizing EML components.

[AI AC Power Detector Sample]

- Project 7: Prompt AI to generate a circuit to light up an LED using a voltage source value that is less than the turn on voltage of the diode. Figure 8 shows the project description to allow for AI-assisted contrarian design and thinking.

c. Reflection and AI task:
   i. (15 points) Curiosity: Prompt AI to generate a circuit that can be used to light up an LED using a low value voltage source (less than the turn on voltage of the LED). Test the circuit suggested by AI. Did you get the desired circuit in the first prompt, or did you have to modify your prompts to get the desired circuit? Was the suggested circuit like the one created in 2a)? Reflect on AI's ability to generate circuits for this application.
   ii. (15 points) Connections: Prompt an AI tool to generate a list of applications that use circuit 2. Based on the search results, comment on the circuit's role in creating value for consumers.

Figure 8: Part of project 7 description emphasizing EML components.

[Joule Thief AI Sample]

Note: Not all AI-assisted executed components and student artifacts are mentioned above. Readers can access videos of other implemented components via the links mentioned above.

Table 1 shows the course components, in a nutshell, mentioning each project's concept focus, required components, deliverables, primary learning outcomes, and EML alignment.

Table 1: Course components summary. Note the EML alignment

Project	**Concept Focus**	**Required Components (Rep)**	**Deliverables**	**Primary Learning Outcomes**	**EML Alignment**
Project 1: Transistor Switching	Basic BJT operation, sensing-based switching, RC delay	NPN/PNP BJTs, LEDs, resistors, LDR, capacitors, pushbuttons, water probes, power supply	Hardware demo videos; PDF report; AI reflection log	Bias and switch BJTs; design sensing and timing circuits; experimentally validate AI-generated designs	***Curiosity:*** AI circuit exploration; ***Connections:*** Streetlight & other switch systems; ***Creating Value:*** Simple sensing solutions

Project 2: Astable Vibrator	Discrete oscillators, feedback, timing & control, light show	BJTs, resistors, capacitors, LEDs, LDR, oscilloscope, power supply	Hardware demo videos; oscilloscope captures; PDF report; AI reflection log	Explain oscillation using feedback and time constants; analyze waveforms; control frequency and duty cycle	***Curiosity:*** AI oscillator designs; ***Connections:*** Timing in systems; ***Creating Value:*** Cost-effective signaling.
Project 3: Water Level Indicator & Pump Controller	Level sensing, thresholds, alarms, actuation, system integration	Transistors, resistors, LEDs, buzzer, 555 timer, relay, probes, power supply	Hardware demo videos; PDF report; AI comparative analysis	Design multi-level indicators; integrate sensing with control; assess low-cost automation	***Curiosity:*** AI meter designs; ***Connections:*** Water systems; ***Creating Value:*** Low-cost automation
Project 4: Advanced Transistor Switching	Signal Amplifiers, latching, optical feedback, temporal shaping	Multiple BJTs, LDRs, LEDs, RC networks, transistor arrays, power supply	Hardware demo videos; PDF report; AI reflection log	Design multi-stage switching circuits; implement latching and delay behaviors; improve safety and robustness	***Curiosity:*** Shaping timing behavior; ***Connections:*** Human–machine interfaces; ***Creating Value:*** Low-tech control solutions
Project 5: KITT Lights System	System-level integration, digital–analog interfacing	CD4017, 555 timer, BJTs, LEDs, diodes, RC fade circuits, power supply	Full system demo video; PDF report; AI-assisted interface design	Integrate subsystems; interface logic with analog loads; debug and optimize complex systems	***Curiosity:*** Alternate architecture; ***Connections:*** Legacy systems; ***Creating Value:*** Relevance of legacy low-tech designs

Project 6: Assorted Applications I	Non-contact sensing, IR detection, touch-based dimming, transformer-less HWR	Inductors, BJTs, TSOP IR sensor, diodes, 2-pin RGB LEDs, mains voltage-rated components, power supply	Hardware demo videos; PDF report; AI-assisted interface design	Apply circuits to real-world safety and consumer contexts; identify hazards and mitigation strategies	***Curiosity:*** AI safety circuits; ***Connections:*** Consumer devices; ***Creating Value:*** Electrical safety awareness
Project 7: Assorted Applications II	Instrumentation, energy conversion, PWM power control, audio signal driven system control, measured frequency response	Comparators, MOSFETs, toroid, microphones, diodes, resistors, LEDs, function generator, oscilloscope	Hardware demo videos; measurements; PDF report; AI prediction vs. reality analysis	Analyze application-grade circuits; compare AI predictions with experimental data; synthesize prior knowledge	***Curiosity:*** Questioning predicted behavior; ***Connections:*** Instrumentation and power systems; ***Creating Value:*** Consumer and maker applications

Research Questions (RQ): The inception and the subsequent execution of the course tried to address the following research questions:

- RQ1: How does a scaffolded, low-tech electronics project sequence influence students' ability to reason about, design, and debug analog circuits using measurement-based evidence?
- RQ2: To what extent does repeated subsystem integration across projects improve students' ability to design, interface, and validate multi-stage electronic systems without relying on microcontrollers?
- RQ3: How does explicit emphasis on safety-oriented and value-driven applications affect students' perception of relevance and responsibility in foundational electronics design?
- RQ4: How does the introduction of AI-assisted circuit design and verification (starting FS 2025) influence students' ability to critically evaluate predicted behavior and rely on experimental measurement when discrepancies arise?

Mapping Research Questions to Projects and Evidence:

- RQ1: Projects 1–7: All hardware demos, oscilloscope measurements, troubleshooting logs, and final videos serve as evidence of reasoning and debugging.
- RQ2: Projects 3, 5, and 7: Multi-stage integration, subsystem interfacing, and emergent system behavior serve as measurable integration performance.
- RQ3: Projects 6 and 7: Safety-driven AC sensing, value-oriented dimming, and consumer-aligned applications produce strong reflection-based evidence.

- RQ4: Projects 1-7: AI-generated circuits, failures, corrections, and prediction-vs-measurement comparisons supply rich evaluative data

Student Feedback

Prior to FS 2025, feedback was obtained using the semester end instructor feedback administered by the university. Since this course is currently implemented at S&T's CEP, which is a relatively small program, and since the course is an elective course, the course enrollment numbers are low! During some semesters, the semester end instructor was not possible since the required enrollment numbers threshold for semester end feedback was not met. Figure 9 shows one example of semester end feedback received.

Instructor:	**Dua,Rohit**	Title:	**Undergraduate Research**
Section(s):	**ELEC ENG 4099 607**	Term:	**FS2022**

Number Responding: **6** Number Enrolled: **6** Percent Responding: **100.00%** Effectiveness: **4.00**

Student Comments

With regards to teaching, what are the strengths of the instructor?

I am not speaking in hyperbole when I say this is the most impactful class I have taken to date. It cemented several years of instruction through practical application. It is my belief that the subject matter was so incredibly important and helpful that it should be mandatory for any student passing through the program. On top of that, I don't think I've ever had more fun in a class. Not only did I learn, but Dr. Dua made it fun and engaging.

Extremely in depth understanding of the material at hand

Dr. Dua has a complete fundamental understanding of the material that was presented during the semester. It is very beneficial to the quality of the course when the professor is able to concisely and accurately answer questions pertaining to the material.

I really liked that the experiments were often modeled around practical uses. I also liked how the focus was not necessary on the precise values of all the components used or the operating conditions of the transistors, but rather how the circuit worked in general and how modifying any of those components would effect it's performance

Incredibly effective teacher, understands what he needs us to do and communicates it clearly.

Very passionate about his electronics, and that passion bleeds into the class!

What suggestions do you have for improving the quality of instruction?

I honestly can't think of anything. All the projects were incredibly practical and useful. I've built a few on my own for home use. Please give Dr. Dua a raise. He's the best professor in the program and this class is one of the most important.

None

No recommendations. The quality of instruction was exceptional.

Class was very BJT heavy. Should incorporate more vacuum tubes for sure. Or not, those are expensive.

Figure 9: Semester end feedback received for FS 2022.

Starting FS 2025, students are required to answer a set of reflection questions addressing curiosity, connections, creating value, and general course reflection. Figure 10 shows the list of questions asked along with answering guidelines.

Total Points: 100 points
Word Limits: Questions 1–3: 250–300 words each; Question 4: 200–250 words.

Please answer the following questions thoughtfully. Your responses should reflect your learning experience, engagement with AI-assisted design, and overall course feedback.

1. (25 points) Curiosity (EML): Reflect on how this course helped you develop curiosity in electronics and design thinking. How did AI-assisted design influence your ability to think differently or challenge conventional approaches? Provide examples from your projects. (250-300 words)
2. (25 points) Connections (EML): Discuss how you connected with concepts from different domains (electronics, AI, creativity) during the course. How did AI tools help you make these connections and explore alternative solutions? Share specific instances. (250-300 words)
3. (25 points) Creating Value (EML): Explain how your projects created value for users or addressed real-world problems. How did AI-assisted design contribute to enhancing the value of your solutions? Include examples where AI suggestions improved your design.
4. (25 points) General Course Reflection: What aspects of the course worked well for you, and what could be improved? Consider project structure, AI integration, resources, and overall learning experience. Suggest actionable improvements for future iterations of the course. (250-300 words)

Figure 10: End of semester reflection questions asked emphasizing the 3Cs of EML [11].

Typical answers received are shown below:

1. *"This course helped me develop curiosity in electronics and design thinking by forcing me to truly understand how some tricky circuits, like the astable multivibrator and the KITT lighting system, actually worked. Instead of just following instructions, I found myself asking why each component was placed where it was, and how small changes in resistance or capacitance could alter the behavior of the circuit. I also discovered new components that sparked my interest, such as the TSOP IR detector and RGB LEDs, which opened up possibilities for interactive and visually engaging designs. AI-assisted design played a major role in shaping this curiosity. Often, the AI provided unconventional solutions or alternative circuit layouts that challenged me to think beyond the "standard" textbook approach. For example, when I struggled with interpreting*

subpar circuit diagrams (or word vomit AI circuit descriptions), the AI helped me troubleshoot by suggesting different wiring strategies or component substitutions. This forced me to experiment, test, and refine my designs rather than simply replicate what I saw. One memorable moment was when I used AI to brainstorm variations of the KITT lighting system. Instead of just sequential LEDs, the AI suggested integrating RGB LEDs with fading transitions, which made me curious about pulse-width modulation and how to achieve smoother effects. These kinds of prompts pushed me to explore deeper technical concepts and gave me confidence to tinker with ideas I might not have attempted otherwise. Ultimately, the combination of hands-on projects and AI guidance transformed my curiosity into a mindset of exploration. I now approach electronics not just as a set of rules to follow, but as a playground for creativity, experimentation, and discovery."

2. *"One of the most memorable connections I made during the course was while designing a water level meter using only discrete components. At first, the idea seemed simple: use transistors as switches that would activate LEDs at different water levels. But as I worked through the design, I realized how much this project connected concepts from electronics, creativity, and even AI guidance. The electronics gave me the foundation, understanding how biasing a BJT could act as a threshold detector, while creativity helped me imagine how to make the display intuitive for users. AI tools bridged the gap by suggesting resistor values and alternative circuit arrangements, which made me think about efficiency and reliability in ways I hadn't considered before. Troubleshooting the three-stage astable multivibrator was another experience that highlighted these connections, though in a much more frustrating way. The circuit looked straightforward on paper, but in practice, it was a nightmare. Timing mismatches, incorrect capacitor charging, and subtle wiring errors made the LEDs blink erratically or not at all. This forced me to connect theoretical knowledge with hands-on debugging strategies. AI helped here too, offering possible fault scenarios and reminding me to check things like capacitor polarity and transistor saturation. Even though it felt horrible at the time, the process taught me how interconnected design thinking really is: theory, practice, and external guidance all had to come together before the circuit finally worked. These experiences showed me that electronics isn't just about isolated components. It's about connecting domains, physics, creativity, and intelligent tools to build systems that actually function. The water level meter and the multivibrator both proved that meaningful learning happens when you embrace those connections, even through the headaches of troubleshooting, into innovative solutions. This mindset will serve me well in future projects and endeavors"*
3. *"The projects in this course created value by tackling practical problems with simple, low-cost solutions. One example was designing a circuit to detect AC power using a BJT amplifier and a pen spring as a makeshift contact. The idea was to provide a quick indicator of whether mains power was present without relying on expensive modules. By amplifying the small signal picked up through the spring contact, the circuit could drive an LED to show power status. This design had real-world value because it offered a resourceful and budget-friendly way to monitor power availability, which is extremely useful in household troubleshooting or small workshop setups. AI assistance enhanced the design by suggesting biasing adjustments for the transistor and reminding me to consider safety isolation, which made the solution more reliable and safer to use. Another project that created value was a "streetlight" control system using a photoresistor to*

detect "daylight". The concept was straightforward: when ambient light dropped below a threshold, the circuit would automatically turn on an LED to simulate a streetlight. While simple, this project addressed a real-world need for energy efficiency and automation. AI contributed by helping me refine resistor values to set the correct sensitivity and by suggesting ways to reduce false triggers, such as adding hysteresis with a feedback resistor. These improvements made the system more robust and user-friendly, ensuring the light responded consistently to changing conditions. In both cases, AI-assisted design elevated the value of my solutions. It didn't just help me build circuits; it pushed me to think about usability, safety, and efficiency. By combining creativity with technical guidance, I was able to deliver designs that solved everyday problems in accessible and innovative ways."

4. *"Overall, the course was well-organized and engaging. The formatting of assignments and projects was clear, which made it easy to follow the progression from simpler circuits to more complex designs. The projects themselves were varied and interesting, keeping me motivated to experiment and learn. Each challenge sparked curiosity about electrical phenomena, whether it was the behavior of transistors, the quirks of timing circuits, or the subtleties of light-sensing components. One area that could be improved is the availability of resources explaining the deeper theory behind certain circuits. For example, in Project 7, the voltage divider (Circuit 5) produced unexpected results: two nearly identical resistors did not halve the voltage at the lower node as expected, but instead showed a strong frequency dependence. A supplemental guide, or even a prompt encouraging students to research a specific concept, would help connect the practical build to the underlying math and physics. This would make troubleshooting less frustrating and strengthen understanding of why circuits behave the way they do. Another suggestion is that when the course asks students to rebuild a circuit from a previous class, it should provide a schematic. Without a diagram, students are left guessing or sifting through old notes, which slows progress and detracts from the learning experience. Despite these challenges, the course offered a strong learning experience overall. It balanced hands-on experimentation with AI-assisted design, encouraged curiosity, and gave me confidence to explore electronics independently. With a few refinements, future iterations could be even more effective at bridging theory and practice."*

Note: semester end instructor feedback was not received since the required enrollment numbers threshold was not met. Currently, only semester end instructor feedback and reflection assignments are feasible owing to low enrollment numbers. A formal quantitative survey-type assessment will be explored in future course iterations.

Observed Pros, Cons and Challenges

So far, the feedback received and observed is largely positive as students seem to enjoy learning about the underlying electronic design principles covered in the projects carried out. Students also enhance their instrument usage, circuit breadboarding, and AI prompting (starting FS 2025) skills. This positive feedback has led to improved marketing of the course for the subsequent generation of students via word-of-mouth. Emphasizing EML, by adding reflection questions and AI-assisted contrarian design, has allowed students to promote curiosity, connections and creating value, in their engineering design thinking and skill development. Since AI-assisted contrarian design is part of a project and, for most projects, a starting circuit diagram is provided, students do not directly jump to seeking AI's help in the design process, which in observation is a major plus!

Progressive Observation of Student Skill Development: Because the course relies primarily on observational assessment of the expected learning outcomes, the following summarizes the most prominent skill developments demonstrated by students by the end of the semester:

- **Enhanced engineering judgment**, evidenced by students' increased ability to identify and reject incorrect circuit implementations, including those generated through AI-assisted tools, and to make sound intuition-based predictions.
- **Strengthened systems-level thinking**, reflected in faster debugging cycles, reduced subsystem incompatibilities, and more coherent and integrated system demonstrations.
- **Improved measurement literacy**, demonstrated through more effective use of oscilloscopes, clearer interpretation of waveforms, and stronger reliance on empirical evidence for design decisions.
- **Heightened value and safety awareness**, shown through students' clearer articulation of user value, more thorough hazard identification and mitigation strategies, and more rigorously justified design choices.

Since FWE is a hardware design, construction and video demonstration laboratory course, it is time consuming, which is the major negative point of the course. Most of the enrolled students, in CEP, work in the local industry. Through numerous informal student discussions and marketing endeavors, it has been observed that students prefer to take exam-based elective courses, which they have found to be less time consuming. This con is one of the reasons for low course enrollment numbers each semester of course offering. This issue has been observed with all the project-based courses offered at CEP [6]. Moreover, the addition of AI-assisted contrarian design, EML components, has increased the required workload, which could potentially exacerbate the low enrollment problem, and perhaps reduce the "fun" aspect emphasized in the course. One silver lining that is offered to students is that the course is currently taught via EE 4099 [9], which is technically undergraduate independent study, and this course can potentially be completed in two sequential semesters. Some enrolled students have taken advantage of this feature, which reduced their workload anxiety! Overall, the cons mentioned are manageable.

Conclusion and Future Work

This paper discussed the created and implemented FWE course with AI-assisted contrarian PBEL components. The project hardware demonstration YouTube video links, included in this paper, show typical examples of the projects executed, which can serve as an inspiration to the reader if there is any interest in implementing a similar course at their institution. The paper also showed typical AI-assisted contrarian design and the 3Cs of EML reflection and discussion implemented components. Basic student feedback shows that enrolled students found the course to be an enjoyable learning experience!

Future work will concentrate on finding a good balance between the required basic project constructions and AI-assisted contrarian design EML components, which can increase the workload. Since the enrollment numbers are low each semester, effort will be made to create a more thorough student feedback survey, which can better statistical insight into which syllabus components work better and which components need improvement. Note, some feedback on possible improvements was received from the required reflection document implemented in FS 2025 (See italicized text on page 17 of this paper). Future effort will concentrate on enhancing feedback using focused reflective questions.

Acknowledgements

The author thanks Nathaniel Van Devender, Ryan Flynn and Cooper Martin, course alumni, to allow links of their FWE project demonstration YouTube video links to be included in this project. Special thanks to Mr. Larry Lamano for creating the voltage divider measurement and test circuit used in project 7.

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