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Combining Technical and Entrepreneurial Skills in an Electric Circuits Course through Project-Based Learning

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Abstract
Educators should always seek opportunities to enhance their course material and equip students with skills to help them achieve success in their career after graduation. One skill that has drawn much attention recently is the entrepreneurial mindset. This paper presents a project-based learning approach that infuses some of the soft skills associated with the entrepreneurial mindset with the technical skills of electric circuit analysis and design through a specific multi-phase, multi-disciplinary project. The course is offered to engineering students majoring in electrical, computer, mechanical, civil, and engineering education. The expected outcomes are effective collaboration and communication, persisting and learning from failure, management, and solving ambiguous problems. In addition, the paper presents all involved details in this project including the phases mentioned above, rubrics used for project evaluation, assessment of students' attitude toward this activity, assessment of project outcomes, and the related ABET student outcomes.

1. Introduction

Educators should always seek opportunities to enhance course material and equip students with skills to help students achieve a successful career after graduation. Recently, skills associated with the entrepreneurial mindset have drawn much attention, especially with regard to engineering education[1,2]. The entrepreneurial mindset is generally regarded as possessing an inclination to innovate, coupled with keen business acumen, in order to bring innovations to fruition and capitalize on latent demand. However, statistically speaking, an entrepreneur is more likely to fail than to succeed. According to U.S. Census data, only 48.8 percent of the new establishments started between 1977 and 2000 still remained after five years. Therefore, the key to success as an entrepreneur is to persist through and learn from failure.

These characteristics of an entrepreneur are important for engineers, and for companies who employ engineering graduates. It is not sufficient for engineers to just be good technical problem solvers. Engineers are expected to interact with clients and communicate their designs and ideas in the vernacular understood by business professionals. Moreover, cost is inherently a fundamental aspect of engineering design. By infusing the entrepreneurial mindset within engineering courses, the importance of cost considerations is made explicit.

Although most engineering programs aim to instill skills related to the entrepreneurial mindset, it is common to focus on these skills more in the freshman engineering courses or in the senior capstone sequence[3]. It is generally regarded as more difficult to incorporate student outcomes related to the entrepreneurial mindset in sophomore and junior-level courses due to the balance of breadth and depth of technical content and a perceived tradeoff of core material for business-related content[4,5]. However, through project-based learning techniques it has been shown that technical skills do not suffer, but rather, if framed properly, project-based learning techniques can improve technical skills while infusing real-world problem solving into our core courses[6]. Hence, project-based learning is a promising paradigm for introducing content supporting an entrepreneurial mindset into the core courses of engineering curricula.

One of the core courses in the Electrical Engineering curriculum is the Electric Circuits course (4 semester credit hours). The course covers electric circuit analysis techniques along with certain aspects of circuit design. The course objectives include circuit analysis, design, simulation, and data gathering and analysis in the laboratory. The analysis-portion of the objectives emphasizes proficiency in the analysis of DC and AC circuits, including operational amplifiers, first-order transient analysis, ideal transformers, and balanced three-phase circuits. The design objectives in the course include design and construction of simple circuits based on given specifications. The lab component of the course emphasizes competence in the simulation of circuits with PSPICE, safely constructing electric circuits, and obtaining experimental data through bench measurements using laboratory equipment such as oscilloscopes and digital multimeters.

At the authors' institution, the Electric Circuits course is a sophomore-level course required for Electrical, Computer, Mechanical Engineering, and Engineering Education students, and may be taken as an elective for Civil Engineering students. Due to the multi-disciplinary nature of the audience, it was easy for the instructors to require from each team to include members from different disciplines.

The expected outcomes of the project are effective collaboration and communication, persisting and learning from failure, management, and solving ambiguous problems. These outcomes agree with the entrepreneurial skills specified by the Kern family foundation[3,7,8]. Such skills are believed to contribute to breakthrough innovation[8].

The rest of the paper is organized as follows: Section 2 presents the project description and how each deliverable mapped to the learning outcomes of the project. Section 3 illustrates some of the samples from students' work. Section 4 presents the assessment rubrics and data. Section 5 presents the related ABET student outcomes. Section 6 describes the students' attitude toward the project. Finally, Section 7 provides a brief conclusion.

2. **Project Description and Learning Outcomes**

The entrepreneurial component of the Electric Circuits course, in its current form, is given as an extra-credit project. This is the second time the project has been offered, and it has been significantly improved in its second offering. A description of the original offering of the project is described in another paper[9]. The project requires students to form teams, or fictitious companies, comprised of two to four members spanning across at least two disciplines. The task is to respond to a Request for Proposal (RFP) that requires the design of a set of temperature sensors using Negative Temperature Coefficient (NTC) thermistors for a customer, which is represented by the instructor. The primary customer requirement is that the temperature sensor should output a voltage in the range of zero to five volts for temperatures in the range of 25°C to 50°C, with an output voltage of zero volts at 25°C and five volts at 50°C. Other than this specification, the remainder of the description was left intentionally ambiguous in order to support the outcome of solving ambiguous problems, which is one of the outcomes associated with the entrepreneurial mindset[3,7,8].

Prior to submitting the written proposal, the teams were required to translate the given customer specifications to engineering specifications or requirements, research the problem, and propose two alternative solutions. Each section instructor of the course provided feedback based on the two alternative solutions to inform the students of the weaknesses and strengths of the proposed solutions and guide them toward developing the best possible solution. Although this step of the proposal development process would not exist in an industry setting, it was useful from a pedagogical standpoint and supported the outcome of persisting and learning from failure, which is one of the outcomes associated with the entrepreneurial mindset[3,7,8].

In the written proposal, each "company" had to list the required materials, show total cost including labor, perform a break-even analysis, illustrate the circuit design and schematics, verify the designed circuit through simulation, plot the voltage-temperature relationship of the designed circuit, establish a detailed testing plan, investigate proper device housings, propose a time schedule for delivery, construct a prototype circuit, perform the tests detailed in the test plan on the prototype, and report results of the tests in an attached specifications sheet for the device. By requiring the students to include the cost of materials, services, and other expenses, the factor of cost was made explicit.

After submitting the written proposal, there was a two-stage evaluation process for selecting the winning bid. In the first stage, each team within each class section was given five minutes to pitch their proposal using a PowerPoint poster in an effort to convince the customer (in this case the section instructor) that their design was the best within the section and should be selected to win the bid. This pitch was aimed to improve the students' ability to effectively collaborate and communicate, which is another outcome associated with the entrepreneurial mindset[3,7,8].

After the first stage, the proposals were ranked and graded by the section instructor according to predetermined evaluation criteria given in the RFP, and the winning teams (of each section) participated in the second stage of pitches. The members of the top group from each section were allowed to meet with their section instructor prior to the second pitch in order to improve their design, testing procedures, and pitch. Based on the results of the second stage (obtained from rubrics developed for the pitch, written proposal, and poster, and provided in Section 4), two "companies" tied for the overall bid. The two winning teams received a monetary prize and were funded to present the project in an ASEE section meeting. All teams were required to build their circuit, execute the test plan as mentioned in the proposal, fabricate the circuit on a printed circuit board, and deliver a working prototype.

3. **Sample Work**

Students who participated in this activity completed all required tasks based on the RFP. Instructors were very pleased with the work carried out by the students. The elements of the project as mentioned earlier include a written proposal, schematic of the designed circuit, constructed prototype, testing, material cost, and a poster presentation for pitching.

Students designed their own circuit, simulated and fabricated it. Figure 1 shows a sample of a circuit schematic and Figure 2 shows students constructing an initial prototype. The written proposal must include a cover letter as a memo. Figure 3 shows a sample cover letter from a participating team. Figure 4 illustrates students testing their own design. Figure 5 shows a sample bill of material. Figure 6 shows a sample of some of the prototypes. Figure 7 displays a poster sample, while Figure 8 captures a team during their pitch presentation.

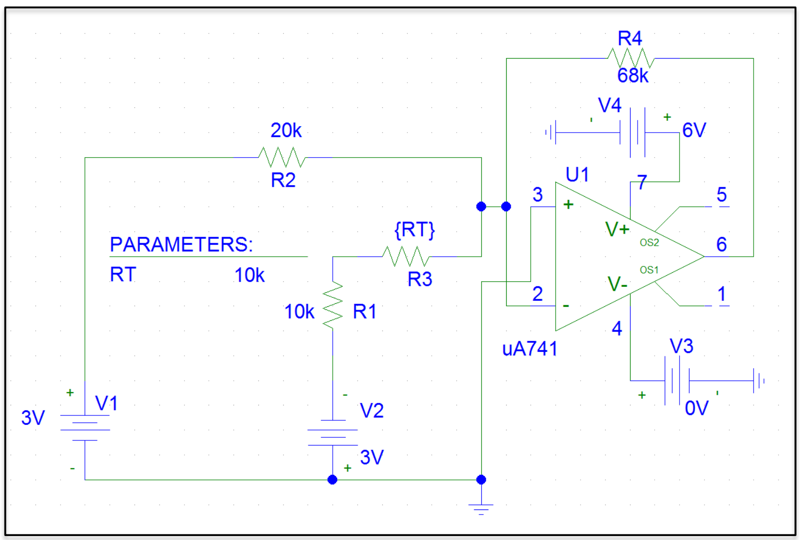

Figure 1: Sample Temperature Sensor PSPICE Schematic

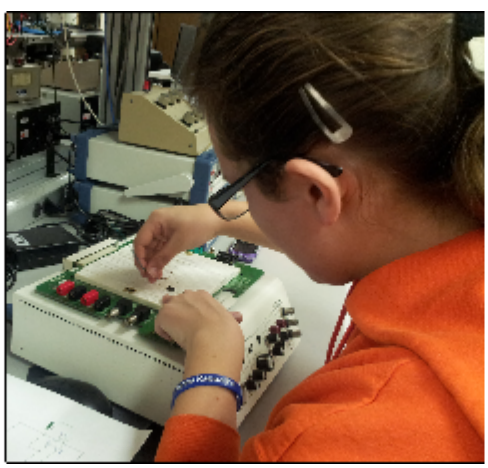

Figure 2: Sample Group Constructing Initial Prototype Circuit

Superior Micro Devices
422 Roll'en Ave.
[redacted]

Dr. [redacted]
CEO
NTC, Inc.
[redacted]

December 3, 2013

Dear Dr. [redacted]

SMD is pleased to submit this proposal in response to the November 8th bid meeting for a single batch of one hundred (100) temperature sensor circuit. It is our understanding with the success of this first batch that the receiving company will be awarded a long term contract with you and your company. It is our hope that you find our product a satisfactory solution for your needs.

<u>Background Information:</u>

On November 8th, 2013, NTC Inc. approached SMD seeking a viable, economic thermostat system. On November 15 SMD submitted drawings and specifications for technical review to NTC. Within a week of submitting the designs for review, SMD received feedback on necessary changes that needed to be made per NTC's technical code. The necessary changes were made and the updated proposed design can be found later on below.

<u>Scope of Work:</u>

Per the bid documents, NTC has requested of SMD to provide a detailed proposal that includes technical specifications, detailed design, cost and a complete bill of materials. Also included needs to be a design analysis of the competition and why SMD's senor is better. These documents are attached below.

Figure 3: Sample Cover Letter of Written Proposal

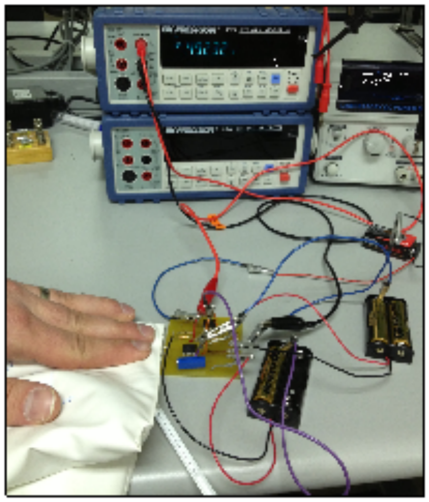

Figure 4: Sample Group Testing Prototype with a Heating Pad

Costs:

Bill of Materials (One Thermistor)				
Item	**Quantity**	**Cost Per Unit**	**Mark Up**	**Total**
AA Battery (2400)	4	$ 0.45	10.00%	$ 1.98
20k Resistor	1	$ 0.11	10.00%	$ 0.12
10k Resistor	1	$ 0.27	10.00%	$ 0.30
68k Resistor	1	$ 0.23	10.00%	$ 0.25
Op Amp	1	$ 0.18	10.00%	$ 0.20
Thermistor (RL1005-5744-103-K)	1	$ 1.76	10.00%	$ 1.94
PCB	1	$ 11.00	10.00%	$ 12.10
Packaging	1	$ 0.35	10.00%	$ 0.39
Total Materials Cost Per Temperature Sensor Unit				$ 17.27

Additional Charges				
	Item	**Quantity**	**Unit Cost**	**Total Cost**
Charge Per Unit	Manufacturing Equipment	N/A	$28.62	$28.62
	Utilities	N/A	$13.47	$13.47
	Sub-Total Cost			$42.09
One Time Charges	Engineering Services	10 Man Hours	$15.75/hr	$157.50
	Consultant	1 Man Hour	35.83/hr	$35.83
	Project Manager	2 Man Hours	$25.55/hr	$51.10
	Over Head	N/A	2% of Total Cost	$0.84

Total Additional Charges	**$42.93**
Grand Total Cost Per Unit	**$60.20**

Figure 5: Sample Cost Breakdown

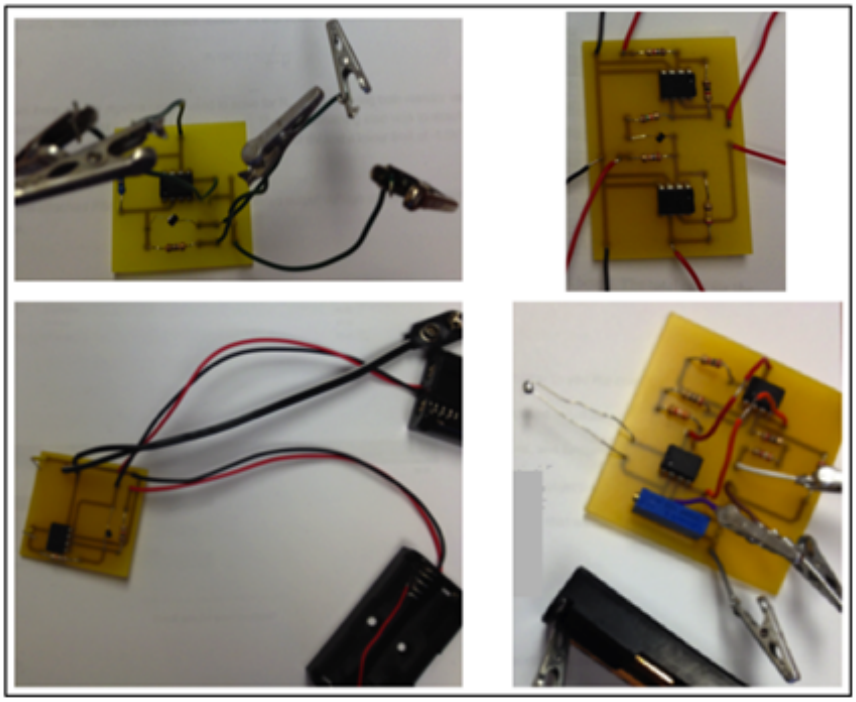

Figure 6: Temperature Sensor Prototype Samples

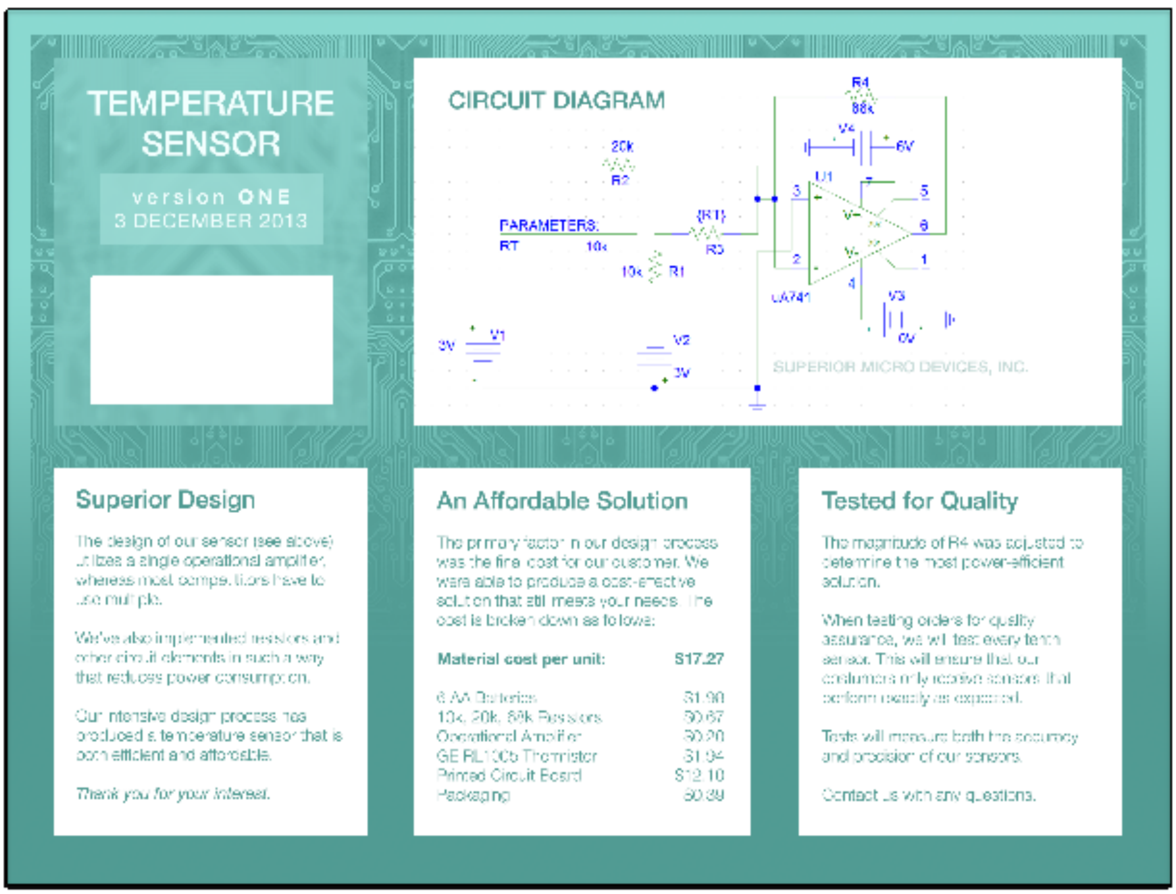

Figure 7: Sample Poster for Pitch Competition

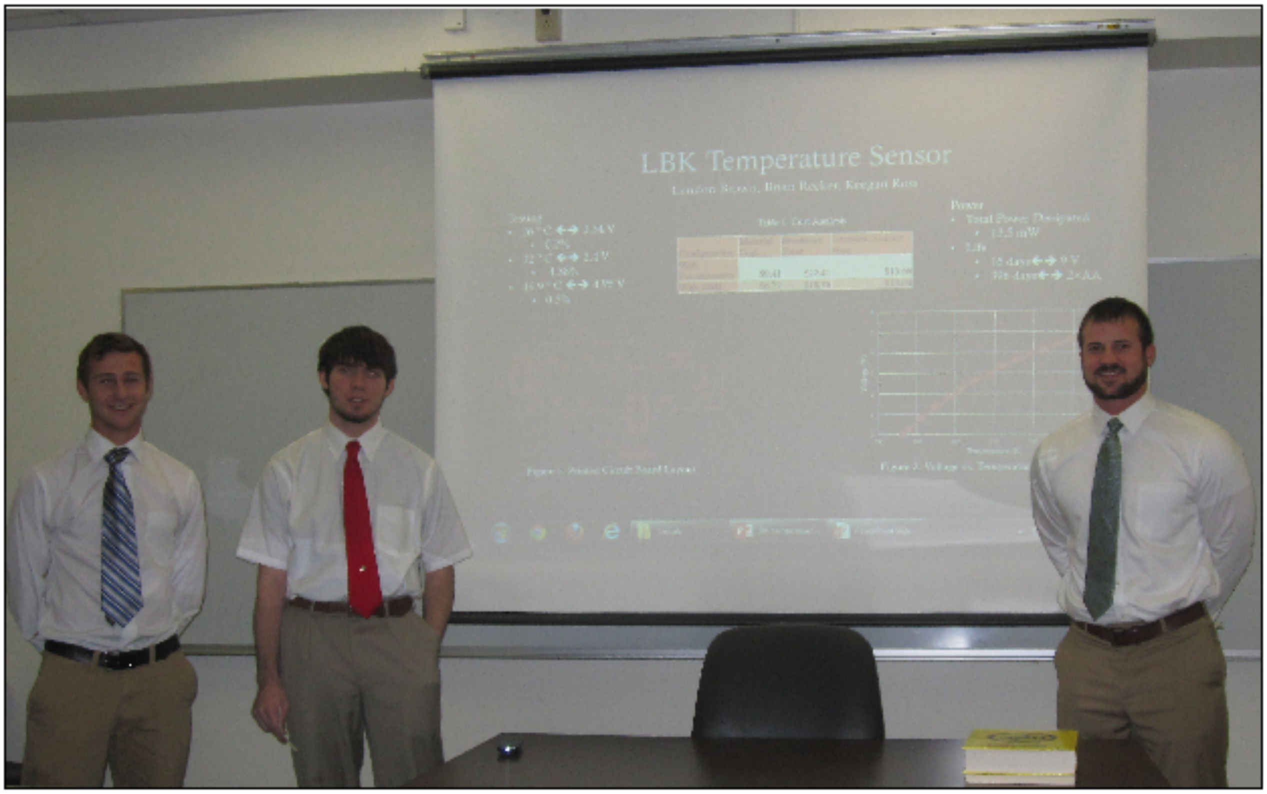

Figure 8: Sample Group Photo at Final Pitch

4. Assessment

There were 45 students from all sections who participated in this project. The 45 participating students formed 13 teams with a majority of the teams consisting of four students and spanning over at least two different majors. The breakdown of students per major is shown in Table 1.

Table 1: Participating Students Broken Down by Major

Major	# Students
Electrical Engineering	7
Computer Engineering	4
Mechanical Engineering	29
Civil Engineering	1
Engineering Education	4

The project was worth up to five bonus points added to the final grade, with the incentive of an extra bonus point for the overall winning team. The breakdown of the grading included 10% for the design alternative document, 50% for the written proposal, 30% for the pitch, and 10% for the poster. The assessment of the written proposal was performed using the rubric shown in Figure 9. The points allocated in each row are percentage points for the overall project. The elements evaluated in the written proposal include the overall quality of the report, deliverables related to manufacturability, deliverables related to cost estimate and delivery, and design functionality.

Written Proposal Rubric

Category	Does Not Meet Expectations	Developing	Meets Expectations	Proficient	Points Received
Overall quality of the report	Thesis is unclear or absent. Writes paragraphs that are underdeveloped, with topic sentences that are missing or unsupported. Writes sentences that are unclear or indirect (pts 0-7)	Provides a thesis that is somewhat developed. Writes paragraphs that are developed inconsistently, with topic sentences that are present, but not fully supported. Writes sentences that are occasionally unclear, indirect or grammatically incorrect. (pts 7-11)	Provides a thesis that is generally clear. Writes paragraphs that are generally well-developed, with topic sentences that are present and supported. Writes sentences that are generally clear, concise, and direct. (pts 11-14)	Provides a strong, clear thesis. Writes paragraphs that are well-developed, with strong, focused topic sentences that are fully supported. Writes sentences that are consistently clear, concise, direct and grammatically correct. (pts 14-15)	
Deliverables related to manufactur-ability	All of the following are missing or wrong: circuit design & simulation, testing plan, layout of PCB & packaging schematic, and voltage-temperature characteristics (pts 0-4)	A large portion of the following list is not available in the report: circuit design & simulation, testing plan, layout of PCB & packaging schematic, and voltage-temperature characteristics (pts 4-8)	Most of the following list is presented correctly in the report: circuit design & simulation, testing plan, layout of PCB & packaging schematic, and voltage-temperature characteristic (pts 8 - 12)	The report contains all the necessary deliverables that guarantee the correct operation of the design (pts 12-13)	
Deliverables related to cost estimate and delivery	All of the following are missing or estimated incorrectly: bill of material, cost analysis, and delivery time (pts 0-3)	A large portion of the following list is either missing or estimated incorrectly: bill of material, cost analysis, and delivery time (pts 3-8)	The following list is present but there are some minor mistakes in the estimation process: bill of material, cost analysis, and delivery time (pts 8-11)	The report estimates the cost and delivery time correctly (pts 11 -12)	
Design functionality	The prototype was neither implemented nor tested (pts 0-3)	The prototype was implemented on a PCB board but did not have adequate time to test it before submitting the proposal (pts 3-6)	The prototype was implemented and tested on a bread board using a variable resistance instead of the thermistor (pts 6-9)	The prototype was fully tested (pts 9-10)	
				Total Points Received (/40)	

Figure 9: Written Proposal Rubric

The assessment result is shown in Table 2. Note that most groups met the expectations in nearly all categories for the written proposal.

Table 2: Assessment of the written proposals showing number of groups in each category

Category	Does Not Meet Expectations	Developing	Meets Expectations	Proficient
Overall quality of the report	0	0	9	4
Deliverables related to manufacturability	0	2	9	2
Deliverables related to cost estimate and delivery	0	0	11	2
Design functionality	0	2	10	1

The pitch assessment concentrated on elements that include argument, rhetoric, and connection with audience, pricing, delivery, prototype, and testing plans, and device functionality and optimality. The rubric used in the pitch assessment is shown in Figure 10. The result of the pitch assessment is shown in Table 3.

Pitch Rubric

Category	Does Not Meet Expectations	Developing	Meets Expectations	Proficient	Points Received
Argument, Rhetoric, and Connection with Audience	Presentation lacks an identifiable central message. Presentation does not rely on credible evidence, or form a valid and true outcome. Does not attempt to go over or elucidate content. Avoids looking at the audience. (0-4 pts)	Presentation contains an identifiable central message, but it argues from a false premise. Argument is not fully supported by credible evidence; the outcome is either invalid or valid but untrue. Rarely summarizes or clarifies content to meet audience's needs. Attempts to draw the audience into the presentation through eye contact. (4-7 pts)	Presentation contains a significant central message, with valid and true outcome adequately supported by evidence and logic. Able to answer basic objections to their conclusions. Reasonably alert to audience's needs and frequently re-states and clarifies appropriately. Relates to the audience through eye contact. (7-9.5 pts)	Presentation contains a compelling central message, with a valid and true outcome fully supported by evidence and logic. Able to answer basic and (at least some) more advanced objections to their conclusions. Effectively summarizes and clarifies content and questions when necessary to meet audience's needs. Shows confidence & interest through effective eye contact with the audience. (9.5-10 pts)	
Pricing	Fails to set a reasonable price point for the product or cannot justify at all the selection of the price. Price point is not at all realistic based on the bill of materials, PCB manufacturing, and other factors, or cannot justify the selection of the price point. (0-3 pts)	Sets a price point for the product, but neglects considerations of fixed and variable costs, competition, and profitability. Price point is not realistic based on the bill of materials, PCB manufacturing, and other factors. (3-6 pts)	Sets a price point for the product which includes some of the considerations of fixed and variable costs, competition, and profitability. Price point is somewhat realistic based on the bill of materials, PCB manufacturing, and other factors. (6-7.5 pts)	Sets a reasonable price point for the product which includes considerations of fixed and variable costs as well as competition and profitability. Price point is realistic based on the bill of materials, PCB manufacturing, and other factors. (7.5-8 pts)	
Delivery, Prototype, and Testing Plans	Proposes an unreasonable time schedule for manufacturing and delivery of the devices or does not mention a time schedule. Does not construct nor display a prototype of the device. Lacks description of the device. Fails to properly describe the testing conducted on the prototype. The testing plans are generally lacking and may not have been executed. (0-3 pts)	Proposes a time schedule for manufacturing and delivery of the devices. Constructs a prototype of the device. Provides some description of the device. Mentions the testing conducted on the prototype. The testing plans are not very comprehensive, thorough, or may not have been fully executed. (3-4.5 pts)	Proposes a somewhat reasonable time schedule for manufacturing and delivery of the devices. Constructs and displays a prototype of the device. Describes the device to convey its proper functionality and indicates that it meets the need of the customer. Communicates the testing conducted on the prototype to demonstrate some level of performance specifications. The testing plans are somewhat comprehensive, thorough, and have been executed. (4.5-5.5 pts)	Proposes a reasonable time schedule for manufacturing and delivery of the devices. Constructs and displays a working prototype of the device. Describes the device in an appropriate level of detail to convey its proper functionality and pique the interst of the customer. Communicates effectively the testing conducted on the prototype to demonstrate the guaranteed level of performance specifications described. The testing plans are comprehensive, thorough, and well executed. (5.5-6 pts)	
Device Function-ality and Optimality	The device is missing any convincing evidence that it will operate as desired by the customer in terms of the input-output relationship. The use of components in the design does not balance at all power considerations, layout, batteries, or location of the temperature sensing element. (0-3 pts)	The device lacks evidence that it will operate as desired by the customer in terms of the input-output relationship. The use of components in the design does not balance very well power considerations, layout, batteries, and location of the temperature sensing element. (3-4.5 pts)	The device is demonstrated to work as desired by the customer in terms of the input-output relationship. This is demonstrated through a voltage vs. resistance plot. The use of components in the design balances power considerations, layout, batteries, and location of the temperature sensing element. (4.5-5.5 pts)	The device is successfully demonstrated to work as desired by the customer in terms of the input-output relationship. This is demonstrated through a voltage vs. temperature plot. The use of components in the design expertly balances power considerations, layout, batteries, and location of the temperature sensing element. (5.5-6 pts)	
				Total Points Received (/30)	

Figure 10: Pitch Rubric

Table 3: Assessment of the pitches showing number of groups in each category

Category	Does Not Meet Expectations	Developing	Meets Expectations	Proficient
Argument, Rhetoric, and Connection with Audience	0	1	10	2
Pricing	0	2	7	4
Delivery, Prototype, and Testing Plans	1	1	9	2
Device Functionality and Optimality	1	2	9	1

The assessment of the posters is carried out by evaluating the team on organization and content, audience anticipation, and aesthetics. The rubric used to evaluate the posters is shown in Figure 11. The result of the poster assessment is shown in Table 4.

Poster Rubric

Category	Does Not Meet Expectations	Developing	Meets Expectations	Proficient	Points Received
Organization & Content	Does not present well the purpose for the device. Audience finds difficulty in following most parts of the visual. Is full of grammatical errors. (0-1 pts)	Presents a purpose for the device that may be slightly opaque. Has some distracting grammatical errors. Audience finds difficulty in following some parts of the visual. (1-2 pts)	Presents a clear purpose for the device that is identifiable. Presents information in a reasonably coherent sequence. Is mostly free of grammatical errors. (2-2.5 pts)	Presents a compelling and clear purpose for the device that is clearly identifiable. Presents information in a coherent, interesting sequence. Is essentially free of grammatical errors. (2.5-3 pts)	
Audience Anticipation	Visual presentation does not seem planned with the audience in mind. Does not anticipate audience expectations/ questions in advance at all. The visual layout and schematics do not tie the aspects of the presentation together. (0-1.5 pts)	Attempts to plan visual presentation with the audience in mind, but not very effectively. Does not anticipate audience expectations/ questions in advance very well. The visual layout and schematics have some impact on the audience but does not necessarily tie the aspects of the presentation together effectively. (1.5-3 pts)	Visual presentation seems planned with the audience in mind. Anticipates audience expectations/ questions in advance to some extent and designs the visual accordingly. The visual layout and schematics lead to an impact on the audience that ties many aspects together in a reasonable manner. (3-3.5 pts)	Plans the visual presentation with the audience in mind. Correctly anticipates audience expectations/ questions in advance and designs the visual accordingly. The visual layout and schematics lead naturally to a strong impact on the audience that ties all aspects together effectively, in a focused manner. (3.5-4 pts)	
Aesthetics	Poster is not attractive and stands out for all the wrong reasons. Poster is not comprehensible and uses poor quality or inappropriate images, charts, tables, illustrations, etc. (0-1 pts)	Poster is not very attractive. Poster is not easily comprehensible and uses sometimes inappropriate images, charts, tables, illustrations, pictures, etc. (1-2 pts)	Poster is fairly attractive. Poster is comprehensible and uses adequately appropriate images, charts, tables, illustrations, pictures, etc. (2-2.5 pts)	Poster is eye-catching, attractive, and stands out distinctively. Poster is easily comprehensible and uses appropriate and well-designed images, charts, tables, illustrations, pictures, etc. (2.5-3 pts)	
				Total Points Received (/10)	

Figure 11: Poster Rubric

Table 4: Assessment of the posters showing number of groups in each category

Category	Does Not Meet Expectations	Developing	Meets Expectations	Proficient
Organization & Content	0	0	8	5
Audience Anticipation	0	3	7	3
Aesthetics	2	2	5	4

5. Related ABET Students Outcomes

Upon the completion of this project, students certainly gained some knowledge related to circuit design and collaborated with each other working toward a common goal. In addition, it can be claimed that the project activity supports the following students outcomes set by ABET:

(a) an ability to apply knowledge of mathematics, science, and engineering;
(b) an ability to design and conduct experiments, as well as to analyze and interpret data;
(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability;
(d) an ability to function on multidisciplinary teams;
(e) an ability to identify, formulate, and solve engineering problems;
(g) an ability to communicate effectively;
(i) a recognition of the need for, and an ability to engage in life-long learning;
(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

6. Students' Attitude

Students' attitude toward this project was positive. Students were capable of organizing their own work and managing their own time. Throughout the process, students collaborated and worked together to make sense of what was going on. It is evident from the work submitted by the students that they generated meaningful questions, managed complexity and time, transformed data, and developed logical rationale to support decisions. Some students expressed their appreciation to the instructors for giving them the opportunity to work on such a project.

7. Conclusions

It is strongly believed by the authors that the business side of engineering is best conveyed through project-based learning techniques, which are inherently more applied and focused on real-world problems. Further, incorporating the entrepreneurial mindset into a course naturally makes the course content more accessible from a practical standpoint and students better see how the technical content applies in the real world.

Project-based learning techniques are well-suited for a technical course like Electric Circuits. The project described in this paper is successful because it has a significant technical side in which the students gain a lot of knowledge and ability in some of the issues that go into circuit design and fabrication. Through the multi-disciplinary interactions and collaborations, the written proposal, and the pitch process, there are also many soft skills that are improved as well. In particular, the project aims to improve written and verbal communication, management, persisting and learning from failure, and solving ambiguous problems.

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