Integrating Entrepreneurship in Engineering Class Projects through Hypothetical Modifications of Existing Products

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Abstract

Many educators have argued that problem-based and project-based learning pedagogies are effective frameworks to impart the entrepreneurial mindset to students. In this paper, the focus is on a project-based learning technique whereby students use an existing product available in the marketplace as the starting point for the design concept, and the problem given to them is a set of hypothetical modifications of the product to address real customer concerns. The paper provides the details of the project, the student solutions, and the assessment of student work.

1. Introduction

The entrepreneurial mindset has been identified by engineering educators and employers alike as a vital attribute of engineering graduates[1,2,7]. Although it is difficult to capture a concise definition of what it means to have an entrepreneurial mindset, attributes such as curiosity of the ever-changing world, perseverance through failure, and business acumen are often used to describe it.

Many educators have argued that problem-based and project-based learning pedagogies are effective frameworks to impart the entrepreneurial mindset to students[3,4,5,6,8,9]. In this paper, the focus is on a project-based learning technique whereby students use an existing product available in the marketplace as the starting point for the design concept, and the problem given to them is a set of hypothetical modifications of the product to address real customer concerns. The idea of using existing products as a starting point for redesign has been considered in another paper, which has a greater emphasis on developing redesign competencies and less emphasis on the entrepreneurial aspect[10].

The students must interpret the customer feedback and properly integrate that feedback into the design modifications. The proposed technique is made possible through the plethora of publicly available customer feedback on the websites of online vendors.

To illustrate the concept, we provide a running example of a class project given to the students of a senior-level electrical engineering course. The course in which the class project is assigned is called System Design, which is a lab-based course that meets once a week in a three-hour lab session and is worth one-semester credit hour. The structure of the course and technical capabilities of the senior-level students taking the course enable good results from the students.

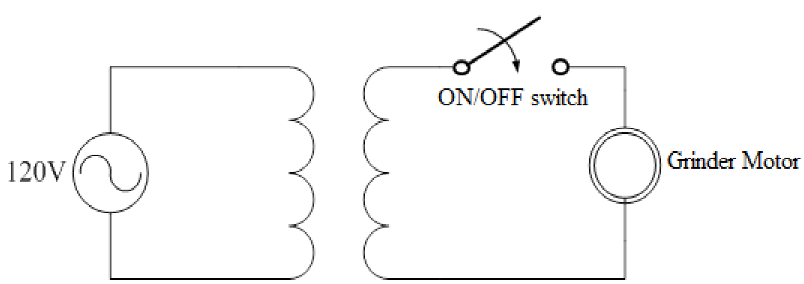
The rest of the paper is organized as follows. Section 2 provides a description of the class project used to illustrate the hypothetical redesign of an existing product while incorporating real customer feedback. Section 2 also provides a discussion of the characteristics of a product that make it suitable for hypothetical redesign in a class project. Section 3 describes the schedule of the class project and how details are progressively disclosed to the students. Section 4 illustrates sample student work. Section 5 details the learning outcomes of the class project and how they are assessed using several rubrics developed for the System Design course. Finally, Section 6 concludes with summarizing thoughts on the project along with the student feedback.

2. Project Description and Product Selection

There were 11 students in the System Design class. These students formed three groups by self-selection: two 4-student groups and one 3-student group. For the duration of the class project, the students play the role of engineers at the company WonderMill. In order to facilitate interest and buy-in from the students while also providing an understanding of the requirements for the class project, the students are given a project description document. This document states the following:

"You are an electrical engineer employed by WonderMill, the manufacturer of the world's #1 rated electric grain mill used as a home mill to make homemade flour. The product development team is interested in automating the popular electric grain mill so the mill turns on automatically when the grain is in close proximity to the grinder inlet in the feed hopper. The prototype mill for testing the new circuitry will be driven by a 30V AC, 15W motor operated via a 4:1 step-down transformer that transforms the 120V, 60 Hz outlet voltage to the appropriate 30V.

Currently, the grinder in the electric grain mill is operated using an on/off switch, as shown in Figure 1.



(a)

(b)

Figure 1. (a) Circuit representation of the current electric grain mill; (b) WonderMill electric grain mill

You must design and implement control electronics equipped with an appropriate proximity sensor that will automatically turn the grinder motor on/off based on the proximity of the grain to the inlet of the grinder in the feed hopper. Your electronic control system will be integrated within the whole system as shown in Figure 2, which will eliminate the need for the ON/OFF switch.

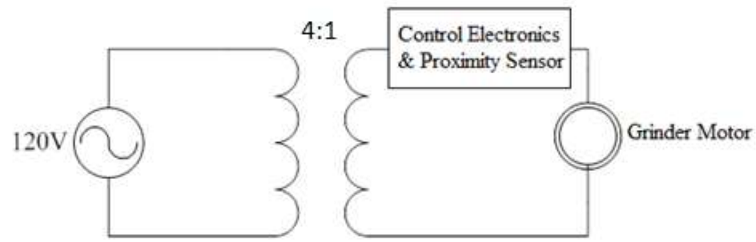


Figure 2. Circuit representation of the desired electric grain mill.

The control circuitry should be capable of driving the 30V AC, 15W prototype motor with up to 500mA. Safety, cost, and customer appeal are other criteria that should be addressed."

The selection of the product to choose for redesign should be based on the following characteristics of the product. First, the product should be a relatively simple device whose components and functionality should be easily understood by students. Second, the product should be applicable to the discipline of the engineering students involved (e.g., electrical engineering students should work on a redesign of an electrical product, etc.). Third, the product should have several relatively straightforward potential design modifications that the instructor can discern, so that the students' task of redesign is achievable in a class project. Fourth, if a portion of the redesigned product is to be prototyped, those components should be relatively inexpensive so the prototype is not too costly to the instructor's institution; moreover, the redesign of the product should not add too much to the cost of the product to make it financially viable in the market. Finally, the product needs to have significant customer reviews and feedback on the websites of online vendors so the instructor can summarize the key customer concerns and incorporate those concerns as part of the hypothetical redesign. This is perhaps the most important characteristic from the entrepreneurship perspective, since the hypothetical redesigns should satisfy realistic customer needs and desires.

The electric grain mill has all of these characteristics, which is why it has been selected as the product for hypothetical redesign. The focus in the project on selection of a proximity sensor and the design of the control electronics is given because the students are electrical engineering students. If the students were, for example, mechanical engineering students, perhaps a better focus of the project would be the redesign of the mill to reduce vibrations in order to reduce the noise produced during its operation (a real customer concern). Another focus could be on preventing the motor from overheating perhaps by the addition of heat sinks.

3. Project Schedule and Scaffolding

The class project required six weeks to complete. The schedule is summarized in Table 1, which includes the other class activities in grey in order to see how the electric grain mill project is staggered among other class projects. Two hours of the first three-hour class period were used for introducing the project and implementing the project scaffolding. Students were allowed to submit purchase request forms during the second class period (a week later) in order to obtain any parts needed for their prototype that were not available in the lab. Students were limited to $30 per group in the amount they could spend on parts to encourage cost efficiency as an integral part of their design. The remaining time in the second week and third week (Weeks 4 and 5 of Table 1) were utilized for other class projects in order to provide the necessary time for the ordered parts to arrive. The fourth week (Week 6) was dedicated to building the prototype, performing necessary tests, tuning, and sketching the design concept. The groups had to demonstrate their working prototypes and present their design concept in the fifth week (Week 7). Finally, after an additional week due to Fall Break (Week 8), the students submitted the written group reports (Week 9).

Table 1: Electric Grain Mill Project Schedule (including other class activities for reference)

Week	Date	Content
3		Electric Grain Mill Project Introduction Signal Conditioning Project Individual Demonstration
4		Electric Grain Mill Project Parts Inventory and Purchase Request Antialiasing Analog Filter Project Introduction Signal Conditioning Project Individual Report Due
5		Antialiasing Analog Filter Project Implementation and Testing
6		Electric Grain Mill Project Implementation and Testing Antialiasing Analog Filter Project Individual Demonstration
7		Electric Grain Mill Group Presentation/Demonstration DC Motor Control Project Introduction
8		Fall Break: No Class
9		Electric Grain Mill Project Group Report Due DC Motor Control Project Implementation and Testing

The concept of project scaffolding (also known as progressive disclosure) is used in the implementation of the class project in order to explicitly provide many of the design requirements and customer feedback points in a manner that also encourages individual thought and creativity.

There are four key documents that are used in the scaffolding of this class project. The first is the project description handout provided in Section 2. This document is presented to the class with a brief class discussion of the basic idea and requirements. After the class discussion, the groups are allowed some time (approximately 20 minutes) to comprehend the problem and begin to formulate potential solutions. Next, a design considerations document is provided to the students providing salient hints to keep in mind during the design process such as design modification, device options with respect to switching, sensor options, and design safety. Following another period of group design time (again approximately 20 minutes), the students are provided a customer feedback document that summarizes many of the customer concerns and suggestions that real customers have reported on the websites of online vendors who sell the grain mill such as the customer's ability to SWITCH OFF the electric mill in the middle of the milling cycle, availability of multiple options with regard to flour coarseness, complaints about the flour collection canister (the bin that holds the grounded flour), and grinder motor overheating and noise. Finally, a thermistor description document is provided to students to narrow their focus with regard to temperature sensors to use for the overheating issue reported by customers.

4. Student Work

In this section, we briefly describe some of the technical approaches taken by students and provide sample illustrations of student work. Then, we describe some of the ways in which the customer concerns are addressed.

On the technical side, all three groups used one or more Light-Dependent Resistors (LDRs) for the proximity sensor and decoupled the control electronics from the power circuitry of the motor using a relay. A couple of groups used the LDR network in a voltage divider configuration to bias a transistor that controlled the relay, whereas the last group used a comparator op amp circuit with the LDR network in a voltage divider configuration on one of the inputs of the comparator op amp in order to bias the transistor which controlled the relay. The design with the comparator op amp circuit is shown in Figure 3. The relay is modeled using a voltage controlled switch in PSPICE. Resistors R7 and R10 in Figure 3 represent the LDRs.

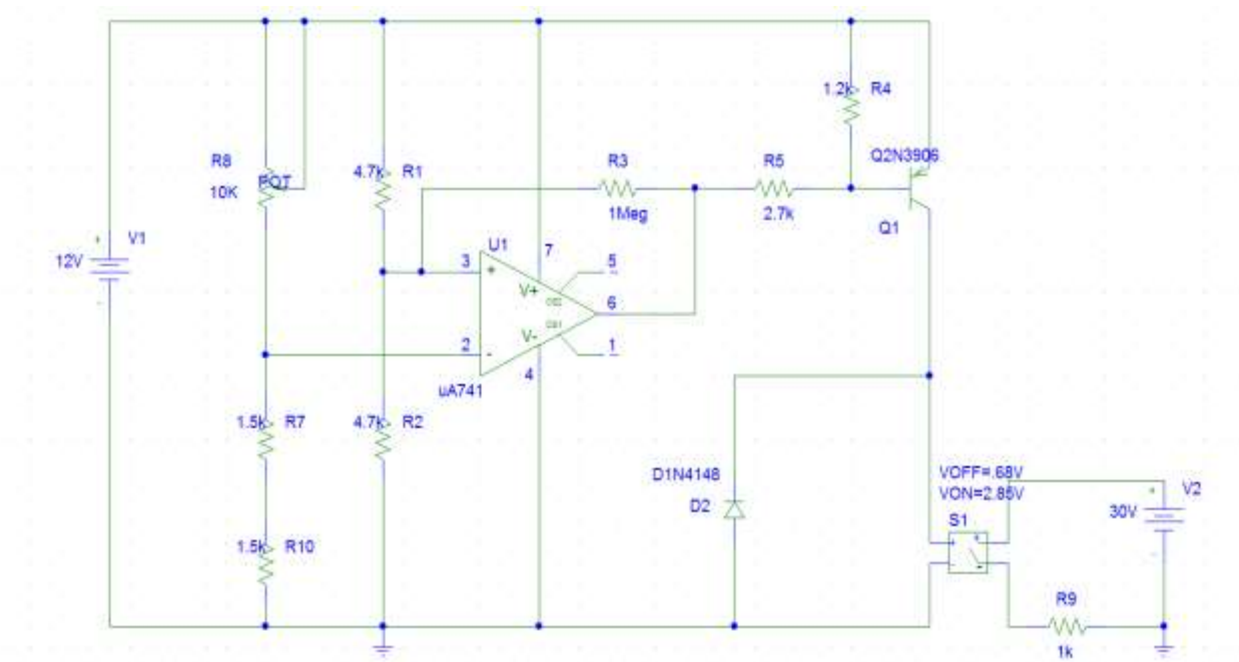


Figure 3: Sample Control Electronics for the Automatic Grain Mill Design Concept

The layout of the two LDRs whose functionality is illustrated in Figure 3 is shown in Figure 4. The idea of this group is to require both LDRs to be occluded in order to turn on the grinder motor. The two LDR configuration was advocated as a safety feature by the group. Since both LDRs must be covered for the motor to turn on, it would presumably be more difficult for a human hand to activate the motor.

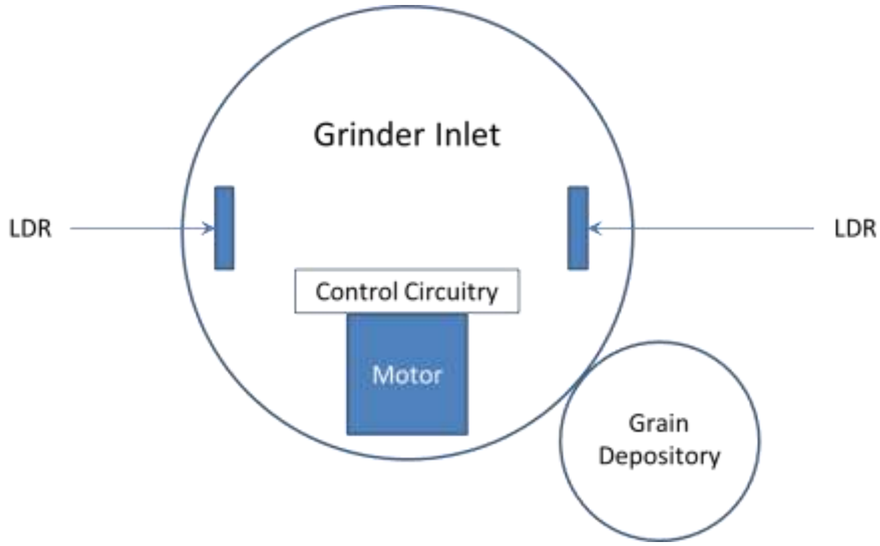


Figure 4: Sample Schematic of Automatic Grain Mill Design Concept Layout

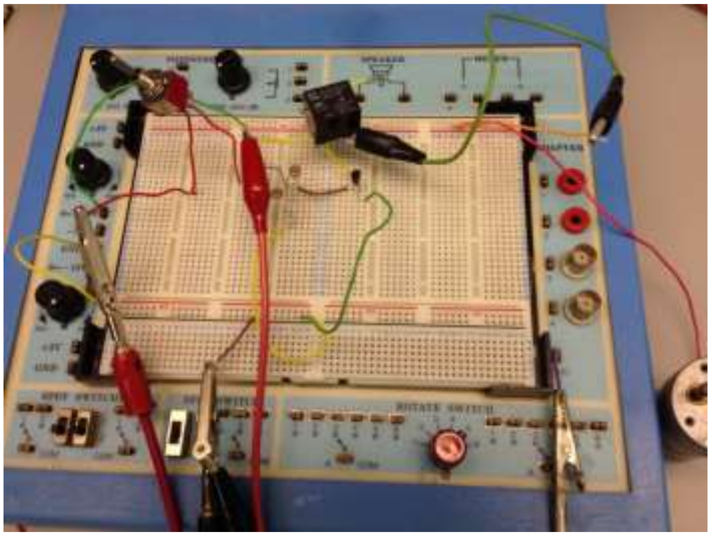


Figure 5: Sample Prototype of the Control Electronics and Proximity Sensor

Students were considering some customer concerns and how to incorporate safety in their prototype. One group had the practical safety feature of a mesh lid that covers the grinder's inlet preventing a child from sticking her or his hand into the grinder. All groups incorporated a thermistor into their design, which would automatically shut off the grinder motor if it overheated. One group added a potentiometer to regulate the voltage and therefore speed of the motor to provide different granularities in terms of the coarseness of the flour. Unfortunately, none of the groups addressed the motor noise issue nor the complaints about the flour collection canister.

5. Assessment of Performance and Learning Outcomes

The System Design course is structured to encourage independent thinking and design from individual students and students in groups. It requires integrating knowledge from different areas of electrical engineering in the design of complete and practical systems. Communication skills are heavily emphasized including both written and verbal communication. Written communication is assessed through individual and group reports and verbal communication is assessed as part of the prototype demonstration and the group presentation grades. The specific group project presented in this paper also requires students to assess the needs and concerns of customers and tailor their design to address those needs and concerns. The learning outcomes of the course that are specifically addressed by this project include:

1. Design and construct control electronics that respond to environmental conditions using an appropriate sensor.

2. Integrate multiple components into an overall working system.

3. Assess customer needs.

4. Tailor the design of a system to integrate the motivations and perspectives of multiple stakeholders.

5. Develop and implement test plans and procedures.

6. Demonstrate effective communication of information, concepts, and ideas in writing.

7. Demonstrate effective communication orally.

Several rubrics have been used to assess the student work for several projects in the System Design course at the authors' institution and are presented in the following subsection. There are rubrics that assess writing quality (Table 1) and format and content (Table 2) in group reports. There is a rubric to assess the prototype demonstration performance (Table 3). Finally, there are rubrics to evaluate the individual performance (Table 4) and overall group performance (Table 5) in the group presentations.

Rubrics
Table 2 gives the writing quality assessment of the group project report rubric. The key metrics for writing quality are paragraph structure, word choice, voice and tense, spelling and punctuation, and audience, conciseness, and reproducibility.

Table 2: Writing Quality Table in Group Project Report Rubric

Writing Quality						
	Excellent	**Above Avg**	**Avg**	**Marginal**	**Unsatisfactory**	**Pts**
Para-graph Struc-ture	**4pts** Paragraph structure is strong and each paragraph flows well into the next	**3pts** Paragraphs are generally limited to one idea, but not always well connected together	**2pts** Paragraphs sometimes have unrelated ideas expressed and missing introductory & transitional sentences	**1pt** Paragraphs often have unrelated ideas expressed and many missing introductory & transitional sentences	**0pts** Report is NOT organized effectively into paragraphs	
Word Choice	**4pts** Words are used correctly and with precision; writing indicates mastery of technical concepts	**3pts** Mostly acceptable vocabulary; technical terms are used correctly	**2pts** Somewhat informal vocabulary and minor inaccuracies in use of technical content	**1pt** Informal vocabulary and many minor or a couple of major inaccuracies in use	**0pts** Incorrect usage of technical terms and excessive informality	
Voice & Tense	**4pts** Near perfect use of tense and voice	**3pts** Minor issues with tense and voice	**2pts** Few mixed or improper tense and decent use of passive/active voice	**1pt** Frequent mixed or improper tense and marginal use of passive/active voice	**0pts** Abundant misuse of tense and voice	
Spelling & Punc-tuation	**4pts** No spelling or punctuation mistakes	**3pts** Few spelling or punctuation mistakes	**2pts** Several spelling and/or punctuation mistakes	**1pt** Frequent spelling and punctuation errors; incorrect capitalization	**0pts** Spelling & punctuation interfere with understanding	
Audience, Concise-ness, & Reprodu-cibility	**4pts** Effectively targets the intended audience both in the amount of information and the way it is presented; work can easily be reproduced	**3pts** Mostly appropriate content, but sometimes not presented as concisely as possible; work could be reproduced with effort	**2pts** Sometimes extraneous information and sometimes lacking necessary information; authors may need to be contacted on one or two points to be able to reproduce	**1pt** Extraneous information and often lacks needed information; not confident authors could explain how to reproduce	**0pts** Wrong audience; not concise; could not be reproduced	

Table 3 provides the metrics for assessing the format and content of the group project reports. A group report formatting guide is provided to the students indicating the required structure of the report in terms of which sections should be included. There is a row entry for each section of the group report, including introduction, problem description, constraints, and criteria, proposed solution and analysis, simulations, testing and implementation, conclusions, and group dynamics and individual workload.

Table 3: Format and Content Table in Group Project Report Rubric

Format and Content						
	Excellent	**Above Avg**	**Avg**	**Marginal**	**Unsatisfactory**	**Pts**
Report Format	**5pts** Formatted as outlined in Report Format Guidelines	**4pts** Renamed but similar sections	**3pts** Missing title page, different, but mostly appropriate section names	**2pts** Inappropriate sections (do not outline well what is included)	**1-0 pts** Missing hierarchical structure	

Intro-duction	**5pts** Successfully motivates the problem; provides excellent high-level description of problem, solution, and results; outlines report	**4pts** Mostly successful in motivation of the problem; provides good high-level description of problem, solution and results	**3pts** Provides decent high-level description of problem, solution, and results	**2pts** Missing high-level description of problem, solution, or results; poor high-level descriptions	**1-0 pts** Missing high-level descriptions and does not successfully motive problem	
Problem Des-cription, Con-straints, & Criteria	**10pts** Clearly & concisely defines problem, identifies important criteria & constraints, specifies I/O and attributes, superbly defines architecture, and interfaces with other components	**9-8 pts** Clearly defines the problem, identifies some important criteria & constraints, specifies I/O, and some discussion of architecture, and interfaces with other components	**7-6 pts** Defines the problem, and identifies few criteria &constraints; not a clear specification of I/O; little or unclear discussion of system architecture or interfaces with other components	**5-4 pts** Problem is mentioned yet ill defined, lacking in criteria & constraints; little and unclear discussion of system architecture and interfaces with other components	**3-0 pts** Problem is not defined, severely lacking in criteria & constraints; no discussion of system architecture or interfaces	
Pro-posed Solution & Analysis	**20 pts** Design is well presented through nice models and/or diagram(s) with a thorough and clear description; Design is expertly analyzed through sound reasoning and/or mathematics	**19-18 pts** Design is presented through models and/or diagram(s) with a good description; Design is analyzed through sound reasoning and/or mathematics	**17-14 pts** Design is presented through models or diagram(s) with some description; Design is fairly analyzed with mostly sound reasoning and/or mathematics	**13-10 pts** Design description is missing necessary diagrams, models, or description; Analysis of design has significant mistakes or is generally lacking	**9-0 pts** Design is poorly presented; Analysis of design is missing, is completely erroneous, or is incomprehensi ble	
Simu-lations	**10 pts** Appropriate simulation tool; superbly set up simulation experiment; excellent presentation and analysis of results	**9-8 pts** Appropriate simulation tool; good setup; good presentation and analysis of results	**7-6 pts** Appropriate simulation tool; missing some aspects of the setup; decent presentation and analysis of results	**5-4 pts** Appropriate simulation tool; missing most of the setup; poor presentation and/or analysis of results	**3-0 pts** Inappropriate simulation tool or missing simulations; missing or very poor analysis of results	
Testing & Imple-menta-tion	**20 pts** Well thought and reasonable test plans; Detailed procedural description; excellent presentation of results with insights; includes exhaustive parts and equipment list	**19-17 pts** Mostly useful test plans; good description with most details; good presentation of results with some insights; good parts and equipment list	**16-14 pts** Decent test plans; decent description missing some details; decent presentation of results; mostly complete parts and equipment list	**13-8 pts** Poor test plans; poor description missing details; poor presentation of results; mostly incomplete parts and equipment list	**7-0 pts** Very poor test plans; awful description with few details; missing presentation of results; missing parts and equipment list	
Conclu-sions	**5 pts** Concise summary of problem & solution; adds value to report; insightful discussion of redesign/lessons	**4 pts** Good summary; adds some value to report; good discussion of redesign/lessons	**3 pts** Decent summary; marginal additional value to report; some mention of lessons and redesign ideas	**2 pts** Poor summary; no additional value; little mention of lessons or redesign ideas	**1-0 pts** Poor or no summary; no additional value; no mention of lessons or redesign	

Group Dyna-mics & Indivi-dual Work-load	**5 pts** Roles & tasks clearly assigned; expertly describes successes, & failures; outlines ways team efficiency and quality can be improved; prior changes well documented	**4 pts** Roles & tasks assigned; describes successes, & failures; outlines ways team efficiency and quality can be improved; changes documented	**3 pts** Roles & tasks assigned; describes few successes, & failures; few ways team efficiency and quality can be improved	**2 pts** Roles & tasks assigned; avoids successes, & failures discussion or ways team efficiency & quality can be improved	**1-0 pts** Roles & tasks NOT assigned; missing success & failure discussion; missing team improvement	

The rubric used for assessing the demonstration of the prototype is given in Table 4. Important assessment metrics include troubleshooting, test plans and methods, demonstration, performance of the prototype, and duration of the demonstration.

Table 4: Prototype Demonstration Rubric

	Excellent	**Above Avg**	**Avg**	**Marginal**	**Unsatisfactory**	**Pts**
Trouble-shooting	**20-18 pts** Requires little to no guidance	**15-18 pt** Requires some nontrivial involvement	**12-15 pts** Requires substantial involvement	**9-12 pts** Cannot troubleshoot alone	**0-9 pts** No attempt to troubleshoot or gives up	
Test plans and methods	**20-18 pts** Well thought & reasonable test plans and methods; well implemented	**15-18 pt** Some potentially useful test plans and/or methods; implemented	**12-15 pts** Some potentially useful test plans, not all implemented	**9-12 pts** Too few test plans or poor implementation of plans	**0-9 pts** No suitable test plans or methods	
Demon-stration	**20-18 pts** Requires little to no guidance with correct description; very clear description	**15-18 pt** Description of functionality is mostly correct; mostly clear description	**12-15 pts** Description of functionality has some notable errors; somewhat clear description	**8-12 pts** Description is full of errors and needs assistance; poor description	**0-8 pts** No attempt to demonstrate or gives up	
Perfor-mance	**20 pts** Exceeds customer specs and behaves as desired	**18-19 pt** Meets customer specs and behaves as desired	**15-18 pts** Mostly meets customer specs and behaves mostly as desired	**12-15 pts** Nearly meets specs and behaves somewhat as desired	**9-12 pts** Meets some perfor-mance points **0-9 pts** Fails to perform in any way as desired	
Dura-tion	**20 pts** Demonstrates and describes within 5 minutes	**18-19 pt** Demonstrates and describes within 6 minutes[1]	**12-17 pts** Demonstrates and describes within 9 minutes	**8-12 pts** Demonstrates and describes within 11 minutes	**0-8 pts** Demonstrates and describes within 15 minutes	

[1] A point is deducted for each additional 30 seconds taken to demonstrate.

The group presentation rubric is broken into two tables: one for individual presentation and one for group presentation. Table 5 provides the individual assessment table and Table 6 contains the group assessment.

Table 5: Individual Assessment Table in Group Presentation Rubric

Individual Presentation Quality						
	Excellent	**Above Avg**	**Avg**	**Marginal**	**Unsatisfactory**	**Pts**
Tech-nical Com-munica-tion & Rhetoric	**25pts** Presents subsystem or subtopic with valid outcomes fully supported by test data, mathematical reasoning, market research, or other appropriate data. Speaks using appropriate language and demonstrates mastery of technical jargon.	**20-24pts** Presents subsystem or subtopic with valid outcomes mostly supported by test data, mathematical reasoning, market research, or other appropriate data. Speaks using mostly appropriate language and uses technical jargon correctly.	**17-19pts** Presents subsystem or subtopic with mostly valid outcomes mostly supported by test data, mathematical reasoning, market research, or other appropriate data. Speaks using mostly appropriate language but has one or two issues with technical jargon.	**12-16pts** Presents subsystem or subtopic with some valid outcomes partially supported by test data, mathematical reasoning, market research, or other appropriate data. Speaks using some inappropriate language and sometimes misuses technical jargon	**0-11pts** Presents subsystem or subtopic with unsubstantiated claims. Often speaks using inappropriate language and misuses technical jargon	
Connec-tion with Aud-ience	**25pts** Effectively summarizes and clarifies content and questions when necessary to meet audience needs. Shows confidence and interest through effective eye contact, clear voice, and polished presentation.	**20-24pts** Summarizes and clarifies content and questions when necessary to meet audience needs. Shows some confidence and interest through eye contact, clear voice, and mostly polished presentation.	**17-19pts** Reasonably alert to audience's needs and frequently re-states and clarifies appropriately. Relates to the audience through eye contact. Somewhat difficult to hear and somewhat unpolished presentation	**12-16pts** Rarely summarizes or clarifies content to meet audience's needs. Attempts to draw audience into the presentation through eye contact, but is difficult to hear and unpolished in presentation	**0-11pts** Does not attempt to go over or elucidate content. Avoids looking at the audience.	

Table 6: Group Assessment in Group Presentation Rubric

Overall Group Presentation Quality						
	Excellent	**Above Avg**	**Avg**	**Marginal**	**Unsatisfactory**	**Pts**
Tech-nical Com-munica-tion & Rhetoric	**10 pts** Contains a compelling central message, with valid outcomes fully supported by test data, mathematical reasoning and logic. Speaks using appropriate language and demonstrates mastery of technical jargon.	**8-9pts** Contains a strong central message with valid outcomes mostly supported by test data, mathematical reasoning, market research, or other appropriate data. Speaks using mostly appropriate language and uses technical jargon correctly.	**6-7pts** Contains a central message with mostly valid outcomes mostly supported by test data, mathematical reasoning, market research, or other appropriate data. Speaks using mostly appropriate language but has one or two issues with technical jargon.	**4-5pts** There are some valid outcomes partially supported by test data, mathematical reasoning, market research, or other appropriate data. Speaks using some inappropriate language and sometimes misuses technical jargon	**0-3pts** There are many unsubstantiated claims. Often speaks using inappropriate language and misuses technical jargon	
Connec-tion with Aud-ience	**10 pts** Effectively summarizes and clarifies content and questions when necessary to meet audience needs. Shows confidence and	**8-9pts** Summarizes and clarifies content and questions when necessary to meet audience needs. Shows some confidence and interest	**6-7pts** Reasonably alert to audience's needs and frequently re-states and clarifies appropriately. Relates to the audience through eye contact. Somewhat difficult to	**4-5pts** Rarely summarizes or clarifies content to meet audience's needs. Attempts to draw audience into the presentation through eye contact, but is	**0-3pts** Does not attempt to go over or elucidate content. Avoids looking at the audience. Not good with	

	interest through effective eye contact, clear voice, and polished presentation. Able to answer questions and objections to conclusions.	through eye contact, clear voice, and mostly polished presentation. Able to answer questions	hear and somewhat unpolished presentation. Is mostly comfortable with questions, but misunderstands some of the questions	difficult to hear and unpolished in presentation. Is mostly uncomfortable with questions, and misunderstands some of the questions	questions	
Custo-mer & Market Need	**10 pts** All key constituencies are identified and customer/market needs are described and addressed. The approach to address the need is unique and innovative	**8-9pts** Most constituencies are identified and key customer/market needs are described and addressed. The approach to address the need is sound and reasonable	**6-7pts** Some constituencies are identified and key customer/market needs are mostly described and mostly addressed. The approach to address the need is mostly sound and somewhat reasonable	**4-5pts** Few constituencies are identified (if any) and key customer/market needs are partially described and partially addressed. The approach to address the need is not very good	**0-3pts** No clear constituencies are identified and key customer/market needs are ignored. The approach to address the need is not viable	
Organ-ization	**10 pts** Information presented in logical and interesting sequence that the audience can easily follow	**8-9pts** Information presented in logical sequence that the audience can easily follow	**6-7pts** Information presented in somewhat logical sequence that the audience can follow	**4-5pts** Information often not presented in logical and interesting sequence that the audience can follow	**0-3pts** Organization is generally poor and the audience has difficulty following	
Dura-tion	**10 pts** Presentation does NOT exceed 12 minutes	**8-9pts** Presentation is between 12 and 13 minutes	**6-7pts** Presentation is between 13 and 14 minutes	**4-5pts** Presentation is between 14 and 15 minutes	**0-3pts** Presentation exceeds 15 minutes	

Results of Assessment

The assessment results of the student work using the rubrics are presented in Tables 7-11. Tables 7 and 8 present the rubric assessment results for the group project reports. Overall, the writing quality was good. With regard to the format and content, generally the solutions were viable and well explained. However, one group added customer specifications that were not documented anywhere and left out several customer issues that were explicitly listed in the customer feedback document, resulting in an unsatisfactory grade on the problem description, constraints, and criteria section. Another group explained the simulation setup but did not include all of the simulation results, which resulted in a marginal grade on the simulation section.

Table 7: Writing Quality Assessment of Student Group Project Reports

Writing Quality						
Row	**Criterion**	**Excellent**	**Above Avg**	**Avg**	**Marginal**	**Unsatisfactory**
1	**Paragraph Structure**	**1**	**1**	**1**		
2	**Word Choice**		**1**	**2**		
3	**Voice & Tense**		**2**	**1**		
4	**Spelling & Punctuation**		**3**			
5	**Audience, Conciseness, & Reproducibility**		**3**			

Table 8: Format and Content Assessment of Student Group Project Reports

Format and Content						
Row	Criterion	Excellent	Above Avg	Avg	Marginal	Unsatisfactory
1	Report Format	3				
2	Introduction		1	2		
3	Problem Description, Constraints, & Criteria		1	1		1
4	Proposed Solution & Analysis		1	2		
5	Simulations		1	1	1	
6	Testing & Implementation		2	1		
7	Conclusions		2	1		
8	Group Dynamics & Individual Workload		1	2		

Table 9 contains the rubric assessment results for the prototype demonstration. For the demonstration, a random team member from each group was selected to demonstrate and explain the prototype for the control electronics and proximity switch. Based on the assessment results, we can see that the students were concise with their demonstrations and required little to no guidance in troubleshooting their prototypes. Two out of three of the groups had good test plans. The explanations of the device functionality were generally good, but one group erroneously described the operation of the PNP transistor used in their solution. The performance criterion was the lowest performing of all the criteria due to all groups failing to address at least one of the customer issues. Generally, the customer complaints of loudness and connection issues between the feed hopper assembly and canister were ignored by all groups.

Table 9: Prototype Demonstration Assessment

Row	Criterion	Excellent	Above Avg	Avg	Marginal	Unsatisfactory
1	Troubleshooting	3				
2	Test plans and methods		2		1	
3	Demonstration	1	1	1		
4	Performance			2	1	
5	Duration	3				

Tables 10 and 11 contain the assessment results of the individual presentation quality and group presentation quality, respectively. Based on the data of Table 10, all students performed well in the presentation, with nobody standing out as either excellent or poor. Generally, students were well prepared and fairly polished in their presentations. However, the reasoning behind the circuit design of one group had some flaws, which resulted in a marginal performance in technical communication.

Table 10: Individual Assessment of Student Group Presentations

Individual Presentation Quality						
Row	Criterion	Excellent	Above Avg	Avg	Marginal	Unsatisfactory
1	Technical Communication & Rhetoric		8	3		
2	Connection with Audience		8	3		

Table 11: Group Assessment of Student Group Presentations

Overall Group Presentation Quality						
Row	**Criterion**	**Excellent**	**Above Avg**	**Avg**	**Marginal**	**Unsatisfactory**
1	**Technical Communication & Rhetoric**		**2**		**1**	
2	**Connection with Audience**		**2**	**1**		
3	**Customer & Market Need**		**2**	**1**		
4	**Organization**		**1**	**2**		
5	**Duration**	**3**				

Finally, the rubrics are used to assess the learning outcomes associated with this project. Table 12 provides the mapping of rubric row entries to learning outcomes along with the assessment results for the learning outcomes. Since Table 10 is individual-based and the rest of the tables are group-based, Table 12 reports a single value for each learning outcome, which is the average value of the overall class. A Likert scale is used with 0=Unsatisfactory and 4=Excellent for each row entry used in the assessment of each learning outcome. A weighted average of the applicable row entries in the rubrics is reported, given by the following equation:

$$\text{Weighted Class Average} = \sum_{\text{rubric rows used}} \frac{4*(\#\text{excellent}) + 3*(\#\text{above avg}) + 2*(\#\text{avg}) + 1*(\#\text{marginal})}{(\#\text{ rows used})(\#\text{ entries per row})}$$

Table 12: Learning Outcome Assessment

Learning Outcome	**Rubric Table & row entries used for assessment**	**Weighted Class Average**
1	**Table 3 (row 4), Table 4 (all)**	**2.722**
2	**Table 3 (rows 3-6), Table 4 (all)**	**2.630**
3	**Table 3 (row 3), Table 6 (row 3)**	**2.167**
4	**Table 3 (row 3), Table 6 (row 3)**	**2.167**
5	**Table 3 (row 6), Table 4 (row 2)**	**2.500**
6	**Tables 2 and 3 (all)**	**2.615**
7	**Table 4 (row 3), Tables 5 and 6 (all)**	**2.807**

6. Reflections and Conclusions

The System Design course as a whole ran very smoothly, and this project was executed well by students. They have expressed their appreciation of the project-based nature of the course in the course evaluation that was conducted at the end of the semester. They expressed that it is a very good course where knowledge from other courses was incorporated into the assigned projects. Some students added that this course gave them the opportunity to question things along the period of the course: how devices work, how they integrated together to form a system and so on. Some students complained about the “non-electrical” content of some of the assigned projects; however, they understand that this how they are exposed to real life projects and the way to deal with them.

As a conclusion, students learned a great deal about design and its business aspect. In addition, they believe that the project-based approach is a very effective teaching style where it promotes team work, ability to solve ambiguous problems, communication skills, dealing with customers, consideration of realistic constraints, and most importantly, integrating their knowledge in electrical engineering from different areas and putting it together to create functional systems that satisfy desired specifications.

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