A Sensor Application Design Project for Mechanical Engineers

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1. Introduction

The "ability to design and conduct experiments, as well as to analyze and interpret data" is an essential component of engineering education, as incorporated into ABET Criteria 3[1]. In the author's department, this criterion is met in part by a junior-level course in Experimental Methods. The course introduces students to hardware and software commonly used for data acquisition, as well as methods of data analysis and communication. Developing the ability of students to conduct experiments, analyze data, and interpret their results has been done successfully for many years. However, in spite of trying a variety of approaches, the author has struggled to provide effective, meaningful opportunities for students to design their own experiments. It is perhaps significant that, of the five textbooks on experimental methods for engineers that the author has surveyed, only one has significant theoretical content on experimental design[2]. This suggests that the author is not alone in struggling to make this topic accessible to undergraduate engineering students.

One of the most significant limitations in allowing students to develop their own experiments is the high cost of the industry- or research-level equipment typically used in this course. Since equipment selection is a critical aspect of experimental design, requiring students to use the limited range of available sensors essentially removes this aspect of the design process. The advent of low-cost sensors for open-source, education-oriented microprocessor systems such as the Arduino and Raspberry Pi has opened up new opportunities for teaching experimental methods to mechanical engineering students by greatly increasing the range of sensors that can be purchased without significant expense to the department.

The other main obstacle is the need for a design framework or approach that is both flexible and practical – flexible in order to accommodate a wide range of student-generated experiments, and practical in order to provide useful guidance for novices. During the first implementation of the project, students were required to apply the NABC (Need, Approach, Benefit, Competition) design framework[2]. While this was only a relatively small part of the original assignment, it seems to have been effective and will be expanded in the future.

This paper discusses the initial implementation of a class project which requires students to develop a practical application for such a sensor. Although limited by time, resources, and instructor knowledge, the initial results were encouraging. A number of lessons were learned which should make the second iteration of the project even more effective.

2. Context

ME-3511 Experimental Methods is a two-credit course that meets during two 75-minute periods per week. Although there are no prerequisites, the course is taken almost exclusively by mechanical engineering students in their fifth semester. The course outcomes indicate that upon completion of the course students will be able to:

1. Use experimental equipment and procedures commonly found in mechanical engineering practice.
2. Evaluate and quantify the uncertainty in experimental data.
3. Produce effective technical reports, including graphical and tabular presentation of results.
4. Design experiments by specifying appropriate equipment and procedures.
5. Use LabVIEW for data acquisition.

Traditionally, a significant amount of the course – approximately half of the meeting times - has been focused on LabView, while the remainder of the class time covered topics such as experimental uncertainty, data analysis, and communications. Over the past two years, the author has reduced the emphasis on LabView programming to allow more time for other topics and in-class activities.

3. Project Requirements

The objective of the project was to design an application for a sensor chosen from a list of five provided by the instructor. The project was implemented in five stages:

1. An in-class exercise where students used the internet to find the technical specifications of the ADXL 335 accelerometer[4]. Working in teams of two, the students were to identify whether the sensor was analog or digital, active or passive, specify the range and error, and determine the voltage and current requirements (if needed).
2. An in-class exercise where the students connected the ADXL 335 accelerometer to a computer using a National Instruments USB data acquisition component and other required hardware. The students also wrote a simple LabView program to calculate and display the acceleration acquired from voltage output signal produced by the accelerometer.
3. A team activity where the students repeated step 1 (collecting technical specification information) for the five sensors specified for the project, which included an ultrasonic rangefinder[5], a force-sensing resistor[6], a light sensor[7], an RGB color sensor[8], and a flex sensor[9].
4. A design project where each team developed one potential application for each of the five sensors, used a decision-making process of their choice to identify the most promising of the five potential applications, specify the hardware and software required to implement their chosen application, and perform a financial analysis to estimate the cost of building a prototype as well as a per unit cost for mass production.
5. A written report which included a description of their design process (steps 3 and 4), a discussion of potential legal, social or ethical issues related to their proposed application, and an NABC analysis.

Steps 3-5 were completed in teams of four assigned by the instructor. Due to the relatively small class sizes (a total of 51 students in two sections), teams were assigned based on known affinities such as participation in athletics, competition teams, study groups, etc. This approach seemed to work well, although it would not be feasible in many circumstances.

4. Assessment

For the initial implementation of the project, assessment data was obtained from student responses to three sets of survey questions given at the end of the semester. The first set of questions were a self-assessment of the students' abilities, where 0 = very weak, 2 = acceptable, and 4 = very strong:

> **Part A: Based on your performance as a member of your project team, evaluate your individual ability to accomplish the following tasks:**
> 1. Identify a new application for an existing sensor.
> 2. Specify the equipment and estimate the cost required to implement a measurement system.
> 3. Provide effective documentation for measurement hardware and procedures.
> 4. Evaluate potential risks and opportunities of new ventures.

There were 47 respondents, with the average responses shown in Table 1. For these questions there were only eight responses below "acceptable" with no "very weak" responses, suggesting that most students had a fairly high degree of confidence in their own abilities upon completion of the project.

Table 1: Students self-assessment of abilities related to the project

Question	Avg. Response	Std. Deviation
A1. Identify new application	2.91	0.69
A2. Specify equipment/estimate cost	2.57	0.80
A3. Documentation	2.72	0.77
A4. Evaluate risks/opportunities	2.70	0.86

The second set of questions addressed whether the students believed that the project improved their abilities, where 0 = no improvement, 1 = noticeable improvement, and 2 = significant improvement:

> **Part B: Evaluate the degree to which the project improved your ability to accomplish the following tasks:**
> 1. Identify a new application for an existing sensor.
> 2. Specify the equipment and estimate the cost required to implement a measurement system.
> 3. Provide effective documentation for measurement hardware and procedures.
> 4. Evaluate potential risks and opportunities of new ventures.

The average responses to these questions are shown in Table 2. For these four questions, there were only 15 responses of "no improvement" (out of 188 total responses). By contrast there were 56 responses of "significant improvement." The students saw the greatest self-improvement in relation to identifying new applications and in documentation, which mirror the strongest responses from the first set of questions.

Table 2: Students self-assessment of improvement in abilities related to the project

Question	Avg. Response	Std. Deviation
B1. Identify new application	1.30	0.62
B2. Specify equipment/estimate cost	1.13	0.58
B3. Documentation	1.28	0.58
B4. Evaluate risks/opportunities	1.17	0.52

The third set of questions asked the students to evaluate their teammates' abilities, where 0 = very weak, 2 = acceptable, and 4 = very strong:

Part C: Based on their performance on the project, evaluate the ability <u>of your teammates</u> (on average) to accomplish the following tasks:

1. Identify a new application for an existing sensor.
2. Specify the equipment and estimate the cost required to implement a measurement system.
3. Provide effective documentation for measurement hardware and procedures.
4. Evaluate potential risks and opportunities of new ventures.

The average responses to these questions are shown in Table 3. Comparison with Table 1 shows that the students considered their teammates to have similar levels of proficiency to their own. As with the responses from Part A, there were no responses of "very weak" and only four responses less than "acceptable."

Table 3: Students self-assessment of abilities related to the project

Question	Avg. Response	Std. Deviation
C1. Identify new application	2.72	0.71
C2. Specify equipment/estimate cost	2.62	0.71
C3. Documentation	2.64	0.76
C4. Evaluate risks/opportunities	2.70	0.81

For one final point of comparison, the self-assessment responses of Part A were compared to the teammate assessment responses of Part C by taking the difference in response for each question by each respondent. The results are shown in Table 4.

Table 4: Comparison of student's self- and peer-assessment responses.

	% of total responses
Self >> Peers (+2pt difference)	3
Self > Peers (+1pt difference)	20
Self = Peers (0pt difference)	59
Self < Peers (-1pt difference)	17
Self << Peers (-2pt difference)	2

These results indicate that most students were satisfied with the performance of their teammates. Taking all three aspects of assessment together, the results suggest that the initial implementation of the design project was a useful approach to incorporating design into the experimental methods course.

5. Suggestions for Improvement

The author has identified two specific improvements to be implemented the next time this project is assigned. In the initial assignment, the NABC memo was a supporting document to a larger comprehensive report. The author had no prior experience with the NABC approach to design, and was hesitant to base the overall structure of the project on this approach. However, upon reflection, the concepts of Need, Approach, Benefits, and Competition should be an effective way of organizing the report for this project. While perhaps not sufficient for a large-scale design project (e.g. senior capstone), for a shorter project the NABC approach seems to be a good compromise between thoroughness and brevity. Next year the project assignments and reporting requirements will be redesigned to reflect the NABC approach.

The second major change in the project will be the inclusion of a physical prototype. The low cost of the sensor used, in combination with Arduino and National Instruments equipment available within the department should make this possible. While it may not be feasible for students to exactly model their proposed application, they will be expected to build a hardware/software system that uses their chosen sensor for data acquisition and analysis. This may require rearranging some topics in the course so that students have the required skills earlier, but should make the project even more effective in teaching students to design experiments.

6. References

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