From Experiments to Experimentation; A New Philosophy for First Year Laboratories

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Abstract

Traditionally the first year engineering laboratories at Queen's university were chosen to illustrate fundamental concepts in physics and chemistry. Unfortunately, these experiments had evolved into "cook-book" exercises in which the students simply follow the steps outlined in a laboratory manual. Often the student was left with little understanding about the significance of their data or the experimental procedure. In the 2000-2001 school year, we replaced the standard laboratory experiments with a new lab course emphasising experimentation and experiment design. This paper describes the philosophy behind this course, how the course was organized and implemented, and summarises our experiences after the first year.

1. Introduction

A common first year program for engineering students is one of the trademarks of the Queen's University Applied Science Program, with the choice of engineering discipline made at the end of the student's first year. The common first year core includes courses in physics, chemistry, algebra, calculus, graphics, geology, computers and computer programming. Traditionally, both the physics and chemistry courses included a series of labs: 9 in physics and 9 in chemistry over the entire academic year. The preparation, lab work, analysis and report for these labs were all completed within a three-hour lab period each week. Students were guided through the experimental procedure by following the steps outlined in the lab manual. Although they gained practise using a variety of experimental procedures they were often left with little understanding of why the experiment was done in a given way or what the results meant. Evaluation involved marking the lab book report. This was generally poorly done and the student evaluation of the lab portion of the courses was unfavourable.

In 1999-2000, after 3 years of experience with a pilot program involving first year engineering projects, the Faculty of Applied Science removed the chemistry and physics labs from their respective parent courses and introduced a new, full year course entitled APSC100 - Practical Engineering Modules. This course involves two 2-week periods (one at the beginning of each term) of professional skills and safety training (Module 1), a 10-week period of "Introduction to Experimentation" (Module 2) and a 10-week period involving "Engineering Design Projects" (Module 3). A total of 600 engineering students take this course in their first year. This paper relates the authors' experience in developing the Module 2 portion of the APSC100 course.

The removal of the labs from the parent courses and the reduction to a 10-week module necessitated a change in content. This requirement for change was viewed as an opportunity to revise the aim and format of the course so that it could become an independently worthwhile and exciting learning experience for the students. Instead of focusing on the demonstration of chemical and physical phenomena, the focus was changed to experimental design, analysis, and interpretation, with an additional emphasis on technical report writing. The combination of a design component that introduces student ownership, and the selection of more interesting labs (from an engineering student's perspective) was expected to infuse the excitement that should be inherent in experimentation.

2. Course Format and Implementation

Teaching students about experimentation is challenging in a course with no lectures; the labs themselves and their organization have to do the teaching. The course is organized into the three components shown in figure 1. The first component includes two Tutorial Labs, aimed at introducing students to the basics of collecting, analysing and reporting data, as well as experimental design. This is followed by a 6-week cycle of "breadth" labs that utilize a variety of measuring instruments and allow the student to improve their data analysis and report writing skills. The final component is a 2-week project where students design and complete their own laboratory experiment. These three components are discussed in detail below.

2.1 Tutorial labs

Although the tutorial labs begin with brief introductory lectures, they rely on students reviewing the explanatory material before they come to the lab. These labs focus on data analysis and interpretation, rather than physical phenomena. This emphasis is made possible by the selection of technically straightforward concepts.

The first tutorial lab (the superball lab) introduces measurement error, compares data and error analysis methods, and guides the student through a critical evaluation of results. It compares three common analysis methods: error propagation using a single trial, statistical analysis of multiple trials and graphical analysis. The take-home assignment includes a worksheet that assists them with the analysis and evaluation of their data using Excel.

The second tutorial lab introduces simple experimental design, by requiring students to design an experiment to measure the spring constant for a spiral spring. They are given an "Experimental Design Guide" with accompanying "Planning Sheets". These guide them through the process of deciding what to measure, how to measure it, and how to analyse their data in the most effective manner.

2.2 Breadth labs

In the middle component of the course the students cycle through three physics and three chemistry experiments (see figure 1). These experiments were carefully selected to give the students experience using common test and measurement equipment, introduce them to the idea of testing a model, and give them additional practice with the experimental techniques introduced in the tutorial labs.

Three criteria were used to choose the lab topics:

a) They should be related to engineering practise,
b) Experiments typically covered in high school should be avoided where possible, and
c) The underlying principles should be basic enough to be explained in a few paragraphs.

The students are required to produce a formal report following each experiment (except titration). A guide to report writing and an example of a 'good' report are included in the lab manual and on the website.

2.3 Project experiments

The experiment design component is included to increase student involvement and to give students a better understanding of the experimental process. Students gain the insight necessary to more aptly assess the validity of experimental data, critically evaluate the progress of experiments and allow them make sensible revisions if necessary. Students choose a project experiment topic from a list of 10 (5 physics, 5 chemistry). This is done in the 3rd week, allowing ample time for planning. For each project the student is given a goal that must be achieved and the relevant background material. The preliminary designs are checked by staff in week 8, with the students performing their experiment in the final two weeks of term.

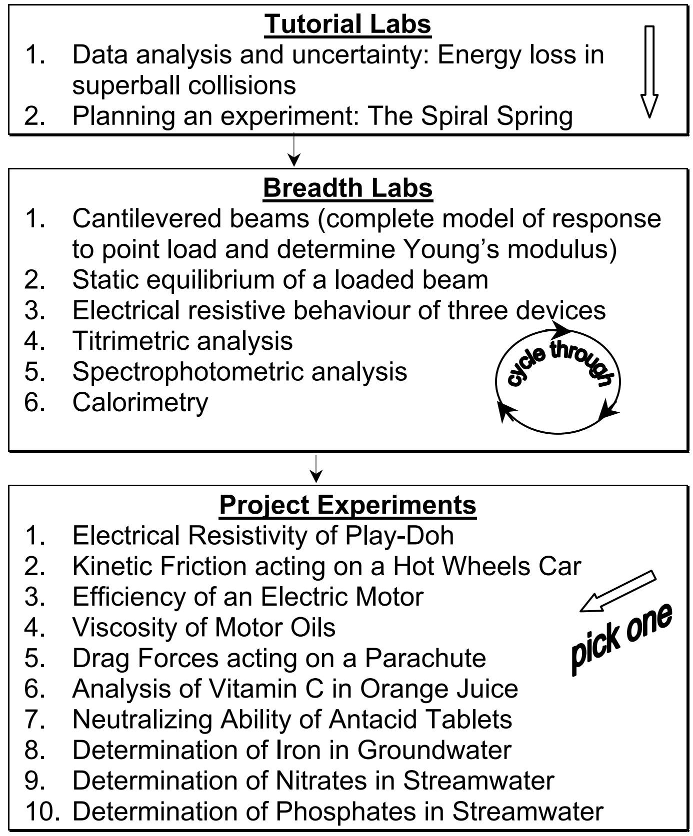

Figure 1: Course outline

The 10 project experiment titles are listed in Figure 1. Criteria used in selecting projects included the following:

a) The goal of each project should be to determine a physical constant or a material characteristic, or to determine the form of a physical model.
b) Problems should be open-ended – i.e. more than one experimental set up will work and/or a variety of problem aspects can be explored.
c) The background relating to equipment and methods should be provided in the tutorial and breadth labs (e.g. the chemistry projects can be done using either titration or spectroscopy).
d) Project topics should appeal to first year engineers (e.g. a lab used with physics students to determine the viscosity of glycerine was turned into a project to compare the viscosity of natural and synthetic motor oils).
e) The resources necessary to complete the project should be available and inexpensive.

f) There must be at least one experimental solution that can be completed in one lab period.

Topics for projects were gleaned from old labs, The Physics Teacher Journal and a variety of web sites (e.g. 1-5). Using these sources as a starting point, projects were developed and tested by a second year summer student to ensure that they were achievable given the time and resources.

The projects section of the course was extremely well received. Students suggested a number of different approaches to their experimental problems and data analysis and showed much more ownership of their work. For example, one group that was determining the viscosity of motor oils located manufacturer's data on the web. They found that their data was similar but that the manufacturer's error bars were larger, and were able to critically evaluate why.

3. Teaching Assistant (TA) manual

Since TAs largely run this course, it is important that they understand the philosophy and are given guidelines to ensure consistent implementation. Explaining the objectives of the course to the TAs also encourages them to "buy into" the philosophy, making the course much more successful. A TA manual was prepared which explained the course philosophy and outlined the marking scheme. Sample lecture notes for the tutorial labs, sample project reports, and hints for each of the projects also were included in the manual. TAs were brought together at the beginning of the year for a presentation of this material and regular feedback was obtained as the course progressed.

4. Assessment of Students

The major part of the grade for this course is based on formal reports written for the breadth and project labs. With the exception of the project lab report, these were done independently by each student. Formal reports are marked for content and presentation as shown in the "Checklist for Markers" (Figure 2). The checklist illustrates that the content portion of the mark focuses on data analysis and interpretation, while the presentation portion emphasises clear communication of technical material. Many students have difficulty with the transition from the writing style they learn in high school to the technical style used in engineering. The report writing guide and example report in the manual provide them with a brief guide to technical report writing. The checklist shown in Figure 2 is returned with each marked report to provide students with helpful feedback.

Checklist for Markers:

In addition to written comments on the formal labs themselves, these sheets serve as a guideline to students for areas that need improvement.

Student Name_________ Experiment # ____ Overall Mark__/10

Content Mark __/5

	Needs work ✔
Understanding of concepts	
Quality of data analysis	
Understanding of error calculations	
Explanation and interpretations of results	
Quality of discussion and answers to questions	

Presentation Mark __/5

	Needs work
Written English, grammar and spelling.	
Clear, concise descriptions	
Formal/technical language.	
Past tense for procedures and results.	
No 'chatty' or 'friendly' statements.	
************************************	**********
Title section complete.	
Abstract summarizes experiment and findings.	
Introduction states purpose and summarizes background.	
One of every type of calculation, no more than 3 lines long and starting with an algebraic expression.	
Significant figures correct? Values and errors have same number of decimal places?	
All variables defined.	
Does discussion answer: Did you find what you expected? How do your results compare with others? Major error sources?	
************************************	**********
Figures and tables numbered?	
Figures and tables referred to in the text?	
Figures and tables all have captions?	
Tables have column headings with units in parentheses	
Table columns aligned, with neat borders	
Graphs have 'real' titles (not just x versus y)	
Graphs properly labelled with units, clear font size	
Axis scales on graphs appropriate?	
Equations for trendlines on graphs with correct variable names? (not just x and y)	

Figure 2: Formal report evaluation

5. Course Evaluation

We have actively sought comments from the TA's and students to help judge the success of the course and to enable us to make refinements for the second year. Overall feedback has been positive, and we have used negative comments as the basis for improvements. Students were surveyed in the last week of each term, and asked to assign a rating of 1(not much) to 5(a lot) to a number of questions. The 4 central questions were:

- Did you gain basic laboratory and measurement skills?

- Did you develop data analysis and interpretation skills?
- Did you gain an understanding of experimental design?
- Did your ability to write and create a technical document develop or improve?

Over 60% of the students surveyed answered these questions with a rating of 4 or above. Amongst the positive comments received were the following:

- The TAs seemed to enjoy what they were doing, which made the experiments much more fun to do.
- Coming up with an experimental design was surprisingly challenging. Very worthwhile.
- Project lab was good because it was ours to pick and ours to figure out.
- Enjoyed learning error analysis.

Negative comments included:

- Still confused about error analysis.
- Error analysis takes too long.
- Too much time spent writing formal reports.
- Language problem with some TAs

We continue to invest considerable time and effort to address the concerns raised by the students in the survey. The following illustrate some of the changes made to date:

- We believe that more practice with error analysis will reduce the time spent writing up the lab, therefore a 'self-help' error analysis guide and assignment was added. This is assigned the first day of term and completed during Module 1 (Module 1 runs in the first two weeks of the term and has no assignments).
- There is now increased emphasis on working through the error analysis in the lab. This reduces the time spent doing the error analysis outside class and enables the student to ask questions of the TA.
- Some of the labs were simplified and any repetition was removed, in order to reduce the time required analysing data and completing formal reports.
- We have introduced an extensive web page that provides additional helpful organisational and technical information. A website 'current notices' board will be used to keep students up to date.

A number of these changes were implemented in the winter term, leading to fewer negative comments in the winter term survey.

Finally, we had comments from students indicating that the enthusiasm, ability to communicate and preparedness of the TAs had a definite impact on the quality of their experience. The preparation and support we give to the TAs will be a priority for next year. We are also considering offering to the students a number of optional tutorials on report writing and error analysis to be held at the beginning of each term.

6. Conclusions

In spite of some relatively minor problems, student and TA response has indicated that the Module 2 (experimentation) part of APSC100 is a significant improvement over earlier physics and chemistry labs that were associated with lecture courses. The combination of an introductory data/error analysis assignment, tutorial labs and breadth labs was sufficient to prepare students to design, complete and analyse their own experiments. The students' success with the experiment projects, and the diversity of solutions that they suggested, provide evidence that the course achieved the goal of helping the students learn about experimentation.

7. References

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