Using Broad-Disciplinary Laboratories to Teach Electric Circuits to First Year Students While Introducing Design and Professional Lab Practices

Cyrus Shafai
Electrical and Computer Engineering, University of Manitoba, Winnipeg, Manitoba, Canada
Cyrus.Shafai@umanitoba.ca

Abstract — It is possible to engage first year students to learn the history and applications of electrical systems in various disciplines from power systems, wireless systems, control, digital systems, biomedical, and micro-sensors though laboratories that emphasize design and expect professionalism. Teaching electrical systems starting with the traditional electric circuits first approach provides little motivation for first year engineering students. Our approach has been to complement lectures in electrical theory with a sequence of laboratories that focus on upper level electrical systems specialties. Laboratory design projects start with a discussion of historical and modern application of the presented technologies. This paper discusses some of the challenges faced and solutions implemented to enable the application of the broad-disciplinary laboratories. Professional lab practices have been introduced with the qualitative assessment of student designs and the expectation that they maintain cleanliness of the laboratory and supply inventory. We have found that TAs are more comfortable (and more critical) in their critique of student designs when assessment is done using verbal quality indicators in place of simple numerical assignment. Accordingly, students make greater effort towards quality lab practices, as opposed to only finding the numerical solutions. We have further observed that students will meticulously return the laboratory to its initial state, if they were required at the outset to source supplies themselves, as opposed being given them.

Keywords: electric circuit, electronic device, laboratory-centered, discovery based learning, group learning, professional practices.

1. INTRODUCTION

The teaching of electrical systems to engineering students traditionally is done by first giving instruction in the subject of electric circuits. This involves rigorous problem solving and laboratories that focus on the various analysis theorems. This education is followed by exposure to electrical systems in later courses. However, this approach is unsuitable for programs where students are in a common first year Engineering core where only one course is assigned to the electrical subject area. Students often lack motivation, particularly students focused on a non-electrical or computer engineering pathway. In addition, this approach faces considerable challenges when teaching to first year students, due to their weak mathematics skills and immaturity in visualizing the abstract topology of circuit problems.

The difficulty in teaching circuit theory, with its mathematical abstractions, to beginning engineering students has been recognized by many. In [1], several factors were discussed that caused difficulty to engineering students from outside electrical and computer engineering (ECE). These included lack of interest, a high level of abstract thinking required, and the many varied topics covered.

In [2], we presented a laboratory-centered approach to introduce engineering students to electric circuits and devices. This was undertaken in the first year, common Engineering core, course ENG 1450 Introduction to Electrical and Computer Engineering at the University of Manitoba. In ENG 1450 we implemented a hands-on approach to electrical systems education. Laboratories projects were developed, with many offering open-ended designs. The design projects required students to explore and construct different types of electrical systems, including motors, communication systems, medical instrumentation, digital systems, and electrical systems using MEMS based sensors. This approach was selected following the efforts of others who have shown that an interactive approach to learning can benefit student retention and understanding [3,4].

This approach has complemented lectures in electrical theory with the design project laboratories. By focusing laboratories projects on upper level electrical systems specialties (cell phone communication, power systems, biomedical circuits, etc.), student motivation is kept high.
In addition, laboratory design projects start with a discussion of historical and modern application of the presented technologies. We have found that this approach provides a strong motivational component to students, especially those who are not inclined to continue in the ECE subject area. This has been observed through increased student engagement and inquiry about advanced concepts presented, as well as a significant increase in ECE enrollment.

Our efforts have shown that it is possible to engage first year students to learn the history and modern applications of disciplines from power systems, wireless systems, control, digital systems, biomedical, and MEMS though labs that emphasize design and expect professionalism. Over the past two years we have expanded our efforts to introduce professional lab practices and qualitative assessment of student design work. This paper will discuss these efforts and the resulting benefits to student education.

2. QUALITATIVE DESIGN ASSESSMENT

A challenged in the implementation of design project laboratories is in their assessment. Grading often involves assessing more than simply numerical results. Additional factors to be considered by professors and instructors are often non-quantitative such as teamwork, quality of construction, and planning.

In the implementation of ENG 1450, professors are required to provide the laboratory historical and scientific introductions. However, laboratory grading is undertaken by graduate student teaching assistants (TAs). TAs do not possess the depth of experience of professors, and very often many TAs are new to the course each term. Accordingly, TAs have difficulty in non-quantitative assessment of student design work.

An example of a design effort in the ENG 1450 course is the construction of a self-leveling platform (Fig. 1) using MEMS inertial sensors. As can be seen from the figure, students must spend considerable effort in constructing a structural frame from cardboard using tape, which then holds the electronic components together. TAs can easily assess the ability of the platform to prevent an object on it from falling when the platform is tilted, however, they have difficulty assigning a grade to the construction of the platform itself. More often than not, TAs have the tendency to give a high numerical grade to any design that works.

The solution that was found was to have the TAs give a verbal grade to the work. That is to say, assign an adjective to assess the quality of the construction of the design, the quality of the wiring in the circuit, as well as the teamwork between group members. The adjectives selected were: Functional – Well Built – Outstanding. Additional grades assigned to the lab report grade for these terms were: Functional 0% increase to lab grade, Well Built 17% increase to lab grade, Outstanding 33% increase to lab grade.

Table 1: Grade assessment – numerical vs. verbal.

<table>
<thead>
<tr>
<th>Lab #</th>
<th>% Functional</th>
<th>% Well Built</th>
<th>% Outstanding</th>
<th>Final Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab 3</td>
<td>13%</td>
<td>35%</td>
<td>39%</td>
<td>74%</td>
</tr>
<tr>
<td>Lab 4</td>
<td>12.27%</td>
<td>44.09%</td>
<td>37.73%</td>
<td>78.02%</td>
</tr>
<tr>
<td>Lab 5</td>
<td>10.91%</td>
<td>32.73%</td>
<td>43.18%</td>
<td>66.11%</td>
</tr>
<tr>
<td>Lab 7</td>
<td>9.09%</td>
<td>30.91%</td>
<td>45.91%</td>
<td>79.74%</td>
</tr>
<tr>
<td>Lab 9</td>
<td>21.82%</td>
<td>28.18%</td>
<td>35.45%</td>
<td>70.08%</td>
</tr>
<tr>
<td>Average</td>
<td>13%</td>
<td>35%</td>
<td>39%</td>
<td>74%</td>
</tr>
</tbody>
</table>

It was found that TA application of this verbal assessment allowed them to be more critical than if they used standard numerical assessment grading. Table 1 shows a comparison of the TA assigned grades for select laboratories when only numerical assessment is given, vs. verbal assessment. We can see that verbal assignment of grades resulted in the TAs being more critical in their assessment of student work. This achieved the desired effect of reducing the average grade for this set of successful labs from an average of 87% to 74%.
3. PROFESSIONAL LAB PRACTICES

The undergraduate laboratory experience is essential to the training of engineering students. Laboratories provide students with hands-on experience in the construction of apparatus, and importantly in the use of instrumentation. Commonly group work is a component of laboratory education, with many undergraduate labs undertaken in groups of 2 or 3, and sometimes more for in the case of Design courses.

The laboratory is also where students learn and practice professional practice skills, which they will take into the workplace after their engineering education. It is then important that attention is paid to the development of professional practice skills during undergraduate laboratories.

Depending on the course, professional practice skills maybe emphasized specifically, and/or the exposure may be gained by a subtle approach. The latter case, that of a subtle approach, is repeated in a majority of undergraduate laboratories to develop professional practice skills. Some examples of individual and group professional practice skills include (many of these skills are interrelated):

**Individual skills:***

- Stress management
  - Developing a positive focus to solve complex and new tasks
  - Stress reduction via time management
- Time management
  - Sub-dividing complex tasks
  - Avoid distractions
- Development of work ethic
  - Organizational skills
  - Take initiative for sub-tasks
  - Take pride in your work
- Confidence
  - Gained through familiarity with common tasks and instrumentation
  - Completion of sub-tasks builds confidence
- Safety
  - Knowledge of dangers and their avoidance
  - Cleanliness/organization of workplace
- Inventory skills
  - Sourcing and returning of supplies

**Group skills:**

- Teamwork

- Divide tasks amongst other group members
- Conflict management
  - Different group members may offer differing approaches
- Giving feedback to colleagues
  - Teaching group members and critiquing work
- Gender equality
  - Working with members of the opposite sex, respect of opinions and knowledge
- Integration of others
  - Based on culture, manner of dress, opinions, language skills, age, etc.
  - Build respect, patience, rapport with others, learn the importance of humor, etc.
- Workplace etiquette
  - Respectful language, respect of personal space, etc.

The laboratories are undertaken by students formed in groups of 4, and are designed to develop many of the various professional practice skills. With the course taken in 1st year, students bring a variety of interests to the group based on their future interest in engineering discipline (civil, electrical, computer, mechanical, biosystems). Accordingly, students bring a variety of skills and background interests into the group. This fact builds many group professional practice skills.

Over the past two years, emphasis has been on two methodologies for developing professional practice.

3.1. Division of Work

Many laboratories now include independent sub-tasks. If attempted together by 1 student, the laboratory would be difficult to complete in the allowed time. Rather, students must divide the sub-tasks amongst each other. This division is decided by the group members themselves. At various times during the lab, some labs require merging of two or more, sub-tasks. This requires coordination of completion time between sub-groups, as well as discussion and pre-planning of construction of each sub-task to allow for their mutual integration.

For example, the self-leveling platform of Fig. 1 requires students to divide themselves into sub-groups. One group determines how to construct the electronic control circuit for the platform. The other group constructs the platform itself. After completion of both tasks separately, they are assembled together for final testing.

Another example is laboratory 10 of the ENG 1450 course, which requires the construction of two independent circuit types. First, an 8-bit shift register fed by an optical input and with optical display of the register
8-bit output. Second, two 4-bit combinational logic circuits must be constructed to turn on a light if their output is true. These two sub-tasks are independently built by the students, who divide themselves into two sub-groups of 2 students each. After completion of each task, the two separate sub-tasks are joined together so that each 4-bit combination logic circuit interrogates 4 of the 8 bits of the shift register (4 low bits, and 4 high bits).

3.2. Inventory and Workplace Cleanliness

This year effort was placed to develop skills in workplace cleanliness and inventory.

Pre-locating lab supplies:

It was initially hypothesized that these skills would be best developed by localizing all equipment needed for that day’s lab in a specific area of the room. This was done by having the TAs gather needed supplies (electronic components such as resistors, lights, IC chips, etc.) from the main inventory cabinets, and place them on a table in a specific location in the room. Additionally, to “encourage” students to clean up, a mark was given for proper return of supplies to this table.

Over the course of a 6 labs, it was found that while students returned the supplies to this table, they were haphazardly discarded onto this table. Typically, at the completion of the lab the table looked like a garbage pile, covered with randomly placed electronic components, wires and garbage (pieces of cardboard, tape, etc.) remaining after they constructed their projects. A new strategy was clearly needed.

No effort taken to pre-locate lab supplies:

It was then decided to try not to help the students by pre-selecting inventory. Rather all supplies were kept in the main inventory cabinets in the room, which were carefully labeled (i.e. a separate bin was available for each type of resistor or IC chip). This required students to spend considerable time at the start of each lab to carefully find and source supplies from many separate individual storage bins. We had initially hypothesized that this would lead to a possible disaster, resulting in our main inventory bins being messed up.

As it turned out, however, this was a great success. By requiring the students to painstakingly source each and every electronic component, they consequently leant the correct location of every electronic component. They then commonly returned each component into their proper location after each laboratory.

In addition, this accelerated student work slightly in subsequent labs. Since they knew where every component was located, they could more quickly source supplies when needed.

Cleaning the work area:

An accidental discovery occurred when the janitors cleaned the floors one day. The janitors carefully placed all chairs onto the tables. It seems the students thought this was what was expected of them. And so instead of chairs randomly strewn around after each lab, students started carefully placing their chairs onto the tables after lab clean-up.

The conclusion that can be taken from this accidental discovery was that if a laboratory starts in a properly maintained manner, students are more inclined to clean their space back to the initial condition. This is something we knew as professors already, however, we were surprised how strong and immediate the effect was on students.

Acknowledgements

The author would like to acknowledge the other professors who have taught this course over the past 5 years. They include Drs. B. Kordi, A. Gole, A. Major, J. Cai, S. Sherif, and D. Oliver.

References


