Know your Lab Stuff: Laboratory Proficiency Exam for an Introductory Circuits Class

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Abstract

Engineering 60 *Electrical Networks* is an introductory class in circuit analysis and design for sophomore engineers at the University of San Diego (USD). The theory in lecture is accompanied by three hours of lab each week. This lab is the first time that engineering students have the opportunity to use basic electrical engineering equipment such as an oscilloscope, a multimeter, a function generator, and a breadboard. One of the primary goals of Engr 60 is to have the students leave the semester with proficiency in all of this equipment. To insure that students are achieving this goal, a laboratory proficiency exam was designed by a junior electrical engineering major. Although students routinely keep a laboratory notebook and do several formal reports during the semester, we decided that a laboratory experience was the best way to gauge a students hands-on laboratory skills. The laboratory skills test is comprised of six different modules. Together, they require proficiency in all the equipment that a student in an introductory circuits class might need. In addition, some of the modules require theoretical knowledge. A group of electrical engineering juniors volunteered to do initial testing of these modules. Feedback from these trials was used to improve the modules. Following this, students in the Engr 60 class at the end of the Spring 2001 semester performed these modules as an extra credit option. Each student performed one randomly chosen module. Response to the modules was enthusiastic in terms of the numbers of students participating as well as their assessment of its usefulness. The modules and student response to them will be discussed in this paper.

Introduction

A crucial aspect of education is assessment and evaluation. In a lecture-based class, this is determined most often by a written test. In a lab, on the other hand, tests are usually not given. Some of the most valuable tools that a student of electrical engineering must acquire are purely manual and can not be tested anywhere but in the lab. One could rationalize that completing the labs means that students have acquired these skills. In other words, they could not have gotten through the lab with a passing grade without working with the equipment in an efficient manner. However, when working in groups, the learning curve has a tendency to become lopsided. Even in groups of only two, one person may get left out of the activity despite the professor's efforts to encourage everyone to fully participate. As a result, a few people at the end of the semester may not know their way around the laboratory well enough to succeed in future courses.

Although students routinely keep a laboratory notebook and do several formal reports during the semester, we decided that a laboratory experience was the best way to gauge a student's hands-on laboratory skills. Thus, a laboratory proficiency exam was designed by a junior electrical engineering major. The exam was designed to provide the instructor with some feedback at the end of the semester as to which techniques students are adept at, and which need to be further stressed. Also, if the students know that they will be eventually tested on the lab equipment, they will have more incentive to actively participate in lab.

A literature search revealed some related work in this area which was helpful in designing our exam. John G. Webster[1,2] at the University of Wisconsin described his "bench exams" in the *IEEE Transactions on Education*. These "bench exams" were used for a three-course sequence of required circuits laboratories with good results. Overall, our goals and Dr. Webster's were similar. His paper gave us a general outline on how these objectives could be carried out. One particular idea that we received from him was the idea of random sampling each of the modules. Instead of attempting to create one exam that covers all of the learning objectives, separate modules were designed which together encompass all of the objectives. Dr. Webster distributed random modules to each of his students. As a result, the students must prepare for all of the objectives and are not required to spend hours in the laboratory during the exam.

Because the instructor has more knowledge and experience in the subject than the students, it often makes it difficult for him or her to gauge how challenging a test will be. Thus, having student help in the design process is beneficial. The benefits of such a two-tiered approach have been previously demonstrated.[3,4] A student who has recently taken the class is closer to the tribulations that the students in the class are dealing with. As a result, the student can help the professor focus on the subject matter that beginning student find more difficult. In addition, a student will see different teaching approaches for different topics, which promote more efficient learning. Once the semester ends, hopefully all of the concepts have been learned. As most engineering career's progress, intuition is developed and it is forgotten why there was once a mental block with certain things and not others, or what teaching methods helped to break these blocks. This is part of what makes a two-tiered learning system so valuable.

Course Structure and Logistics

Engineering 60 *Electrical Networks* is a required introductory course in circuit analysis and design for all engineering majors at the University of San Diego (USD). This includes electrical engineers and industrial and systems engineers. Typically taken in the sophomore year, the course meets for three hours of lecture per week and three hours of lab with prerequisites of calculus and physics. This is the first time that the students have done any serious work with typical electrical engineering lab equipment, including an oscilloscope, function generator, DC power supply, and breadboard. In the Spring of 2001, there were ten lab experiments, which were all coordinated with the theory in lecture. Recent typical class sizes have been about thirty students divided into two laboratory sections. The same instructor usually teaches lecture and laboratory. Lab experiments are performed in teams of two students with rotating instructor-assigned partners. For the EE majors, this course is immediately followed by two semesters of electronics with a weekly laboratory.

The Laboratory Proficiency Exam

The laboratory proficiency exam consists of six separate modules. Each module has its own set of learning objectives. The objectives are what the student is expected to demonstrate by completing the module. The objectives for all six modules encompass the objectives for the entire semester in lab and are shown in Table 1. Each module was designed to take about twenty minutes so that the students could complete more than one in a laboratory period. Students perform the modules individually. The more modules they can complete, the more sure a teacher can be that the student has learned the proper techniques.

Table 1: Objectives for the Engr 60 Lab Proficiency Exam

1. Thévenin Equivalence
   - Demonstrate an understanding of what a Thévenin equivalent is.
   - Find the Thévenin equivalent for a resistive network experimentally.
   - Use the multimeter, the decade resistor, and *Excel*.

2. Circuit Building
   - Show efficiency in building a circuit using a breadboard.
   - Use the multimeter and DC power supply.

3. Voltmeter vs. Ammeter
   - Demonstrate how to correctly measure voltage and current with a digital multimeter.
   - Use the multimeter and DC power supply.

4. Signal Generation
   - Generate a specific signal using the function generator.
   - Set the oscilloscope appropriately so that a signal can be viewed and different aspects of the wave, such as frequency, can be read directly.
   - Use both channels of an oscilloscope.

5. Finding the Time Constant
   - Generate a square wave with the function generator.
   - Use the oscilloscope markers to measure the time constant of an RC circuit.

6. Inverting Amplifier
   - Build an inverting amplifier using an OpAmp.
   - Measure the DC gain (Vout/Vin) of an inverting amplifier using the multimeter.
   - Demonstrate breadboard skills.

Testing with Juniors

After the test was designed, six students from a junior level electronics class volunteered to test the modules. Our goal was to get feedback and make alterations prior to the real testing with the sophomores. We focused on three modules which seemed to be the most complex and thus we were worried about their time constraints: "Thévenin Equivalent" (1), "Finding the Time Constant"(5), and "Inverting Amplifier"(6). We hoped the modules would take approximately twenty minutes for the sophomores, and therefore even less time for the more advanced students. These modules did prove to be slightly too time consuming and/or complex. For the Thévenin equivalent module, the times were 15, 17, and 25 minutes. For the inverting amplifier, the times were 20 and 24 minutes. For the time constant module, the times were 20 and 8 minutes. As a result of this testing, a few hints were given on how to set up the Excel table for "Thévenin Equivalent"(1) and about rise time and fall time for "Finding the Time Constant"(5). Also, we decided to provide the OpAmps at the stations for "Inverting Amplifier"(6).

Testing with Sophomores

In Spring 2001, students in the Engr 60 class performed these modules as an extra credit option during the last laboratory period of the semester. Each student was required to perform one module. They were given the set of exam objectives in Table 1 about a week prior to the exam and told that they would be given one of the modules at random. Therefore, they could go into the lab and study for it like any other test. Two separate types of copies of the procedure were made for each module. Each of the six modules was on a separate sheet of paper. One copy was for the students, which they did not receive until the beginning of the exam. It provided them with the objectives and the procedure. The other copy was for the teacher and TA. This included the objectives, procedure, expected outcome of the experiment, and necessary setup by the TA prior to the student engagement. The students were given a handout that included the objectives as well as procedures as outlined below.

> The Engr 60 Lab Proficiency Exam is designed to provide an opportunity for you to demonstrate the laboratory skills that you have developed during Engr 60. The exam consists of 6 modules whose objectives are listed here. Each module is designed to take no more than 20 minutes. This semester, taking the lab proficiency exam will be an extra credit option. If you choose to do it, you must
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> - Inform Dr. Lord by email that you intend to do so
> - Complete one module during your scheduled lab time (note that you will be randomly assigned to a module)
> - Complete a brief evaluation of the module
>
> You may bring your lab notebook with you to the exam. You will receive a grade for your performance of the module which will be added to your laboratory grade for Engr 60.

The modules were numbered to facilitate organization for the professor and the TA. Students were randomly assigned to a module that they performed independently. Time was kept for each student, but because this was a trial run, there was not a time limit. Students were not expected to need help during the testing, but help was provided in a few occasions. Full credit was given if the module was completed successfully without any help. Immediately following the completion of a module, the students were asked to fill out the anonymous evaluation shown in Table 2.

Table 2: Student evaluation form

Which module did you perform (circle one): 1 2 3 4 5 6
How long did it take you to complete the module: ______________________
Should the lab proficiency exam be a required part Engr 60? (circle one) YES NO
Overall, how difficult did you find this module? (circle one)
Very Difficult Somewhat Difficult Average Somewhat Easy Very Easy
Overall, how clear did you find the instructions for this module? (circle one)
Very Clear Somewhat Clear Average Somewhat confusing Very Confusing
Do you feel that your performance of this module is a good reflection of the lab skills that you have developed in Engr 60? (circle one) YES NO
Briefly explain your Yes or No answer.

Evaluation by Students

One measure of student interest in this proficiency exam is that 23 out of 33 (70%) of the students in the class chose to attempt it. Tables 3 and 4 summarize the students' response regarding the difficulty and clarity of the exam based on the evaluation forms. In addition, of those responding, 75% said that this lab proficiency exam should be a required part of Engr 60 while 25% said it should not.

Table 3: Student Rating of Difficulty of Lab Proficiency Exam

Very Difficult	0%
Somewhat Difficult	17%
Average	48%
Somewhat Easy	22%
Very Easy	13%

Table 4: Student Rating of Clarity of Lab Proficiency Exam

Very Clear	70%
Somewhat Clear	13%
Average	13%
Somewhat Confusing	4%
Very Confusing	0%

Perhaps the most significant question asked on the student evaluation was, "Do you feel that your performance of this module is a good reflection of the lab skills that you developed?" Of the 23 students who chose to take the exam, 18 responded "yes". A few helpful comments were given here as well. Some of the students that answered yes explained:

> "It required several of the methods that I learned"
> "The skills I needed in this lab are exactly what I learned in lab 5"
> "I think the labs, and being able to act the steps out best shows my understanding."

"Without having lab I would have not been able to measure the voltage from the sources before, check the resistor values, or measure the Vout of the circuit."
"I felt confident in what I was doing the whole time and didn't have to refer to my lab manual at all."
"Because the skills required reflect those needed to pass Engr. 60 but my performance lacked…"

The students that answered "no" to this question generally responded by saying that it was too easy. A few of these comments were:

"The skills that I have learned in lab far exceed what was asked in the lab proficiency exam."
"Too easy, although there should be a lab exam at the end of the semester."
"Not all of my strong points are with this one lab, but because of this lab I realize what I need to work on."

Evaluation by Instructor

Most of the students who attempted the proficiency exam did well on it, although they took much longer than we were expecting, finishing in an average of thirty-seven minutes with a range of 5 minutes to one hour. Only thirteen percent of the students finished within the designed 20 minutes. The average score was 4.23 out of 5 with the median being 4.50 and the range being 1 to 5. Forty-six percent of the students were able to complete the module correctly without help, and got a score of 5. Another 33% of the students asked for a small amount of help but then were able to complete the module correctly. They got a 4 or a 4.5 depending on the errors. If there were several problems, they got a 3. For example on Module 6, a student who made all connections correctly but did not establish a common ground received a 4.5 while a student who had made all connections correctly but placed the OpAmp inappropriately on the breadboard received a 4 and a student who had incorrectly placed the OpAmp and forgot to put a ground at pin 3 received a 3. Only 1 student was unable to complete a module satisfactorily after 1 hour and some help. That student had missed the laboratory experiment that covered the material in this module and admitted that he had not really learned it.

Overall, the instructors were happy with the results of the evaluation. Student responses indicated that they genuinely felt this sort of exam is beneficial, even if not in the manner that this particular one was presented. Some of the modules are significantly simpler than others. If it were to be implemented as mandatory, there should probably be some adjustment so that each student has an equal amount of work. This could be accomplished by combining some of the easier modules such as the "Voltmeter vs. Ammeter"(3) or the "Signal Generation"(4) while leaving other modules as a single task such as the "Thévenin Equivalent"(1) and the "Inverting Amplifier"(6).

Perhaps the greatest problems were the twenty-minute time limit and the difficulty in differentiating which students were most equipped with the skills described in the objectives. A few things can be done to address these issues. A time constraint of about 30 minutes may be more reasonable. Also, when the exam is implemented as a mandatory part of the class, it will not simply be extra credit. This will give the students incentive to prepare for it like any other test. A time constraint and the pressure of a mandatory grade should definitely decrease the amount of time to take the exam. This will help in gauging the range of student proficiency because only the better skilled students will finish in the required amount of time.

Conclusions

A laboratory proficiency exam for a sophomore introductory circuits exam was designed by a junior electrical engineer at USD. After preliminary testing with junior EEs, sophomores performed the exam as an extra credit option. Seventy percent of the sophomores chose to do the exam. Student performance on the exam was acceptable but time consuming. Student response to the exam was promising. The majority of students recommended including this exam as a required part of the course next time.

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