Spring 2014

Teaching Electrical Circuits Using a Virtual Lab

Md Zahidur Rahman
CUNY La Guardia Community College

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Mathematics, Engineering, and Computer Science

Abstract

This paper describes an engineering professor's first attempt at designing and implementing a scholarship of teaching and learning (SoTL) study in a basic electrical circuits course at LaGuardia Community College. Inspired by his understanding of Lee Shulman's (2005) concept of "signature pedagogy" and Eric Mazur's emphasis on student-centered approaches (2009, November 12), and aware that his students did not always understand the electrical theories and concepts presented in class, the author decided to change his pedagogy. He explains his efforts to train his students to think as engineers, first by making them more "visible" and "accountable" in the classroom, and second, by offering them hands-on practice through the use of Multisim, a free and open source simulation software. The implications for the teaching of the basic electrical circuits course are offered as well as the author's reflection on his own growth as a teacher and his developing understanding of the scholarship of teaching and learning.

Keywords: *Multisim, simulation, software, engineering, and electrical circuits*

Introduction

In the early 1990s, when I studied for my Bachelor of Science in Electrical Engineering at Bangladesh University of Engineering and Technology (BUET), Dhaka, most of the electrical engineering courses included a 1-or 2- credit laboratory. These labs in courses such as Electrical Circuits, Electronics, Electrical Machines, and Electrical Measurement and Instrumentation complemented the 3-credit lecture in electrical theories and concepts. Instructors usually discussed theories and presented some problems and solutions; they also gave us problems to work on in class and circulated around the room as we worked independently. In the lab, we performed hands-on experiments to test and verify the theories and concepts we had learned in class. Working in groups of two or three students, we performed experiments using authentic electrical tools such as voltmeters, ammeters, multimeters, and rheostats to design, build, and test electrical circuits.

I came to the United States in 1999 to continue my studies in engineering. I was surprised to find that professors did not provide many opportunities for the hands-on experimenting and independent problem-solving that I had experienced in Bangladesh. Instead, they primarily lectured and demonstrated solutions to problems on the blackboard, a pedagogical approach I adopted as a teacher at City College, and later at LaGuardia Community College. Standing at the blackboard, I lectured and wrote out solutions to problems, stopping periodically to ask my students if they had any questions. They rarely did, and I assumed they understood what I was doing. Occasionally, I gave students a problem to solve independently in class. I walked around the room observing students as they worked, but I did not interact with them very much.

I joined LaGuardia Community College's Carnegie Seminar on the Scholarship of Teaching and Learning (SoTL) seminar because I wanted to improve my teaching and my knowledge of SoTL. During our discussions of Lee Shulman's article, "Signature Pedagogies in the Professions" (2005), I reflected upon my own experiences in Bangladesh and in the United States. Shulman, an educational psychologist and past president of the Carnegie Foundation for the Advancement of Teaching, describes a typical engineering class as follows:

> Although the teacher faces his class when he introduces the day's topic at the beginning of the session, soon he has turned to the blackboard, his back to the students. The focal point of the pedagogy is clearly mathematical representations of physical processes. He is furiously writing equations on the board, looking back over his shoulder in the direction of the students as he asks, of no one in particular, "Are you with me?" A couple of affirmative grunts are sufficient to encourage him to continue (p. 53).

Shulman's description sounded a lot like my experience as a student in the United States and the classes I was teaching, but I was no longer sure this approach was effective. Shulman also notes that in lecture-based teaching, there is "almost no reference to the challenges of practice … [and] little sense of the tension between knowing and doing" (p. 54). Shulman's critique of the typical engineering class helped me to see that I was not meeting the goal of preparing my students to become professionals. Engineers must not only understand theories and concepts, but also devise solutions to real-life problems, test their solutions, and troubleshoot those that do not work.

Furthermore, after viewing a video of Eric Mazur (2009, November 12) engaging Harvard students in the study of physics, I realized that I needed to change the dynamic in my classes. Instead of asking "Are you with me?" and turning back to the board while students passively watched me derive solutions to problems, I learned to build in more opportunities for them to solve problems themselves during our class sessions. Now, rather than simply observing as students work and waiting for them to ask me questions, I have begun to move around the class, crouching so I can see their work, understand where they are stuck, and ask questions that help in the discovery of the solution. Additionally, I call individual students up to the board as I sit among the others. I urge them not to be afraid to try; the other students and I will help them as needed. Using these methods, I can detect confusion more clearly and offer help more quickly.

But even with these changes, I felt that my pedagogy was not adequate to prepare students for a career in engineering. "Professional education is not education for understanding alone;" writes Shulman, "it is preparation for accomplished and responsible practice in the service of others" (p. 53). In order to more fully address my pedagoical goals, I needed to provide my classes with more hands-on experiences similar to those I had had as an undergraduate student in Bangladesh.

Electrical Circuits (MAE213) is a 3-credit course required for all civil, mechanical, or electrical engineering majors. Unfortunately, this foundational course does not include a lab hour. Furthermore, due to space and financial constraints, LaGuardia students currently do not have access to an equipped electrical engineering hardware lab. Therefore, our Engineering faculty are exploring simulation software. Such "virtual labs" engage students in realistic problem-solving activities that require the application of theories and concepts learned in the classroom.

Virtual labs offer many advantages, among them powerful processing and simulation facilities, ease of use, and accuracy. Where physical labs are not available, virtual labs can provide students with useful experience (Hackworth & Stanley, 2001; Hall, 2000; Lee, Li, & Cheung, 2002). Moure, Valdés, Salaverría, & Mandado (2004), Butz, Duarte, & Miller (2006), and Swayne (2012) all note that virtual laboratories also have potential for helping students understand theoretical principles. Kollöffel and Jong (2013) studied groups of vocational engineering high school students to assess their understanding of electrical theories and concepts, and found that adding virtual lab experiences to the traditional lecture and hardware lab approach helped students learn theoretical concepts. Their research revealed that students might face some difficulties and need more time to construct, design, analyze, and verify the electrical circuits assignments using real hardware labs. Kollöffel and Jong suggest that virtual labs enable students to perform these tasks more quickly.

MATLAB and Multisim are the two simulation software packages in use at LaGuardia. Utilized for numerical computation and programming, MATLAB is a sophisticated and expensive software package often employed by professional electrical engineers. Multisim, on the other hand, is a free and comprehensive circuit analysis program that allows for the design, analysis, visualization, and simulation of electrical and electronic circuits. In addition to an extremely realistic interface, Multisim allows students to use a mouse and graphics options to create schematic diagrams. Fraga, Castro, Alves, and Franchin (2006) studied groups of college engineering students in an electrical circuits class. Using two computer simulation software programs, PSpice and Multisim, the researchers found that Multisim provided students an environment closest to a real lab. With Multisim, students can use virtual oscilloscopes, multimeters, and ammeters to develop their knowledge of electrical behavior.

Multisim engages students in realistic problem-solving; they can build simulated circuits, learn how to construct complex circuits with various components, and verify the circuit design. After building their simulated circuit, students "turn on the electricity" using Multisim's virtual "switch." With this last step, students can immediately see if the circuit they have designed will function as they planned. If it doesn't, they can continue working on the problem, and utilize their knowledge of electrical theories and concepts to troubleshoot design issues and create alternatives until they arrive at the correct solution to the problem.

The Electrical Circuits course proved to be an ideal environment in which to begin exploring the pedagogical advantages of Multisim. The curriculum focuses on basic components of electrical theory and practice such as resistors, capacitors, and inductors, and reinforces fundamental mathematical and electrical concepts needed for designing and analyzing electrical circuits. Using Multisim allows my students to put their knowledge of theory into practice using a realistic, albeit simulated, environment.

Preliminary Investigation of Multisim

In the informal study of my Spring I 2013 Electrical Circuits course described below, I examined the extent to which Multisim helped 17 undergraduate students (15 male and 2 female students) solve engineering problems. Three students were Civil Engineering majors, ten were Electrical Engineering majors and four were Mechanical Engineering majors. I divided the students into two groups of equal size. For the first half of the semester, the students in Group 1 worked on one project, performing all calculations and solving all circuit design problems by hand without verifying their answers or testing their solutions with Multisim. Group 2 students worked on the same assignment, but used Multisim to verify the accuracy of their calculations and test the viability of their design solutions. In the second half of the semester, the groups switched: Group 1 completed two projects using Multisim, while Group 2 completed the same two projects without using Multisim. This arrangement assured that all students would experience solving problems both ways:

1. Using only hand calculations and hand-drawn circuit designs.
2. Performing hand calculations, and then using Multisim to design, build, test, verify, and troubleshoot their solutions.

As indicated in the Project Scores table below, the median scores revealed that students who used Multisim did slightly better than students who did not.

Table 1: **Project Scores: Hand Calculation or Multism**

	Group 1 Median Score	Group 2 Median Score
Multisim	91.5	91.5
Hand calculations only	88.5	89.0
Percentage increase	3.4%	2.8%

In an effort to get a better picture of students' interactions with the software, I also asked students to respond to these three questions at the end of the semester:

1. Which topics or projects were most difficult for you?
2. Which method (hand calculation only or hand calculations and Multisim verification) better reinforced electrical theories and concepts?
3. What assignments or activities were most effective?

Eleven students concurred that using Multisim was the most difficult part of the projects. Twelve students agreed that performing the assignments with the simulation software is a better way of reinforcing electrical theories and concepts, three students believed that performing hand calculations only is more effective, and two students thought there was no difference between the two. Clearly, the majority of the students considered the mixture of hand calculation and software simulation the most effective way to complete projects and homework assignments.

Although this experiment was conducted with a small sample of 17 students, the results suggest that students do indeed benefit from the use of Multisim.[1] In a short reflection at the end of their projects, one student commented, "With the help of Multisim I was able to verify my answers and correct the one that I had wrong." Another student observed, "By doing this project I learned how to use Multisim to solve circuit problems, I also learned how beneficial it is to use Multisim. It is a very simple and quick way to check your answers for any mistakes."

Ideally, LaGuardia's engineering students should be able to test their designs of electrical circuits using authentic equipment in a well-furnished electrical engineering lab such as the one I used in Bangladesh. Based on the results of my Spring I 2013 experiment, I believe that Multisim offers a next-best solution to the problem of lack of access to realistic environments in which students can test their designs. This necessary hands-on experience brings me closer to a principal component of engineering's signature pedagogy and addresses Shulman's reminders about the importance of preparing students for their professional lives. In future semesters, I hope to continue my efforts to analyze and report upon the effect of using Multisim to help students master electrical engineering theories and concepts.

Notes

1. Both of the female students reported that using Multisim was the most difficult part of the class and noted that, for them, performing the hand calculations was more helpful in fostering understanding of electrical circuit theories and concepts, while the male students noted that Multisim provided a better way to understand the electrical theories and concepts of this course. This difference can potentially be ascribed to the assumption that males usually have more experience in dealing with various software tools and are not as intimidated by having to use software to simulate the circuit.

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