Structured Redesign of a Circuits Laboratory

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Introduction

Laboratory (lab) experiments are an inherent part of the engineering curriculum. It is a well-established principle that students learn best by hands-on experiences. The lab experiments are used to provide students with practical skills but these courses also play an important role of providing necessary engineering skills like teamwork, formal report writing and trouble-shooting (Davies 2008, Al-Bahi 2007, Krivickas and Krivickas 2007, Feisel and Rosa 2013) in addition to providing best safety practices and sensory awareness (Watai, Arthur and Brophy 2007). So it is important to keep the lab courses updated and to frequently evaluate the value proposition of these courses.

With any redesign, it is important that we set clear learning outcomes, provide an effective design to achieve those and formulate an effective way to evaluate and assess the outcomes (Davies 2008, Watai, Arthur and Brophy 2007, Edward 2002). In addition, cognitive learning should be ensured and students should be sufficiently challenged through open-ended designs in order to achieve practical skills (Edward 2002). Opportunities for social skills like team building and professional skills like formal reporting and data recording should also be provided in order to make our students effective engineers in practice (Krivickas and Krivickas 2007, Feisel and Rosa 2013, Watai, Arthur and Brophy 2007).

In the work presented here, a structured approach is taken to redesign and update The Circuit Analysis Laboratory course at our institution. The course has not been updated or revised for a number of years resulting in out-of-date equipment information in the manuals, lack of cohesion in the lecture and the lab courses, significant time spent by teaching assistants (TAs) in helping students, and frustrated students. This report discusses the nature of the course redesigned, motivations that led to the redesign, feedback received from TAs and students prior to the redesign, and tools used to bridge the gaps between lab tasks performed and learning outcomes met.

The course under consideration

The Circuit Analysis Laboratory is an undergraduate level lab course at our institution intended for electrical and computer engineering students. Historically, this particular lab course was associated with one lecture course called Circuits I that focused primarily on basic circuit analysis techniques and time-domain analysis of RLC circuits. In order to reduce the credit hour requirements, a laboratory course associated with the Circuits II course was removed. Some of the material from that lab course was integrated into other lab classes. This resulted in the lab course for Circuits I having elements from two lecture courses. There are up to ten lab sections offered every spring and fall semesters, and one lab section offered during summer, contingent upon enrollment. Each lab section has a cap of ten students for initial enrollment but up to 14 students are accommodated if needed. All lab sections taught on the main campus are conducted by teaching assistants (TAs); these teaching assistants report to a faculty lab coordinator. A total of ten lab experiments are conducted with a formal report and a final exam. The final exam has both a written theoretical portion and a practical portion in which students must independently demonstrate that they can collect and analyze data. The list of lab experiments is as follows:

- Lab safety quiz
- Basic Oscilloscope Operations
- Analog and Digital Multi-meters
- Resistive Networks and Computational Analysis
- Wheatstone Bridge
- Robot kit
    - Replaced with smaller assembly kits (options include Tesla Coil, Birthday Candle, Piano, 3D Xmas tree)
- Measurement of Capacitors
- Inductor Current-Voltage Relationship (was based on Circuits II)
    - Replaced now with Thévenin Equivalent and Maximum Power Transfer
- RMS and Average Values
- Capacitor Current-Voltage Relationship
    - Updated to remove some of the Circuits II components; conceptual information added in order to aid understanding of other Circuits II components
- Transient Analysis using Pspice (Updated to emphasize on Circuits I concepts)

Motivation

There were a number of motivations driving this redesign including lack of cohesion amongst the lab and the lecture course it was associated with, lack of make-up or review sessions, lack of connections between lab tasks and the learning outcomes, and the need of timely revisions on account of changes or updates made to some of the lab equipment.

One factor that stood out for the lab coordinator – the TAs were having a really hard time conducting two labs in particular. On further exploration, it was discovered that these labs were based on Circuits II lecture material and as a result, students did not have any understanding of the concepts in use. The students are required to take this lab when they enroll in the Circuits I lecture course. Since some of the experiments were based on the Circuits II course that students could only enroll in after successful completion of the Circuits I course, students did not understand the lab experiments that were based on Circuits II concepts. The teaching assistants covered the basics but the learning outcomes were not effectively met. In Circuits II instructors' observations, students did not recall any of the Circuits II concepts covered in the lab. The time elapsed between the lab experiments and students getting to learn the actual concepts in the lecture course could be a significant factor. The lab coordinator and the instructors involved in the lecture courses felt that creating cohesion between the lab and one lecture course would be more beneficial to students than trying to cover components from two different lecture courses.

The schedule of the labs was another concern. With the number of activities planned, there was no time left for a make-up or review lab. There were a total of 10 activities including 9 experiments and a robot kit assembly; 2 weeks were assigned to the robot kit assembly. In addition to these activities, there was a formal report and a final exam. Also, students could not actually start working on their lab experiments until they had passed the safety quiz, which typically happens in Week 2 or 3 of the semester. Due to insufficient lab time, students had to finish the lab work on their own time or, sometimes, TAs had to hold lab sessions during holidays or weekends.

A thorough review of the lab manuals, by the TAs and the lab coordinator, revealed that for some of the experiments, the tasks were either not clearly defined or students performed some of the tasks that were not analyzed or used to establish any significant conclusions. It was also determined that some of the tasks were repeated amongst different lab experiments without adding any value. Another observation was regarding the time allocated to each experiment. Each lab period is assigned 2 hours. Some of the lab experiments did not utilize the whole 2 hours and some needed more than 2 hours. So, there was a need to revise the labs to see if some of the elements could be rearranged or redesigned to utilize each lab period to maximize learning.

Finally, during last few years, some of the lab equipment and tools were updated but the lab manuals did not reflect the change. Although the TAs made students aware of the changes, that took away time and often led to confusion. As is good practice with any teaching tool, it was obvious that there was a need to update the manuals to accurately reflect the equipment and tools being used in the experiments.

Survey results

Two surveys were designed, one to get feedback from current and past students as well as a second for current and past TAs to understand the main points and determine the priorities of the redesign. The questionnaire used to survey the TAs is attached as Appendix A and the questionnaire used to survey the students is attached as Appendix B. The survey questions listed in the appendices exclude the demographic type questions that were not related to the lab redesign. The survey questions on both sets used the same topics of query but were phrased differently to get audience specific feedback. -Addition surveys over the next several semesters are planned to measure the impacts of the redesign. The results presented here are based on a limited number of responses since the redesign was undertaken only last semester. Six TAs responded to the survey, but all of these TAs had conducted the labs for at least two semesters. The number of students that responded to the survey request was 13. Some of the points discussed in the previous section were also raised by graduating seniors in their exit interviews or in-person interactions with instructors involved in the redesign process.

Following are some of the key points of the data collected from the TAs:

- Instructions to perform all tasks in the manuals were not always clearly defined.
- Details needed to use the equipment were not up-to-date for all the lab experiments.
- Most of the student teams needed significant intervention by TAs in order for them to successfully complete their tasks.
- Instructions on how the students should use the collected data to form observations or conclusions were not always clear.
- Some of the instructions included in the manuals were redundant; some instructions implied a choice of activities but availability of equipment or based on historical practices, there was no choice available. Tasks should be numbered (instead of bullet points) for convenient step-by-step procedure follow up.

Following are some of the key points of the data collected from the students:

- Half of the students were able to complete their tasks with minimal intervention from the TAs whereas the other half needed significant help from TAs.
- Instructions on how the students should use the collected data to form observations or conclusions were not always clear.
- About 40% of the students expressed that they needed more information from the lecture before they could perform some of the lab experiments.
- Most of the students expressed that they did not think the lab assignments were particularly effective in their learning process.
- Lab manuals were confusing and sometimes, even the TAs were confused.
- The robot kit should be replaces with something inexpensive or the costs should be communicated at the time of enrollment.

Elements of redesign

The process of redesign is not yet complete; the intention is to launch the fully redesigned lab in the Fall 2019 semester. In order to incorporate instructors' input, lab coordinator's input, TA feedback and student feedback, a step-wise approach was devised.

The first step was to draft a course blueprint mapping each lab to its objectives, tasks to be performed, data collected, conclusions established and learning outcomes met. A blueprint was created for each lab experiment. This tool was very helpful in identifying connection gaps between different elements of a lab. For example, some experiments had students performing tasks that did not link to any data collection or conclusions made whereas in other experiments, the tasks performed did not lead to the learning outcomes. This tool also helped in identifying repetition of tasks and presence of information without value addition. As the blueprint was being drafted, the TAs and students were surveyed and their feedback agreed with the identifications made in the blueprint.

Once the main points were established, the second step was to update the manuals for their conceptual content. This included removing redundant information, adding more theoretical and conceptual information where needed, and creating cohesion between different components of each lab experiment. The lab manuals were also updated to include the current details and operations of all the equipment and tools in use.

In the third step, a list of viable alternatives to the robot kit was created. The prime objectives of this task were cost and time. The robot kit is priced at $80 and some students thought that it was a hefty sum for a kit that was just used once and had no use for them later on. Instructors and the lab coordinator involved in the redesign project also felt that, for the learning outcome of working with printed circuit boards and learning soldering skills, there were cheaper options available and by creating a choice, students could choose projects that were fun and usable to them. Two weeks were scheduled for Robot kit assembly, so finding an alternative that met the same learning outcomes within one week was also crucial. All the alterative kits found were priced at or under $10 and can be easily assembled in one lab period thus freeing up a lab period for a make-up lab period or review.

Step four was to redesign the lab experiments that used concepts from the Circuits II lecture course. One of the lab experiments was completely redesigned from scratch using new concepts from the Circuits I lecture course whereas another lab experiment was reviewed to get rid of some of the elements from the Circuits II course while keeping a few elements that could be easily connected to the Circuits I course; more conceptual information was included in the lab manual on those elements that were kept in order to aid the student understanding. It was also made clear in the lab manual that these concepts will be covered in detail in the Circuits II course.

The final step was to make sure that all the lab experiments adhered to a two-hour lab period accounting for time needed for questions, TA intervention, and trouble-shooting etc. Most of this task was accomplished during previous steps of the redesign. For some of the labs, issues with the time limit were addressed by adding a few short tasks so that students used most of the two hours and for some others, tasks were either removed or replaced with more time-efficient tasks that still achieved the learning outcomes.

Summary

In conclusion, a redesign of the circuit analysis laboratory course is underway at our institution. The redesign was undertaken because the students, the lab coordinator, and the teaching assistants raised several concerns about the quality of the lab manuals, lack of cohesions between the lecture and the lab course leading to confusion, and scheduling issues forcing students to finish their work outside of the scheduled lab hours. A structured approach to the redesign was taken and all the key main points identified by several stakeholders were addressed. The primary areas of focus were identified as – remove Circuits II components or provide sufficient theoretical background for students to be able to understand the concept, combine some of the components of different labs with same objectives in order to provide one free sessions for make-up or review labs., and to make sure that there is a connection between objectives, tasks performed, data collected, observations made and conclusions drawn. The fully redesigned lab course will be launched in Fall semester of 2019 but some of the redesigned elements were tested during spring semester of 2019 successfully. The authors intend to continue surveying the TAs and the students in coming years to measure the success and impacts of the redesign.

References

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Appendix A: Survey for Teaching Assistants

Note: For both appendices A and B, Section 1 of the survey collected basic information about semester of teaching, academic standing and department affiliation is not included. Parentheses next to each response is the number of selections for that particular option.

2.1 Is the time allotted for Robotic Kit assembly sufficient?

- Yes (3)
- No (1)
- Not Sure (1)

2.2 Is a written manual or instruction set provided for the robotic kit assembly?

- Yes (5)
- No (0)

3.1 Only consider the laboratory manuals used during or before Spring 2019 for your feedback in the following sections.

3.2 Generally, the objectives for all labs were clearly defined & well explained in the manual.

- Strongly agree (2)
- Somewhat agree (0)
- Neither agree nor disagree (1)
- Somewhat disagree (2)
- Strongly disagree (0)

3.3 Generally, the instructions to perform all tasks in the labs were clearly explained.

- Strongly agree (1)
- Somewhat agree (1)
- Neither agree nor disagree (0)
- Somewhat disagree (3)
- Strongly disagree (0)

3.4 Generally, the details needed to use the equipment (including measurement devices) were correct and up-to-date.

- Strongly agree (1)
- Somewhat agree (2)
- Neither agree nor disagree (1)
- Somewhat disagree (1)
- Strongly disagree (0)

3.5 Generally, the student teams could perform experiments on their own with minimal intervention from TA.

- Strongly agree (0)
- Somewhat agree (2)
- Neither agree nor disagree (0)
- Somewhat disagree (3)
- Strongly disagree (0)

3.6 Generally, the instructions on how the student teams should use the collected data to report their observations/conclusions were clearly explained.

- Strongly agree (0)
- Somewhat agree (1)
- Neither agree nor disagree (0)

- Somewhat disagree (4)
- Strongly disagree (0)

3.7 Generally, the tasks performed by the student teams, data collected, and observations/conclusions reported were all in-line with the objectives defined.

- Strongly agree (0)
- Somewhat agree (2)
- Neither agree nor disagree (3)
- Somewhat disagree (0)
- Strongly disagree (0)

4.1 Generally, students did not need any information from the lecture course to perform most of the labs.

- Strongly agree (2)
- Somewhat agree (0)
- Neither agree nor disagree (0)
- Somewhat disagree (3)
- Strongly disagree (0)

4.2 If needed, students possessed sufficient conceptual background provided in the lecture (prior to them performing the lab).

- Strongly agree (0)
- Somewhat agree (3)
- Neither agree nor disagree (1)
- Somewhat disagree (1)
- Strongly disagree (0)

5.1 If you have additional comments that might help with the redesign of the Circuit I i.e. EE2101 laboratory course, please provide those here.

Appendix B: Survey for Students

Note: Section 1 of the survey collected basic information about semester of enrollment, academic standing and department affiliations etc. Parentheses next to each response is the number of selections for that particular option.

2.1 Is the time allotted for Robotic Kit assembly sufficient?

- Yes (11)
- No (1)
- Not Sure (1)

2.2 Is a written manual or instruction set provided for the robotic kit assembly?

- Yes (13)
- No (0)

2.3 Did the robot kit help you in acquiring new skills that were useful?

- Yes (7)
- Maybe (4)
- No (2)

3.1 Only consider the information provided in the laboratory manuals for your feedback in the following sections.

3.2 Generally, the objectives for all labs were clearly defined & well explained in the manual.

- Strongly agree (1)
- Somewhat agree (7)
- Neither agree nor disagree (1)
- Somewhat disagree (3)
- Strongly disagree (1)

3.3 Generally, the instructions to perform all tasks in the labs were clearly explained.

- Strongly agree (2)
- Somewhat agree (5)
- Neither agree nor disagree (0)
- Somewhat disagree (2)
- Strongly disagree (4)

3.4 Generally, the details needed to use the equipment (including measurement devices) were provided adequately in the manuals.

- Strongly agree (3)
- Somewhat agree (4)
- Neither agree nor disagree (2)
- Somewhat disagree (3)
- Strongly disagree (1)

3.5 Generally, my team could perform experiments on our own with minimal intervention from the TA.

- Strongly agree (3)
- Somewhat agree (4)
- Neither agree nor disagree (0)
- Somewhat disagree (3)
- Strongly disagree (3)

3.6 Generally, the instructions on how your team should use the collected data to report their observations/conclusions were clearly explained.

- Strongly agree (1)
- Somewhat agree (3)
- Neither agree nor disagree (2)
- Somewhat disagree (5)
- Strongly disagree (2)

3.7 Generally, the tasks performed, data collected, and observations/conclusions asked to be reported were all in-line with the objectives defined.

- Strongly agree (1)
- Somewhat agree (9)
- Neither agree nor disagree (0)
- Somewhat disagree (2)
- Strongly disagree (1)

4.1 Generally, we did not need any information from the lecture course to perform most of the labs.

- Strongly agree (1)
- Somewhat agree (7)
- Neither agree nor disagree (2)
- Somewhat disagree (3)
- Strongly disagree (0)

4.2 Any conceptual information needed from the lecture course was sufficiently covered before the lab completion.

- Strongly agree (3)
- Somewhat agree (6)
- Neither agree nor disagree (0)
- Somewhat disagree (4)
- Strongly disagree (0)

5.1 Identify the skills that you acquired via EE2101 Labs.

- Able to identify different components like resistor, capacitor, inductor (3)
- Able to identify and use appropriate measurements devices like multimeters and oscilloscope to measure required values (2)
- Able to use function generator to generate a specific frequency and magnitude of a waveform (1)
- Able to use oscilloscope to record a waveform in desired units/division
- Able to construct a circuit given a description (1)
- Able to solder components on a PCB (Robot kit lab)
- Other; please list in the text box provided (4)

5.2 How effective were the lab assignments in the learning process? A lab assignment is considered to be completion of a lab with all of its components including any calculations and analyses that might have been performed.

- Extremely effective (0)
- Very effective (1)
- Moderately effective (3)
- Slightly effective (6)

- Not effective at all (1)

5.3 How effective were the EE2101 labs in reinforcing or bettering your understanding of concepts learnt in the lecture course, EE2100?

- Extremely effective (0)
- Very effective (1)
- Moderately effective (4)
- Slightly effective (3)
- Not effective at all (3)

6.1 If you have additional comments that might help with the redesign of the Circuit I i.e. EE2101 laboratory course, please provide those here.