122nd ASEE Annual Conference & Exposition
June 14 - 17, 2015
Seattle, WA
Making Value for Society
Paper ID #11534

Teaching an Electrical Circuits Course Online

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Abstract

Due to the increased demand for MOOCs, online, flipped, and hybrid courses, it is becoming more important to identify techniques to also teach engineering courses virtually without compromising standards. This paper will present a comparison of teaching an electric systems course for non-majors online and in a face to face classroom. It will provide a motivation for this transition and examine the related literature for teaching engineering courses online. It will also detail the challenges and lessons learned in transitioning an engineering course with an integral laboratory component to an online format. In order to measure the effectiveness of the new format, the assessment will examine student mastery of the course objectives as measured by several instruments including homework, exams, quizzes, and labs. There will also be qualitative data presented in the form of student evaluations and end of course surveys. Finally, based upon the results of the analysis, recommendations will be provided for best practices in teaching circuits online.

Electrical systems is a sophomore-level introductory course in DC and AC circuits. This course covers topics such as Kirchhoff's laws, operational amplifiers, Thevenin equivalent, superposition, phasor analysis, and complex power. This course is a cornerstone in the engineering educational program for several disciplines. It has a calculus and physics pre-requisites and is typically required early in the students' academic career. A key part of mastering the concepts in this course is the integration of a laboratory component to demonstrate real world application of the concepts presented. The laboratory assignments typically involve a breadboard, resistors, capacitors, inductors, operational amplifiers, function generators, power supplies, multimeters, and oscilloscopes. Due to the required laboratory assignments, there were some challenges in transitioning from bench top lab instruments to laptop virtual instruments and these will be discussed.

The motivation for this paper was to examine the efficacy of offering an electrical systems course online compared to the face to face course. The motivation for offering an online version of the course was to meet student demand. This course is offered at a primarily undergraduate engineering school with very few summer courses. Since most students have internships, co-ops or research opportunities in the summertime and they also have a desire to get ahead in the curriculum, offering this course online was the ideal solution. However, it was extremely important that student performance in the course was not compromised by moving to the online format. This course requires the same level of interaction and quality as the on-campus courses so it cannot follow the same model as MOOCs. There must be individual student attention and the hands-on lab component must have the same rigor and meet the same learning objectives as the on-campus version. As part of the assessment, the student performance on the course objectives will be compared for the two formats. There will also be an analysis of the qualitative and quantitative metrics based upon the end of course evaluations and other surveys. Based upon the results of the analysis, the instructor will make recommendations or best practices for transitioning and engineering course with an integral lab component to an online format.

Introduction

This paper will describe the design and implementation of an online electrical circuits course offered at a small private, technical teaching four-year institution in the Midwest. According to US News and World Reports, Rose-Hulman Institute of Technology is ranked as one of the top undergraduate engineering universities in the country. The electric circuits course is a sophomore level course for non-majors that covers concepts related to DC and AC circuits. This course was offered online for two subsequent years during the summer session. The motivation was to allow students who desired to get ahead or stay on schedule in their curriculum to do so while on internships, co-ops, or research experiences. It was vital that the teaching and engagement standards were not compromised in the transition to online. This institute has a small faculty-to-student ratio and the faculty members teach all of the courses including labs. The ratio is typically 12-to-1 and the typical size of this course is 30 students. The faculty are required to actively engage with the students and have multiple office hours during the week.

This paper will present a literature review of similar engineering courses offered online at other universities and compare and contrast the implementation with the one described here. In addition, the methods will be described with respect to the objectives, outcomes, format, and assignments. The qualitative and quantitative results of student performance as measured by the assignments and end of course surveys will be compared to the on-campus format. The author has also taught this course in a face to face environment for the past 8 years. Finally, based upon the results, conclusions will be drawn and recommendations will be made for the best practices for offering an online engineering course with an integral lab component.

Literature Review

LaMeres and Plumb presented a paper to compare and contrast the online and traditional delivery of a microprocessor laboratory component for a junior-level computer systems course[1]. The lecture component of this course was achieved with a lecture capture tool and course management system. The students were required to log in and watch several lecture videos throughout the week and take quizzes on them. The lab component was achieved by using remote lab technology which teaches the same measurement techniques as the traditional hands-on experience. The students used a remote desktop connection to access the logic analyzer and could not physically see and touch the microprocessor hardware. However, there was a webcam so that the students could view and hear the basic I/O on the FreeScale platform. The students used a common computer lab at a dedicated time for the labs in order to have cell phone access to a teaching assistant for questions. In general, the assessment indicated that statistically there was no significant difference between the two delivery approaches.

Mitros et al. presented the first electronic circuits course taught online to tens of thousands of students as a MOOC via edX[2]. This model had students online 24 hours per day which allowed for real-time responses to questions. This course allowed automated grading and had to overcome the lack of in-person interactions and access to laboratory equipment. The course was a sophomore-level course on electronic design that was taught over 16 weeks. The students watched 2 hours of interactive content per week which included a self-assessment. There were also tutorials which illustrated derivations and a physical implementation of the circuit. The student also completed a problem set and lab with a web-based simulator. The course was semi-synchronous in which assignments were expected to be completed by a certain deadline. The authors stated that the learning activities promoted active learning due to the multimedia presentation. This approach followed the Socratic Method and the students were not allowed to move on until they mastered a sufficient level of mastery on the subject expertise. This approach followed a tutoring style where the student and instructor viewed a common piece of paper. There was a discussion forum where students could ask questions anytime. All of the labs were completed by experimenting with circuit design in a web-based schematic capture and simulation tool. In the online format, there was no way to evaluate the thought process since students could only enter answers to problems so partial credit was not assigned. To compensate for this, students were given three tries to arrive at the correct answers on homework and exams. The problems had randomized parameter values to focus on student learning and reduce academic misconduct. The biggest challenge with the online format was assessment of open-ended questions and maintaining engagement throughout the course.

Enriquez presented the results of a study comparing the performance of on-campus and online students in a sophomore-level circuit analysis course in a public two-year institution[3]. The content was delivered simultaneously to on-campus and online students by using tablet computers and Elluminate Live! Software. The lectures were also recorded and archived for later access. This course was part of a community college that met 3 hours per week for sixteen weeks. The sample size was 25 online students and 30 on-campus students. Both sets of students received identical homework and exams and the results indicated that there was no statistical difference in the levels of performance between the two groups. The author stated that although there are some advantages to dual mode teaching, it does place demands for extra effort on the part of the student and instructor. The on-campus students took the lab course concurrently with the lecture course while very few of the online students did. This put the online students at a disadvantage because they were not able to apply and experimentally verify the concepts learned in the lecture. For this course, the circuits lab was only required for the electrical engineering majors although they were in the same lecture course. The online students uploaded their homework through the Moodle course website. The online students came to campus to take each of the four tests as well as the final exam. The retention rates and success rates were similar for both modes of the course.

Based upon the review of the literature, it is evident that it is possible to deliver an online engineering course with some measure of success. The course described in this paper is most similar to the one offered at the community college by Enriquez. However, one key difference between this course and all three of the ones reviewed would be the active hands-on lab component thus this will be the primary focus of this presentation.

Method

In order to maintain consistency with the on-campus version of the electrical systems course, the same syllabus, calendar and lab manual were used. The only changes made were those necessary in order to deliver the course online. The on-campus course met 4 times per week including three 50-minute lectures and one 150-minute lab. The online version of the course had the video version of the same lectures delivered by using partial lecture notes. There were 3 midterms, 2 lab practical exams, 8 labs, 10 quizzes, 10 homework assignments and a final exam. Students were required to successfully complete all of the lab projects and earn an overall weighted exam average of at least 60% in order to receive a passing grade in the course. The grade was based upon the criteria in Table 1.

Table 1: Electrical Systems Course Grading Criteria

Midterms	36%
Final Exam	26%
Homework	10%
Labs and Memos	15%
Lab Practical Test	5%
Quizzes	5%

The course topics were based upon Kirchhoff's voltage law and Kirchoff's current law. The topics included node voltage method, mesh current method, superposition, source transformations, Thevenin's theorem, maximum power transfer, operational amplifiers, phasors, and AC power.

In preparation for the course, students were required to attend an in-person meeting with the instructor before the summer in order to communicate expectations and make sure they were clear on the online learning format. It was made clear to them that taking an online engineering course was much more difficult than taking one on campus. It was explained that they should expect to double the efforts they would give to the on-campus version of the course. Therefore, it was mandatory that they were focused, disciplined and were capable of independent learning. To help with this self-assessment they all had to complete the Test of Online Learning Success (ToOLS) and email the instructor the results as their first homework assignment.

The students were also required to purchase the study guide (partial lecture notes), textbook, and lab manual before leaving campus for the summer. In addition, they were required to purchase the lab kit and checkout the National Instruments myDAQ from the parts/instrument room. The lab kit included various resistors, capacitors, inductors, potentiometers, a voltage regulator, wire kit, and a breadboard. The cost of the study guide and parts kit was approximately $20. The Moodle course website was used as repository for documents, downloading and uploading assignments, asking questions and completing quizzes. MasteringEngineering by Pearson education was used for the homework assignments. Multisim and the NI myDAQ were used to complete the pre-labs and laboratory assignments. This course was semi-synchronous where the students had specific deadlines to submit assignments but could work at their own schedule throughout the week. Piazza was used for classroom discussion and questions. The instructor had one evening of office hours per week by using Google Hangout. During this hour, the instructor would screen share her desktop to answer questions and review for exams. Figure 1 provides an example of a screen share from the Google Hangout.

Lectures

The lectures were created by using Camtasia Studio with a Tablet PC and then uploaded to YouTube for the students to view. The partial lecture notes were completed as the instructor's voice was recorded demonstrating the application of the circuit analysis and design concepts.

This would be similar to the lecture format for the on-campus students although there was no opportunity to stop the instructor by asking a question. However, the online student had the additional benefit of rewinding or watching the lectures as many times as necessary. The use of the partial lecture notes also created an active learning opportunity for the students. There were also tutorial videos available on YouTube to help students review who were still struggling with certain concepts. Figure 2 provides a screenshot of the lecture video.

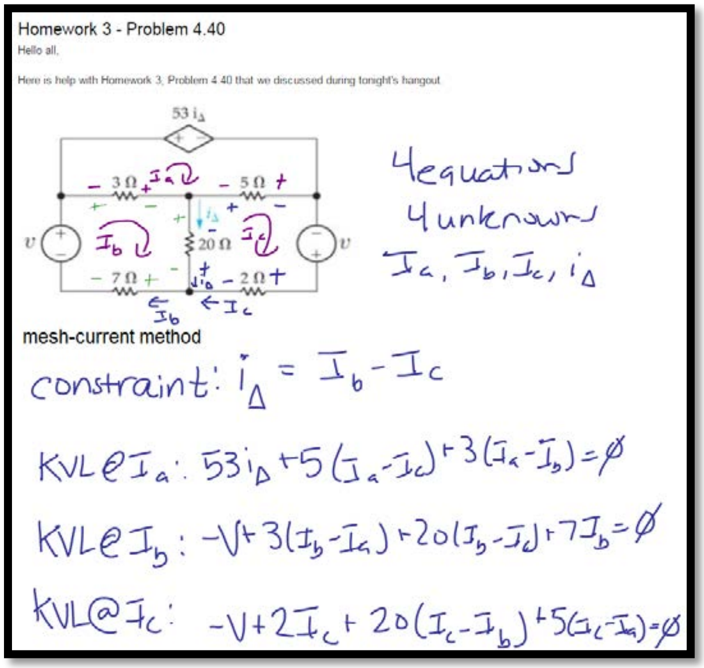


Figure 1: Google Hangout Screenshot (Homework Help)

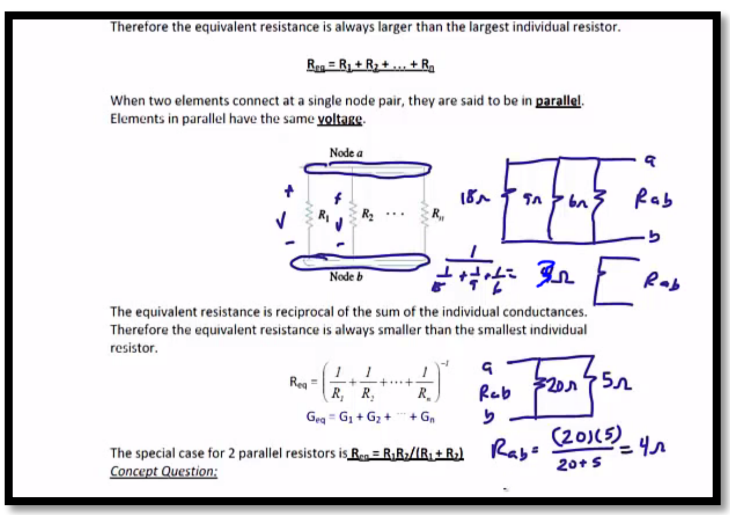


Figure 2: Circuits Lecture Video Excerpt Example[4,5]

The course study guide can be found at

and the lecture videos can be found at.

Quizzes

At the beginning of each week the students were required to complete an online quiz on Moodle. The quiz was timed, multiple choice and had randomized questions and answers. The quiz was based upon the prior week's lecture, homework, and labs. The quiz typically had 10 questions that required the student to complete short problems or answer conceptual questions. Figure 3 shows an example of a portion of a Moodle quiz.

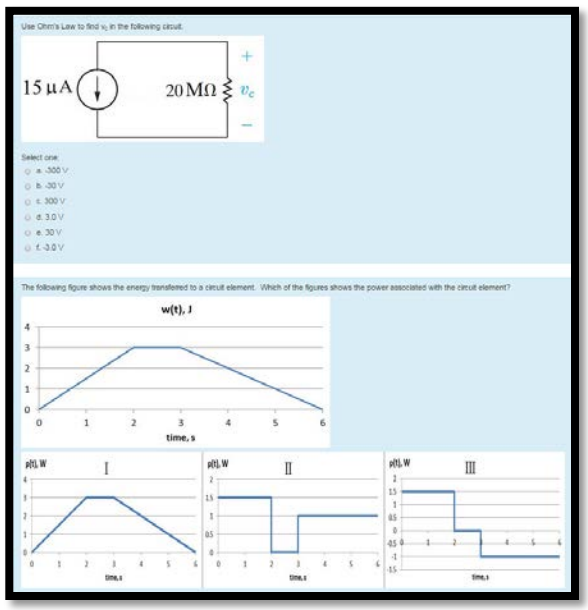


Figure 3: Moodle Quiz Screenshot

Homework

All of the homework assignments were completed in MasteringEngineering. The on campus students also used MasteringEngineering to complete their homework. The student was given one week to complete the assignment. Since these problems were more difficult than the quiz questions, the students were given 3 tries to arrive at the correct answer. As stated by the authors of the edX paper, there were no opportunities to provide partial credit since it was not possible to follow the thought process. Figure 4 shows an example of the MasteringEngineering homework problem set.

Exams

The midterm exams were typically 4 to 5 open ended questions that required the students to complete circuit analysis and design problems. The questions were randomized by setting a variable resistor value to the student's campus mailbox number. This randomization was meant to reduce any potential academic misconduct. The student was given a two hour window to download the exam, complete it, scan it and upload it to the Moodle Dropbox. The instructor used a tablet PC in order to mark up the exam and provide substantive feedback. Since all of the problems were similar other than the final numeric answer, it was possible to expedite the process by creating an algorithm in Maple, MATLAB or Excel. The final exam was double the length of a midterm exam and the student was given 4 hours to complete it. Figure 5 provides an example of a graded midterm exam.

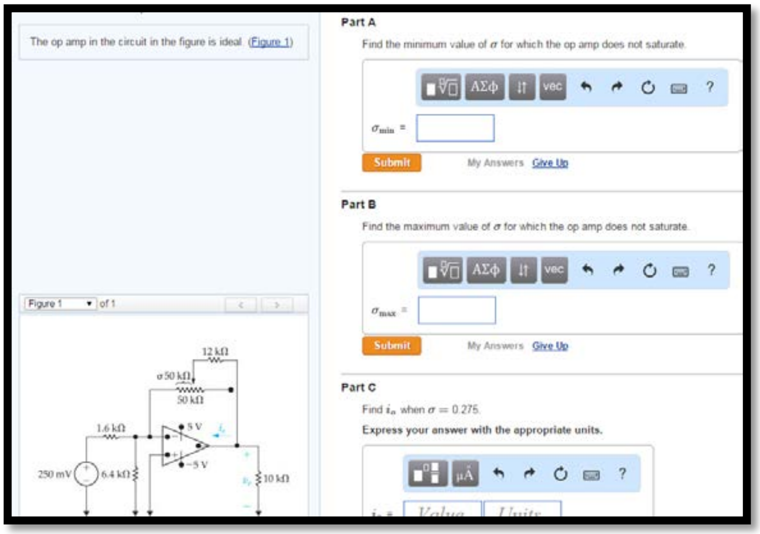


Figure 4: MasteringEngineering Homework Screenshot

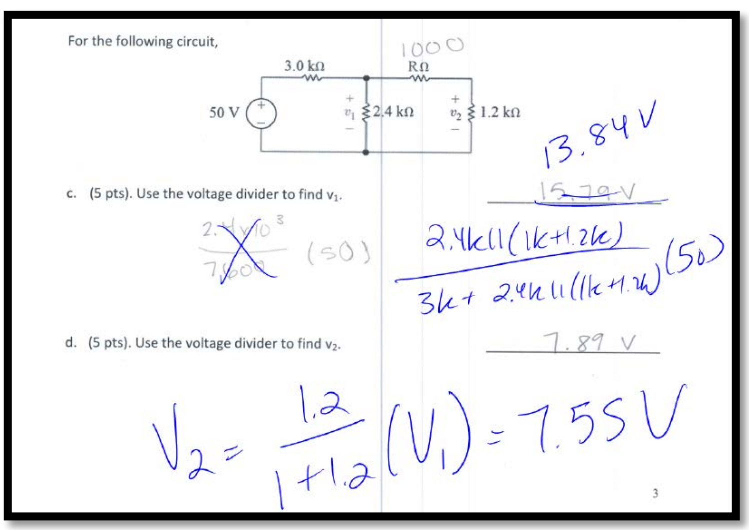


Figure 5: Student Exam Example

Labs

There were 8 lab experiments to be completed by the student during the 10 week summer quarter. The lab required the student to complete a pre-lab that involved analytical calculations and circuit simulation of the lab procedure circuit by using Multisim. This process enabled the student to check their own work and become familiar with the circuits before building them. The students were also required to watch videos on using Multisim, NI myDAQ, and lab equipment. The NI myDAQ was used to create virtual instruments on the student's laptop including a 15V and 5V power supply, multimeter, oscilloscope, and function generator. The voltage regulator was used to create a variable power supply and current source from the NI myDAQ power supplies. The voltage regulator was only used for the online course since the on-campus students had access to benchtop equipment.

Some of the lab equipment videos also demonstrated how to build circuits and take measurements. When some students struggled with the pre-lab, simulation, circuit assembly and measurements the instructor also uploaded examples to Piazza. The lab manual not only provided a step by step procedure of how to complete the lab but also provided screenshots of the circuits and measurement results so that the students knew when they made a mistake. The on-campus students submitted a lab composition book to document the procedure, circuits, measurements, data, and results. Since it was not possible for the online students to submit a lab composition book, they would document their lab in a memo. The memo included the purpose, procedure, and results of the lab experiment. The memo also included screenshots from the measurement instruments and Multisim, and images from the circuits on the breadboard. Table 2 provides a summary of the lab experiments. Figures 6 - 9 provide examples of the pre-labs, videos, images, and screenshots to assist the students with the lab.

Table 2: Electrical Systems Labs

Week	Assignment
1	Ohm's Law
2	Series and Parallel Resistance
3	Kirchhoff's Voltage and Current Laws
4	Circuit Theorems
5	Practical Test 1
6	Op-Amp measurements
7	AC Measurements
8	AC Circuits
9	AC Power
10	Practical Test II

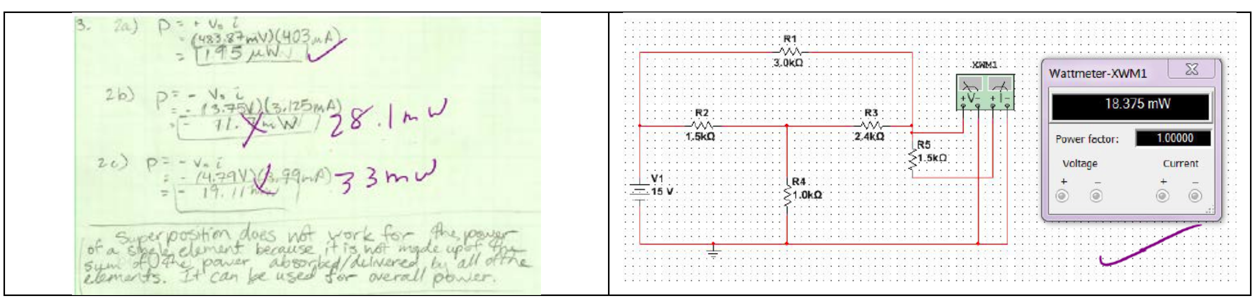
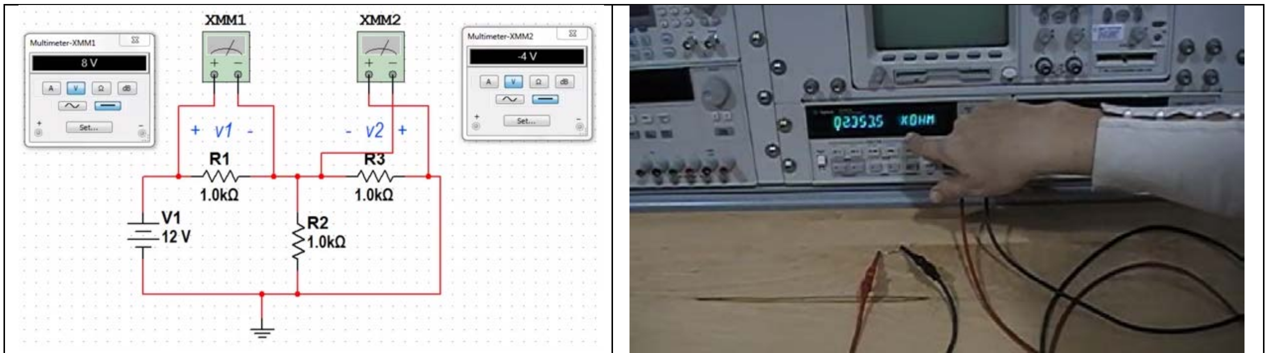


Figure 6: Pre-lab Examples



a. Multisim tutorial | b. Instrumentation tutorial

Figure 7: Circuit Simulation and Tutorial Videos Screenshots

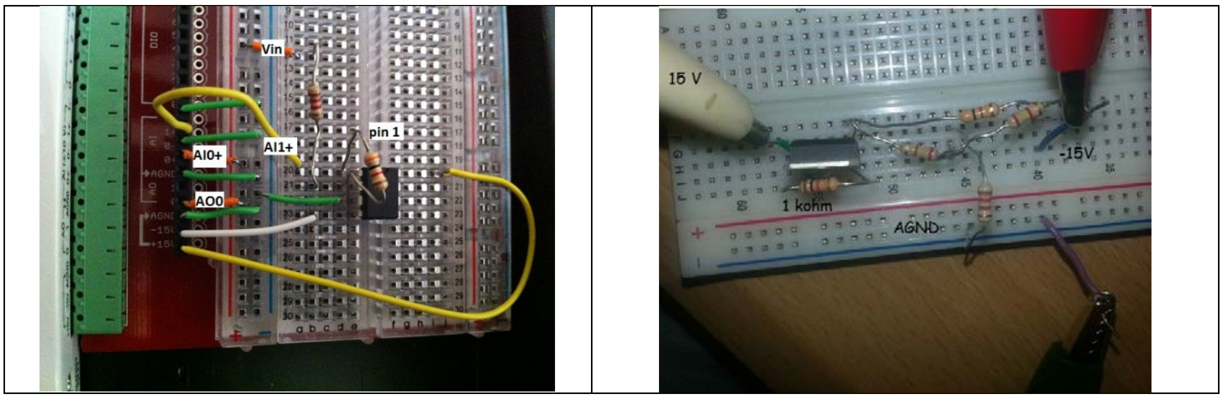


Figure 8: Circuit Images

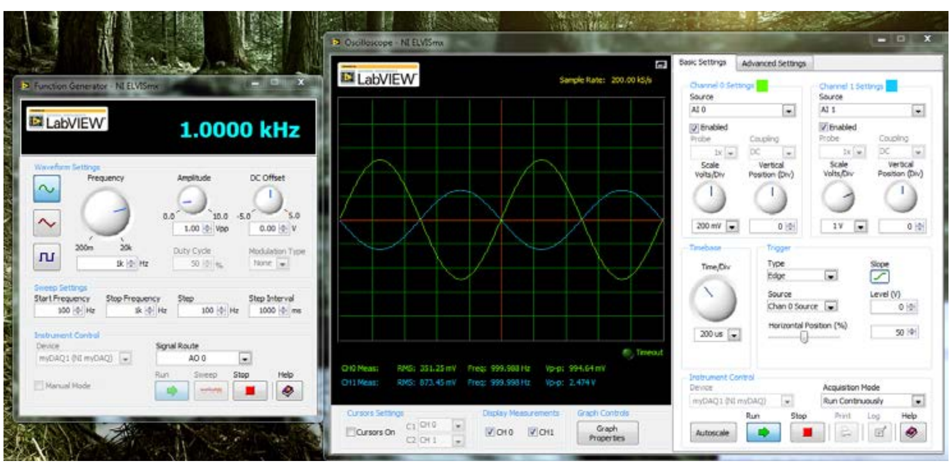


Figure 9: Measurement Results

Lab Practical Exams

As shown in Table 2, there were two lab practicals during the quarter. This exam was short-answer and required the student to build circuits, take measurements and upload screenshots from the breadboard and instrumentation. The exam was timed and the students had 2 hours to complete approximately 12 questions. Figure 10 provides an example of a graded lab practical exam question.

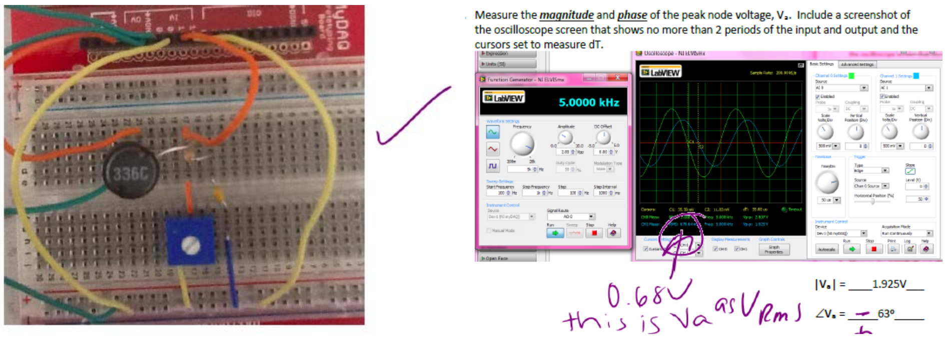


Figure 10: Lab Practical Example

Results

In order to evaluate the online version of the electric circuits course, it was compared to the qualitative and quantitative data from the on-campus version. The quantitative data was the assignment scores. The qualitative data was based upon end of course surveys. The on-campus course used for the analysis had an enrollment of 30 students. The enrollment from the two summer courses was 11 and 9, respectively.

Quantitative Data

Students were asked to rate the difficulty of the course on a scale from 1 to 10 with 10 being most difficult. Only 7 of the 20 students responded to the survey and 28% rated the course as 9 or higher, 57% rated it as a 7 or 8 and 14% rated the course as a 5. The students were also asked to rate which part of the course was the most difficult to take online. The choices were watching lectures, completing quizzes on Moodle, completing homework on MasteringEngineering, completing midterms, completing lab practicals, completing labs with NI myDAQ, or completing prelabs with MultiSim. There were only 3 of these categories that the students felt contributed to the difficulty, they were the labs, lectures, and prelabs at 71%, 14%, and 14%, respectively.

Of the 20 students who took the course online over the two summers 7 of them passed with a C or better, 6 earned lower grades, and 7 withdrew. The retention rate for the course is lower than the on campus version but this can be expected since some students were not sure what to expect and may have added the course to get a feel for an online engineering course. Figure 11 shows an illustration of the comparison of the Moodle online timed quiz scores for the fall 2011 traditional class, summer 2013 and summer 2014 online courses. It should be noted that there is a significant decrease in performance in the first offering of the online course but the scores increase by 10% with the second offering. Figure 12 shows the MasteringEngineering homework performance over the 10 assignments and indicates an increase consistent with the traditional course offering after the first online course offering. Figure 13 shows a comparison of the traditional to my DAQ lab scores with the lab practical exam. Figure 14 shows a comparison of the midterm and final exams for the traditional and online courses.

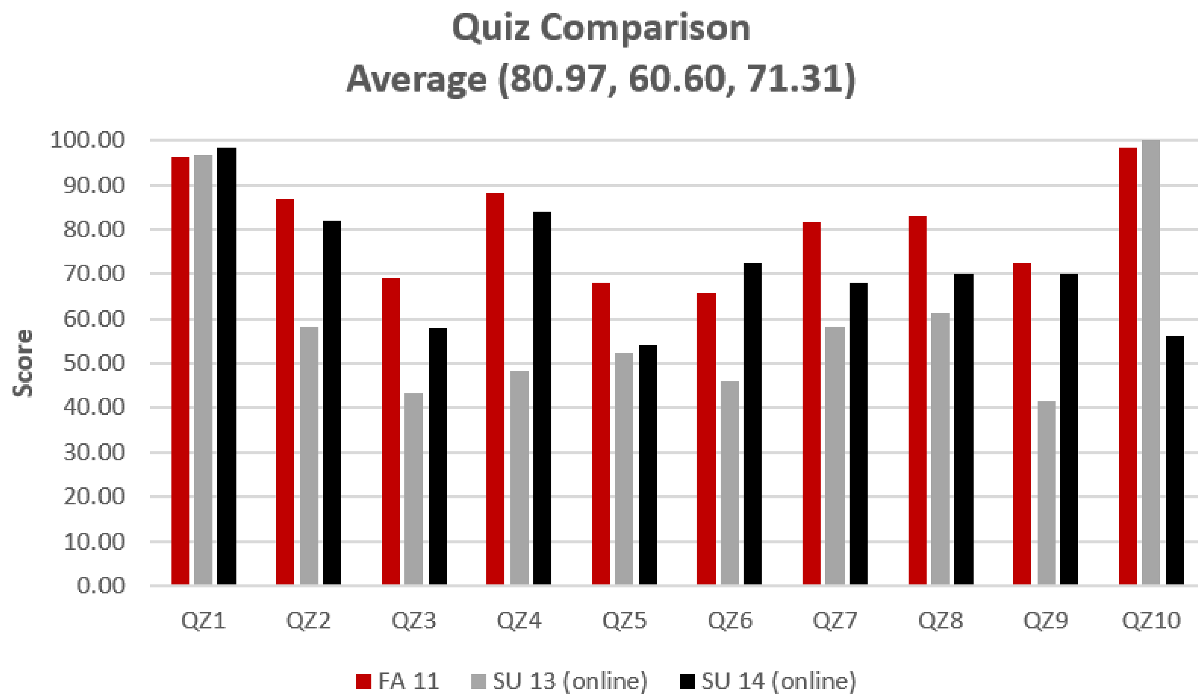


Figure 11: Comparison of Quiz performance between traditional and online courses

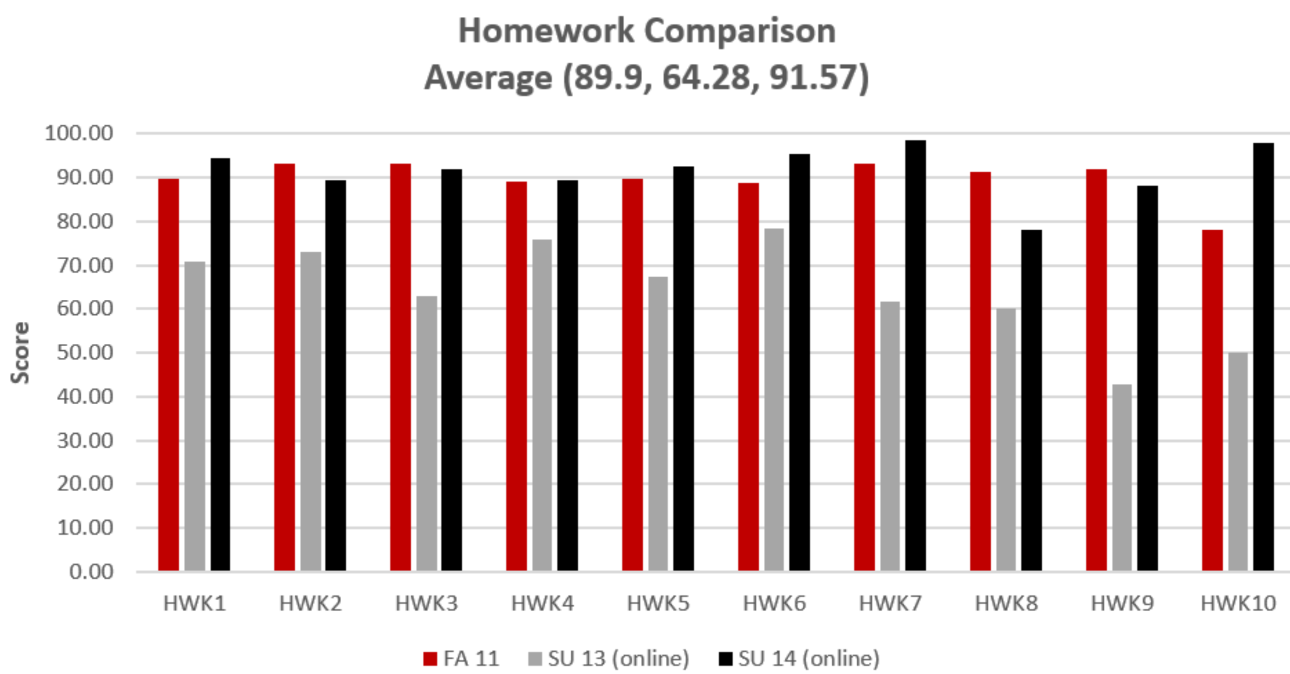


Figure 12: Comparison of homework performance between traditional and online courses

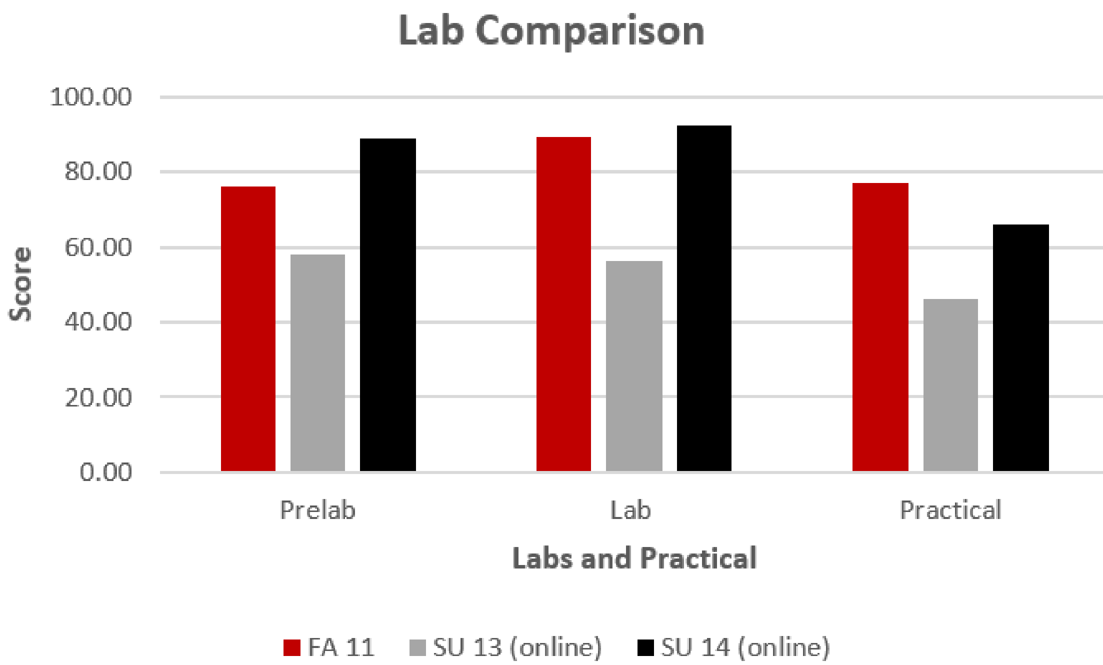


Figure 13: Comparison of lab performance between traditional and online course

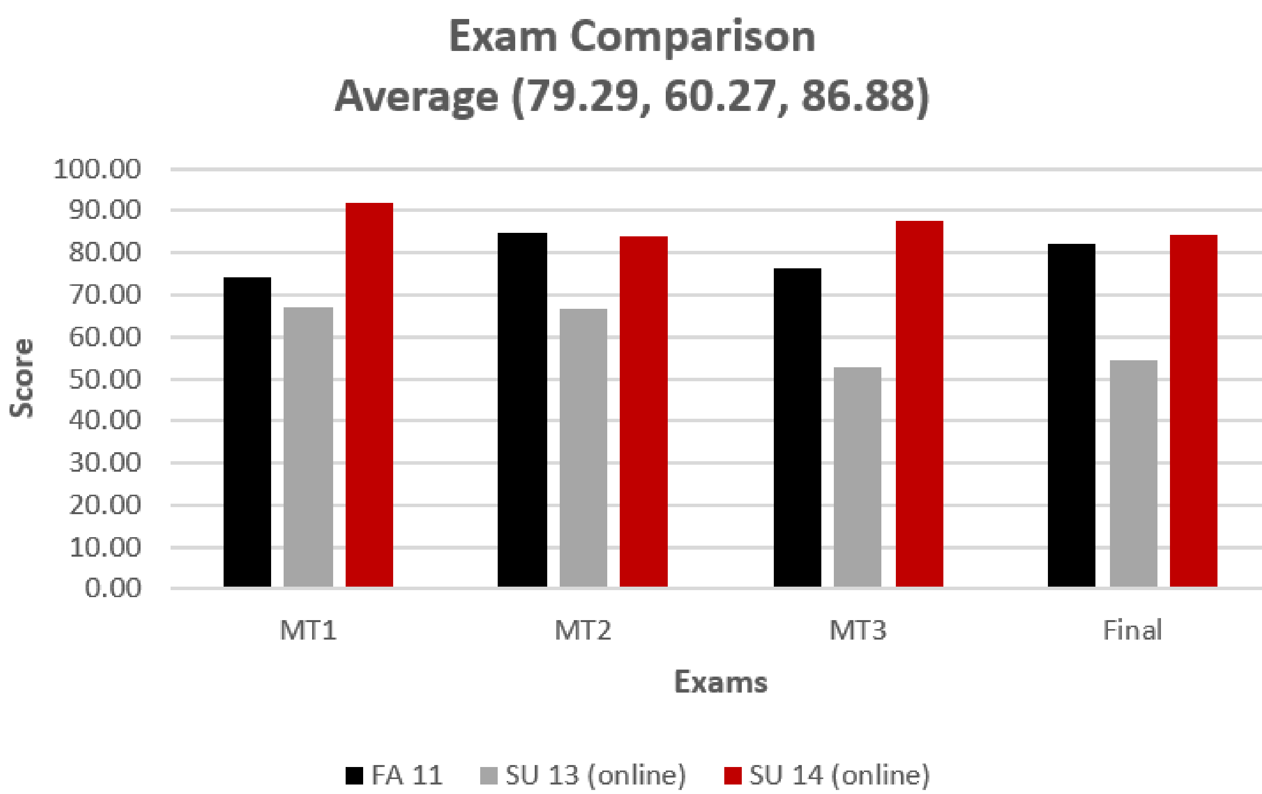


Figure 14: Comparison of exam performance between traditional and online course

Qualitative Data

In order to obtain qualitative feedback about the course, student comments were selected from the student course evaluations and other surveys. One student stated that the labs were much too difficult and it was sometimes difficult to understand all of the materials. Another student stated that the labs were difficult because of difficulty debugging circuits. It should be noted that some of these problems are also present in the face to face classroom but it is easier to get immediate assistance with issues such as debugging or asking questions. One student felt that the course was more difficult because it was not possible to ask questions on the spot. One student felt that it is hard to communicate homework problems via email in order to get assistance when there were problems. It was hoped that the addition of an online resource such as Piazza or Google Hangout would help with these issues. Finally, one student stated that the online timed quizzes were difficult because the material was new. Most of this feedback is consistent with the face to face course where there is typically 10 to 15% who feel that the labs, homework, and exams can be the most difficult part of the course.

Conclusions and Recommendations

In conclusion, it was possible to teach an electric circuits course online with a similar level of engagement to the face to face version of the course. In fact at times there was more engagement because the students had the instructor for a longer period of time during the virtual office hours and email conversations. In order to prepare for the online engineering course experience, the quarter before the online course was taught there was an in person meeting between the students and faculty member. This meeting was used to communicate expectations, explain the logistics of online learning and emphasize that it is more difficult than a face to face engineering course. These challenges required the students to be much more focused, disciplined, diligent, and independent. They were told that they should expect to increase the time they would give to the on-campus version of the course by at least 1.5 or 2 times. In addition, it was explained to the students that the lab component would be the most difficult due to their lack of familiarity with lab equipment, circuit simulation and wiring a circuit on a breadboard. This problem is further exacerbated by the fact that students typically have problems debugging circuits whether an instructor is present or not.

Although the students were in different time zones and countries, it was also necessary to use Google Hangout to have at least one set hour of office hours per week. This feature was added after the first offering of the course when it was found that there was a need for a more real time question and answer session. This was a time for students to ask questions and for the faculty member to emphasize concepts the students were struggling with and review for the exams. By using the screen sharing feature, the students were able to observe the instructor work problems or share their screen to demonstrate their questions. Another activity used to maintain a consistent level of engagement, was to respond to all emails or questions posted within 24 hours. In addition, the instructor provided a mobile phone number for immediate access during periods when there would be extended time away from the computer. Since there was also some flexibility in the summer course schedule, breaks were also timed around the instructor's travel schedule.

Even though there was a group discussion board in the Moodle course management software, it was severely underutilized the first year. This was despite the fact that the students were highly encouraged to post all questions there, they continued to email the instructor. This required the instructor to post the question and response to the group discussion board to reduce the amount of redundancy. However, in the second year, Piazza was introduced to replace the discussion board because it allowed anonymous posting. This one change greatly reduced the number of instructor emails and greatly increased the engagement between the students and faculty. An interesting trend was that the students no longer passively waited for the instructor to respond to questions but became proactive in helping each other. This activity along with the Google Hangout more accurately modeled the interactions from classroom discussions or students studying together in an on-campus setting. By doing these things, it became evident that the students in the online course actually engaged with the faculty member more than the on-campus students. When the class was taught on campus only about 15 to 20% of the students would come to office hours, email questions or ask questions in class. However, in the online format 80 to 100% would email questions, post to Piazza or attend the Google Hangout. Finally, the faculty to student ratio was greatly improved from the on-campus class. The on-campus class typically has 30 students while the online course had an average of 10. Since most of them participated in some level of contact with the faculty member, there was much more individualized attention via the emails, phone calls, Piazza, and Google Hangout. For some of the students, this change may have been the difference in them mastering the concepts that some find difficult.

Some things done to insure academic integrity was to have timed online quizzes with randomized questions and answers. In addition, the homework was in MasteringEngineering with randomized questions and answers. For the midterms and final exam, some of the resistor values were set by the students' campus mailbox number. This meant that although the problems may be similar, they all had different answers. Since this was the variable in each problem, it was possible to automate the grading by using Excel, MATLAB or Maple. On the lab practical exams, students were required to use a potentiometer to set the variable resistor to their campus mailbox number in some of the circuits. In addition, for the labs and practical, they submitted zoomed in images of the breadboard, screenshots of Multisim and the virtual instruments to indicate that their work was correct and authentic.

There are several recommendations which may improve future offerings of an electrical circuits course online. Since the primary challenges were the difficulty of completing laboratory experiments, it would be helpful during the orientation meeting to review some of the key necessary laboratory skills. This includes an introduction to Multisim, the breadboard, NI myDAQ, and virtual instruments. In addition, although it would be an inconvenience to some students, making attendance at some of the virtual office hours and posting questions to Piazza mandatory would possibly improve the course's retention and pass rate.

Bibliography

1. LaMeres, B.J. & Plumb, C., "Comparing Online to Face-to-Face Delivery of Undergraduate Digital Circuits Content", IEEE Transactions on Education, Vol. 57, No. 2, May 2014.

2. Mitros, P. F., Affidi, K. K., Sussman, G. J., Terman, C. J., White, J. K., Fischer, L., & Agarwal, A. (2013, May). Teaching electronic circuits online: lessons from MITx's 6.002 x on edX. In Circuits and Systems (ISCAS), 2013 IEEE International Symposium on (pp. 2763-2766). IEEE.
3. Enriquez, A. "Assessing the effectiveness of dual delivery mode in an online introductory circuits analysis course," in Proceedings of Annual Conference and Exposition of the American Society for Engineering Education (ASEE), Jun. 2010.
4. ES203 Electrical Systems Study Guide. Retrieved March 14, 2015, from http://www.rose-hulman.edu/~berry123/Courses/ES203.html
5. ES203 Electrical Systems Online Lectures. Retrieved March 14, 2015, from https://youtu.be/UF7BiHrToDA?list=PLBK7yyieyrAaoICgz6hfjs4rBGucLc2V5.