ASEE's 123rd Annual • Conference & Exposition • New Orleans, LA • June 26-29, 2016

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Paper ID #15868

Toward a Comprehensive Online Transfer Engineering Curriculum: Assessing the Effectiveness of an Online Engineering Circuits Laboratory Course

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Toward a Comprehensive Online Transfer Engineering Curriculum: Assessing the Effectiveness of an Online Engineering Circuits Laboratory Course

Abstract

Community college engineering transfer programs prepare a significant percentage of graduates from university engineering programs, yet face challenges from a fragmented lower division engineering core curriculum, limited scheduling options for students, and sometimes marginal enrollment patterns. In addition, most small college programs are run by one permanent faculty, making it difficult to provide lower-division engineering courses with the breadth and frequency needed for effective and timely transfer preparation. Through a grant from the National Science Foundation Improving Undergraduate STEM Education program (NSF IUSE), three community colleges from Northern California collaborated to increase the availability and accessibility of the engineering curriculum by developing resources and teaching strategies to enable small-to-medium community college engineering programs to provide a comprehensive set of lower-division engineering courses. These courses can be delivered either completely online, or with limited face-to-face interactions. This paper presents the development and testing of the teaching and learning resources for an online Engineering Circuits Laboratory class, a one-unit laboratory course offered alongside the circuit theory course, which is already available in an online format. The class materials cover the use of basic instrumentation (DMM, Oscilloscope), analysis and interpretation of experimental data, circuit simulation, use of MATLAB to solve circuit equations in the real and complex domain, and exposure to the Arduino microcontroller. A systems approach to selected topics is also introduced as a way to contextualize student exposure to the material. The paper presents the results of the pilot and a second implementation of the curriculum, as well as a comparison of the outcomes of the online course with those from a regular, face-to-face course. Additionally, student surveys and interviews are used to determine student perceptions of the course resources, student use of these resources, and overall satisfaction with the course.

1. Introduction

For the past 5 years, the Joint Engineering Program (JEP) at Cañada College has provided a group of participating California community college faculty a framework for sharing online teaching techniques and curricula designed to be delivered via streaming webcast from the classroom. Participating faculty are trained in the use of tablet-enabled notebook computers during the Summer Engineering Teaching Institute (also at Cañada College), and a key element to the success of this program is the sharing of presentation materials that are annotated during lecture as if on a virtual whiteboard. The approach requires no post-processing by faculty, and allows remote students to ask questions in real time during the classroom session or access the archives after the class.

The primary mission of JEP is to increase the number of STEM transfers from community college in order to address a national shortfall in STEM graduates[1,2]. It strives to accomplish this by increasing access to a variety of key engineering classes for distant or working students, offering flexible scheduling options for all students, providing quality teaching materials for small college faculty (who are often the sole engineering faculty at their college), and helping small engineering programs reach a more stable enrollment pattern. The institutional impact of JEP has been felt not only at Cañada College, which has seen an eight-fold increase in engineering enrollment, but also at adopting schools like Monterey Peninsula College (MPC), which has seen a doubling since joining the consortium. Participation in JEP requires only three days of training and little course revision on the part of faculty, yet by augmenting on-campus sections with an additional cohort of online students, it greatly enhances the efficiency of instructional personnel. It is a model that could easily be (and has been) adopted by faculty in other STEM disciplines.

Although JEP has succeeded on many fronts, one area of difficulty has been dealing with the laboratory component of many engineering classes. Requiring online students to participate in classroom labs undermines the effectiveness of JEP classes and motivated a follow-on project to investigate alternatives that would include the development of online or reduced-presence laboratory components. This project, known as Creating Alternative Learning Strategies for Transfer Engineering Programs (CALSTEP), is funded by a grant from the NSF IUSE program, and focuses on four key classes in the lower-division engineering curriculum: Introduction to Engineering, Engineering Graphics, Engineering Materials, and Engineering Circuits. It explores ways of offering lab activities for these classes in an online context. The following report presents an in-depth look at the Circuits Lab development and assessment portion of the project which took place on the Monterey Peninsula College campus in Spring of 2015.

2. Development of Online Circuits Labs

In accordance with the accepted goals for a classroom laboratory course, the development effort was designed to provide student competencies in: instrumentation and measurement of circuit variables; evaluation of circuit models; devising experiments; collecting, analyzing, and interpreting data; designing, building and assembling circuits; and more[3,4], only in a remote, online-learner context.

With an expectation that remote online learners working independently on circuit labs and out of sight of the instructor are liable to encounter overwhelming difficulties and be unable to resolve anomalous measurements, a guiding philosopy was adopted to A) keep labs simple to the extent possible; B) aim to provide “fault proof” activities, and C) rely on the use of circuit simulation and other virtual lab opportunities for a greater proportion of the activities.

Alongside the content, a set of support resources for online learners was also developed. Since it is difficult to capture the steps of a complex lab activity through streaming video during a classroom lab, with all the distractions of a group of students working through the material at different rates, an alternative set of studio videos, produced by a former student of the class, was also provided for the hardware labs. These videos proved to be the most popular learning aids for online students. Videos demonstrating the final outcome of the hardware labs and the different steps involved in accomplishing them went a long way to establishing the context that online students find difficult to obtain from reading through the lab handouts. Other ways of supporting online students include a discussion forum for posting questions and receiving answers, online office hours for students to ask questions of the instructor, and classroom videos guiding students through the non-hardware portions of the labs (simulation and analysis).

The Circuits Lab Kit

A large portion of this project involved the design of the circuits laboratory kit, a low-cost, reusable, shoe-box sized container mailed (loaned) to online students at the start of the semester. Each unit contains a breadboard powered by two 12VDC wall adapters, a components kit with a relatively simplified set of parts, a DVM, a USB oscilloscope (Digilent's Analog Discovery), a speaker for audio experiments, and an Arduino microcontroller for sensor experiments. Using a 3D printed bracket to anchor a pair of barrel jacks allows for bringing DC power from the wall adapters directly to the breadboard. A 5V regulator combined with a potentiometer provides an adjustable voltage source for those experiments requiring one. Since the kits are provided free to students, most of the contents will be reused in future semesters, with the exception of the basic components, which can be refreshed for approximately $10/kit per semester. Eventually the circuits lab kit will be made available through a web store staffed by community college students at Monterey Peninsula College.

Although not included in the circuit kit, use of a web-based circuit simulator was another important component of the labs, providing students an intuitive, fault-tolerant user interface, while MATLAB (or a free, open-source equivalent) provides the computational support.

Laboratory Activities

Table 1 summarizes the content of each lab activity in the initial set of labs developed as well as the proportion of activities in 5 key modalities (analysis, breadboarding, simulation, application/design and instrumentation). The circuit kit is flexible and provides opportunities for additional experiments to be developed in future semesters. Several labs (5, 6, and 10) use circuit simulation to help students verify their analytical work, while others (4 and 7) use circuit simulation to illustrate basic principles. The inclusion of an Arduino microcontroller is intended to provide opportunities for students to explore realistic applications of the circuit principles and techniques they are mastering. A final project option is also provided for students wishing to obtain extra credit in the theory portion of the class.

Table 1. Proportion of five different activity modalities in each lab.

	Activity Modes				
Circuit Lab Topics	Analysis	Breadboard	Simulation	Application	Instrument
1. Introduction to MATLAB	100%				
2. Safety, Breadboards, DMM		100%			
3. Circuit Simulation			100%		
4. Series and Parallel Circuits		45%	45%	10%	
5. Nodal and Mesh Analysis	60%		40%		
6. Thevenin Equivalents	50%		50%		

7. Op-Amp Circuits		60%	30%	10%	
8. Nonlinear Devices: Diodes and Transistors		90%		10%	
9. First Order Circuits and Oscilloscopes		30%			70%
10. First Order Time Domain Simulation	60%		40%		
11. Complex Numbers, Phasors and MATLAB	100%				
12. Phasor Nodal, Mesh and MATLAB	100%				
13. Measuring AC Circuits		20%			80%
14. Intro to Microcontrollers		30%		50%	20%
15. Frequency Selective Circuits	45%	45%		10%	
Final Project				100%	

3. Results of the Implementation

To assess the effectiveness of these online circuits laboratories, in Spring '15, we piloted the curriculum to students enrolled in dual sections of circuit theory (3 units) and circuit lab (1 unit) classes offered in both online (n=9 students) and on-campus (n=11 students) formats, both taught by the same instructor who developed the lab materials. Both groups used the same lab kits and the same lab activity guides. Table 2 shows a summary of statistics comparing the two cohorts— showing retention and success, amount of work completed, student time to completion (as reported on their lab reports), and an abbreviated concept inventory[5] at the end of the class. Note that due to the focus of our current grant effort, the statistics reflect only the lab class and exclude the results of the theory class, although the concept inventory test may be influenced more strongly by the circuit theory class than by the lab activities.

Table 2. Comparisons of retention (percentage of students who finished the class), success (percentage who passed the class), amount of lab work completed, and other performance metrics between online and classroom participants.

Student Performance in pilot Circuits Lab course	Online	On Campus	Differ
	(n=9)	(n=11)	
Retention	89%	82%	7%
Success	67%	82%	-15%
Labs Completed	79%	95%	-16%
Avg Time per Lab	4 hours	2.75 hours	45%
Lab Tests	96%	95%	1%
Concept Inventory	63%	62%	1%

The results shown in Table 2 indicate that, while retention was slightly higher for the online cohort, success (in the lab class) was 15% lower. This was perhaps due to an apparent tendency of online students to focus their limited time resources on the more unit-heavy lecture theory class and neglect their lab work (79% labs completed vs 95% for on campus students). The largest discrepancy, 45%, was seen in the average time students reported on their reports it took to complete the labs – 4 hours for online students vs 2.75 for on-campus students. It is possible that the extra time to complete labs for online students reflects a different manner of assessing time – for instance, online students might include breaks and other interruptions in the total reported time required. It is also possible that a lab completed intermittently would require more time just for repeatedly restarting and reorienting to the work at hand. One might speculate that an imbalance in time required for online labs further reduces the cost-benefit ratio for online students in terms of work performed for the theory class vs work performed for the lab class. Ultimately, the online students performed about the same as the classroom students on lab tests and the concept inventory test. This could be interpreted a number of ways, but clearly, the increased difficulty of online students in completing the labs on their own needs to be taken into consideration. Beyond that, the significance of the other results is diminished by the small sample size.

To gain a fuller picture of the (online vs classroom) student perspectives on their experience in the class, a comprehensive feedback survey was given to all students. The survey covers the perceived impact of the labs on student understanding, the resources that students found the most helpful, why online students were taking the class in that mode, whether there was sufficient guidance on how to complete the labs, and many other aspects of the class.

While the complete results are included in the appendix, the statistics of key findings is shown in Table 3. When the statistics are converted into averages, student perception of the impact of the labs on their understanding of circuits concepts, on a scale of 1 to 5 was equivalent – 4.3 for online and 4.4 for classroom students. On the other hand, student perception that the labs connected to the theory class was 4.5 for online and 5.0 for classroom students, showing a possible sense of disconnect among online learners as to motivation for the work they were asked to perform. Student sense of sufficient guidance to complete the labs was 3.67 (online) and 3.85 (classroom), again possibly reflecting a sense online students feel less supported in their lab activities. Student sense of understanding the learning objectives before the lab was 3.96 (online) vs 3.08 (classroom), a tip in the other direction, possibly due to the labs sometimes being revised after the classroom session to smooth the experience for the online students. Student sense of understanding the learning objectives after the lab was 4.33 (online) vs 4.29 (classroom). Finally, their sense that the labs helped students understand concepts in the book or lecture videos was 4.67 (online) to 3.30 (classroom), possibly implying that the online students did gain conceptual benefits from the labs they did complete.

Table 3. Key student perception survey statistics (see appendix for complete results).

Survey Question	Online (n=6)	Classroom (n=10)
Impact of labs on understanding ccts?	50 % rated at 5 (extrmly helpful) 33% rated the impact at 4 17% (1) rated the impact a 3	50% rated impact at 5 40% rated impact at 4 10% (1) rated the impact a 3
Connection between lab and theory?	50% strongly agreed 50% agreed	100% strongly agreed
Sufficient guidance on how to do labs?	17% (1) strongly agreed 67% agreed 7% (1) disagreed	44% strongly agreed 55% agreed
Understanding of learning obj. before started lab ?	16% (1) strongly agreed 67% (4) agreed 16% (1) undecided	11% (1) strongly agreed 33% (3) agreed 22% (2) undecided 22% disagreed 11% strongly disagreed
Understanding of learning obj. after concluded lab?	33% (2) strongly agreed 67% (4) agreed	44% (4) strongly agreed 44% agreed 11% (1) undecided
Labs made student understand concepts in videos/book ?	100% agree (33% strongly agree)	22% strongly agreed 22% agreed 44% undecided and 11% (1) disagreed

Once again, the most significant difference between the two cohorts reported by the post-semester student survey was that online students reported spending an average of 4.6 hours per week (ranging from 4-6 hours), while classroom students reported spending an average of 2.75 hours per week (ranging from 1.5 – 3 hours), which compares with the numbers reported on their lab reports. The longest time to complete a lab by online students averaged 6.5 hours and ranged from 6-8, and for classroom students averaged 4.3 and ranged from 3-6. In general, online students expected to spend longer on the labs (3.9 hours on average) than the three hours reserved for the classroom period, however the actual amount of time spent exceeded their expectations considerably.

Finally, in expressing what they felt the most effective resources were for completing the labs, online students gave the highest value to the TA-developed studio videos explaining each of the lab steps: "*Rachel's videos were great, because I could actually see what I was supposed to be doing with the hardware. It would have been virtually impossible to figure it out by myself.*" On the other hand, classroom students found the lab handouts to be the most supportive, as one might expect, since most of them did not need to refer to the videos for support. Given the amount of time spent developing these videos, it is rewarding that they were so well received by their intended audience. A drawback to the long term use of video tutorials, however, is their tendency to need continuous refreshment as components, instrumentation and lab activitities evolve. We will be exploring ways of efficiently updating the tutorial videos during the next offering of the laboratory class.

4. Conclusions

As part of a grant funded effort to increase access to crucial laboratory-based classes for California community college engineering transfer students, a set of online labs and support materials was developed and piloted on a small cohort of online and on campus students at one community college in Northern California. The labs were designed to support online learners by reducing the complexity of the lab work and provided support with TA developed video tutorials. Student learning outcomes and perceptions of the effectiveness of the lab content was evaluated. Although student learning between the two different cohorts was effectively similar, the large increase in time required for online students to complete their labs compared to classroom students, in spite of the resources targetting the online cohort such as tutorial videos, seems to be a major factor in diminishing the amount of laboratory work performed by online students.

Based on these observations as well as the outcomes and feedback from students, a number of changes will be highlighted for future offerings of the online circuits lab curriculum at Monterey Peninsula College, primarily focused on reducing time to completion for labs that were especially long in duration. First, specific will be reduced in scope and simplified. Second, we will be pairing online learners with partners who can work through the labs while connected over the web, a change we hope will partially alleviate the isolation of online learners. Third, during activities requiring lengthy calculations, answers to intermediate calculations will be provided to speed up the process of error checking. Fourth, taking a different tack, inclusion of open-ended constructivist activities (both virtual and physical) will be investigated for inclusion into the labs as a way to strengthen student self efficacy. As well, the injection of systems level activities, such as constructing small but practical physiological measurement circuits, will be explored for their potential to better contextualize and engage students in their exposure to the challenging analytical concepts. These modifications will take place during the next phase of the project, which will also focus on encouraging the dissemination of these online circuits lab materials to other college campuses to support increased online access for students.

Acknowledgements

This project is supported by the National Science Foundation through the Improving Undergraduate STEM Education (IUSE) program, Award No. DUE 1430789. Any opinions, findings, and recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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Appendix

MPC STUDENT SURVEY SUMMARY – CIRCUITS, ONLINE LAB VS FTF LAB		
Monterey Peninsula College Spring 2015		
	Online Responses (6)	FTF Responses (8) and Signed up for Online but taking class mostly FTF (2) for total of 10
College affiliation	67% (4) all MPC 16% (1) only Circuits at MPC 16% (1) also at other colleges	8 (80%) all MPC 2 (20%) also at other colleges 0 only Circuits at MPC
Number of units	12 units average; range 7-13.5	12 units average; range 5-18
Outside commitments	Average 30 hours; range 10-56	Average 21 hours; range 10-35
Lab assignments	Average 4.6 hours; range 4-6	2.75 hours average; range2-3.5
Longest spent on lab assignment	Average 6.5 hours; range 6-8	Average 4.3 hours; range 3-6
Labs requiring longest	Thevenin (2); Lab 9 (2); AC (1)	Lab 12, Phasor, Nodal Mesh (6) ; Lab 10 (1); Thevenin (1);
Reasonable amount of time for lab activity	Average 3.9 hours; range 3-6	Average 2.5; range 1.5-3
Why online	2 (33%)scheduling conflict 2 (33%) distance makes it easier 1 (16%) prefers online	
Use of online forum	3(50%) use MPC forum; 3 don't participate in online forum	
Most effective resources	On scale from 1-5 w. 1 least and 5 most useful: Highest ratings: 100% gave Rachel's videos a 5 84% gave written lab handouts a 4 or 5 (17% a 5) 84% gave classroom video recordings and email w. instructor	On scale from 1-5 w. 1 least and 5 most useful: Highest ratings: 90% gave written lab instructions a 4 or 5 (50% a 5) 50% gave each of following a 4 or 5:

MPC STUDENT SURVEY SUMMARY – CIRCUITS, ONLINE LAB VS FTF LAB		
Monterey Peninsula College Spring 2015		
	a 4 or 5 (50% a 5 for both resources) Lowest ratings: 100% gave google for other resources a 1 or 2 50% gave photos and videos posted on Google+ a 1 or 2 (1 gave this a 5) 33% gave MPC online forum both asking and reading a 1 or 2	Rachel's and classroom video recordings (30% a 5; 20% a 4) Email w. instructor (25% a 5) MPC online forum posts (50% a 4) Google other resources (50% a 4) Lowest ratings 40% gave Google for other resources a 1 or 2 (3 a 1) 30% gave each of the following a 1 or 2: Classroom video recordings MPC online forum reading and writing Photos and videos posted on Google+
Why most effective resources	5 of 6 commented on Rachel's videos for their step-by-step instruction and for pointing out pitfalls "*Rachel's videos were great, because I could actually see what I was supposed to be doing with the hardware. It would have been virtually impossible to figure it out by myself*"	3 mentioned lab handouts which sere as a how-to manual and are "useful" and "descriptive" 2 of 10 mentioned class recordings that allow you to learn at your own pace 2 noted the instructors response to questions 2 Rachel's videos for being "clear"
Preferred video format	Highest ratings (3 or 4 on scale from a-4): 83% recorded live classroom to watch after session concludes (with 83% a 4) 50% video indexing (with 50% a 4)	Highest ratings (3 or 4 on scale from a-4): 70% live streaming w ability to ask questions remotely in real time (with 30% a 4) 50% recorded live classroom to watch after session concludes (with 30% a 4) 40% video indexing (with 40% a 3)

MPC STUDENT SURVEY SUMMARY – CIRCUITS, ONLINE LAB VS FTF LAB		
Monterey Peninsula College Spring 2015		
	Lowest ratings (1 or 2) 67% live streaming videos (33% a 1) 50% video indexing (33% a 1)	Lowest ratings (1 or 2) 70% recorded studio (with 30% a 1) 50% recorded live classroom (with 25% a 1)
What makes you prefer this format (of video?)	Recorded live classroom works for flexibility and reinforces what students are learning, allowing them to repeat information and slow-down (mentioned by 5 of 6)	
What type of online conversations/technology do you prefer?	50% MPC 50% don't use forum for own questions, but read postings by others 0 identified FaceBook and Google + as source	30% MPC 40% don't use forum for own questions, but read postings by others 1 identified FaceBook and Google + as source
Why not use online forum?	67% like to figure things out on their own 33% don't want everybody to see their questions	50% get things done during class time 40% have time management issues 30% don't want everybody to see their questions
How can we increase participation in online forum?	One suggestion each: Improve ease of use Extra credit Organize questions by topic Don't want others to see my questions	Improve ease of use (4) – including one calling for better interface Offer credit (1) Schedule time for conversations (1) Don't want others to see my questions (1)
Impact of labs on understanding of circuits	On a scale from 1-5 where 5 is extremely helpful 83% rated the impact at 4 or 5 with 50% at 5 17% (1) rated the impact a 3	On a scale from 1-5 where 5 is extremely helpful 90% rated the impact at 4 or 5 with 50% at 5 10% (1) rated the impact a 3
Connection btw lab and classroom	50% strongly agreed and 50% agreed there was a connection	100% strongly agreed there was a connection

MPC STUDENT SURVEY SUMMARY – CIRCUITS, ONLINE LAB VS FTF LAB		
Monterey Peninsula College Spring 2015		
Sufficient guidance on how to do the labs	17% (1) strongly agreed, 67% agreed and 7% (1) disagreed	44% strongly agreed and 55% agree
Understanding of learning obj. before started lab	16% strongly agreed (1) and 67% agreed (4) ; 16% (1) undecided	11% (1) strongly agreed and 33% (3) agreed; 22% (2) undecided; 22% disagreed and 11% strongly disagreed
Understanding of learning obj. when concluded lab	33% strongly agreed (2) and 67% agree (4)	44% (4) strongly agreed; 44% agreed; 11% (1) was undecided
Labs made student understand concepts introduced in videos/book	100% agree (33% strongly agree)	22% each strongly agreed or agreed (for total of 44%) 44% undecided and 11% (1) disagreed
Labs taught additional skills/concepts not covered in videos/book	33% strongly agree (3) and 55% (5) agree. 11% undecided	67% (4) strongly agree and 33% (2)agree
Favorite lab	2 commented on early labs	
Liked best	Hands-on experience (2) Online format with flexibility and ability to take time to really understand (2) Learning skills that are relevant for transfer/rest of life (1)	Connection between theory and practice/hands on element (4) *When I was able to connect homework problems with the breadboard and realize ohhh thats how it works*
Challenges	Time requirement (2) – more difficult online and therefore more time consuming *I think not doing it as a class, or more specifically being there in the class, because you could have partners or the instructor help you out that way you can get it done during that 3 hour period instead of working on it throughout the week.* Getting stuck/troubleshooting (2)	Trouble shooting/finding errors (3) Learning/working w Analog Discovery (2)
Ideas for improvements	Provide answers for different steps/end of lab session (not sure what means but 2 mentioned this) "*Maybe have an answer for the lab question and let the students write how*	3 suggestions related to having more clarity on lab objectives before lab begins 1 suggestion to post FAQs

MPC STUDENT SURVEY SUMMARY – CIRCUITS, ONLINE LAB VS FTF LAB		
Monterey Peninsula College Spring 2015		
	to get the answer on the lab report,sometimes we are not sure whether we are getting the right answer or not."	Provide answers for lab question (1)