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Strengthening Community College Engineering Programs through Alternative Learning Strategies: Developing an Online Engineering Circuits Laboratory Course

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Abstract

In an effort to extend access to the lower-division engineering curriculum for non-traditional students, three community colleges from Northern California collaborated to develop resources enabling four laboratory-based engineering classes (Intro, Graphics, Circuits, and Materials) to be performed in a remote, online setting, or with limited face-to-face interactions. Funded by a grant from the National Science Foundation Improving Undergraduate STEM Education program (NSF IUSE), this work builds on prior efforts to provide online access to the lecture-only engineering classes in the lower-division transfer pattern, while also seeking to improve the efficacy of community college engineering programs facing challenges with staffing, scheduling, and fluctuating enrollments. This paper presents results from a second implementation of a one-unit Engineering Circuits Laboratory class, 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. Results from both implementations are used to generalize outcomes between online vs. face-to-face cohorts, and are contextualized with input from student surveys and interviews on the perception, use and overall satisfaction of the course and its resources.

1. Introduction

In 2016, for the second year in a row, students at Monterey Peninsula College (MPC), a community college along the central coast of California, have had the option to enroll in either a face-to-face (F2F) or fully online section of both Engineering Circuits (i.e. circuit theory) and Engineering Circuits Laboratory classes, which are offered as co-requisites in the lower-division transfer pattern for most engineering majors in California[1]. At the beginning of the semester, students in the online section of the laboratory class receive a portable shoe-box sized bin of electronics components and instrumentation, and use it to perform lab experiments on their own or with a virtual lab partner. Both online and F2F cohorts use the same materials, and F2F students are able to borrow kits to do experimentation at home if they desire.

The development and assessment of the circuits laboratory curriculum is the focus of this paper. (Online delivery of the circuit theory class has been established for over 4 years now at MPC.) Funded by a grant from the National Science Foundation Improving Undergraduate STEM Education program (NSF IUSE), the present work is being performed for a project known as Creating Alternative Learning Strategies for Transfer Engineering Programs (CALSTEP) and involves faculty from three community colleges in Northern California. The primary goal of the CALSTEP project is to facilitate access to key lower-division laboratory courses, or courses with a strong laboratory component, in the engineering transfer curriculum, and thereby help address a national shortfall of STEM graduates[2,3]. The specific courses covered by CALSTEP's efforts include Introduction to Engineering, Engineering Graphics, Materials Engineering, and Circuits Laboratory. Lessons learned from each faculty's experience implementing and disseminating their curriculum have been shared and used to improve overall outcomes in all courses.

A secondary goal of the CALSTEP program is to strengthen small community college engineering programs, which are often challenged by trends toward greater fragmentation of engineering core requirements (by major and institution), low or variable enrollment in engineering classes which can lead to cancellations, and the sheer breadth of subject coverage required for an often single-faculty engineering department to offer. CALSTEP is able to build on the success of prior efforts of its members in implementing online lecture courses in engineering, which demonstrated significant enrollment increases at participating colleges, as well as improved student outcomes (both in retention and success). Other factors influencing the CALSTEP program are the recent standardization of engineering transfer patterns to the Cal State university system brought about by the implementation of SB 1440 (the Student Transfer Achievement Reform Act, which provides guaranteed admission pathways from the California Community Colleges to the Cal State system), and the state Online Education Initiative, which seeks to provide seamless access to online courses to all students across the entire California Community College system.

The following report presents a summary of the Circuits Lab curriculum itself, and an assessment of two implementations of the curriculum that took place at MPC in Spring 2015 and Spring 2016, as well as an implementation of the curriculum in a F2F setting at a second college in Spring 2016.

2. Development of Online Circuits Labs

The lab development effort was designed to provide student competencies in accord with the thirteen goals for engineering educational laboratories identified by the ABET/Sloan effort[4,5], only in a remote, online-learner context. These goals include: instrumentation and measurement of circuit variables; evaluation of circuit models; devising experiments; collecting, analyzing, and interpreting data; designing, building, and assembling circuits; learning from failure; and creativity in problem solving.

Remote online learners working independently on circuit labs and out of sight of the instructor are liable to encounter overwhelming difficulties and may be unable to resolve anomalous measurements. To mitigate these challenges, a guiding philosophy 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, including a set of studio video tutorials produced by a former student of the class, 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). In the student perception surveys that took place after the semester, online students favored the video tutorials over all other modes of instruction, while the F2F students worked primarily with the laboratory handouts.

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 12 VDC 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 (Figure 1), totalling less than $300 per kit. Using a 2.1 mm jack allowed for bringing DC power from the wall adapters directly to the breadboard. A 5 V 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.

Figure 1. Example circuits laboratory kit provided to online students.

Although not included in the circuit kit, use of a web-based circuit simulator (CircuitLab) was another important component of the labs, providing students an intuitive, fault-tolerant user interface, while MATLAB (or a free, open-source equivalent) provided 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 approximate proportion of activities in 5 key modalities. 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. Approximate proportion of five different activity modalities in each lab: **Analysis** using circuit theory and MATLAB, **breadboarding** of physical circuits, **Simulation** of circuits using CircuitLab, a web-based simulator, **Application/Design** activities to contextualize theoretical principles, and use of **Instrumentation** including a standard DMM and Digilent's Analog Discovery USB oscilloscope and waveform generator.

	Activity Modes				
Circuit Lab Topics	Analysis	Breadboard	Simulation	Application	Instrument
1. Introduction to MATLAB	100%				
2. Safety, Breadboards, DMM		50%			50%
3. Circuit Simulation			100%		
4. Series and Parallel Circuits		20%	45%	10%	25%
5. Nodal and Mesh Analysis	60%		40%		
6. Thévenin's Theorem	50%		50%		
7. Op-Amp Circuits		40%	30%	10%	20%
8. Nonlinear Devices: Diodes and Transistors		50%		10%	40%
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	30%	30%		10%	30%

3. Results of the 2015 Implementation at MPC

To assess the effectiveness of these online circuits laboratories, in Spring 2015, 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. One might think the distinction between online and F2F cohorts would be relatively clear-cut; however, in practice, students who registered for the online section would sometimes switch to F2F for the labs, and students enrolled in the F2F section would sometimes request to borrow a lab kit to make up for an absence from the laboratory session or to prepare for a lab practical exam. The results reflect the instructor's observation of each student's predominant participation mode, and do not attempt to assess the impact of an occasional F2F student performing a makeup lab remotely.

Table 2 shows a summary comparison of outcomes between the two cohorts, with the top section showing measured statistical performance outcomes and the bottom section showing the results of a student perception survey rating different aspects of the lab experience on a 5-point scale, where 5 is most favorable and 1 is least favorable. The statistical data in the top section of Table 1 shows retention and success, amount of work completed, student time to completion (as reported on student lab reports), and an abbreviated circuits concept inventory (Concept Inventory A[6]) administered at the end of the semester.

Table 2. Comparisons of performance metrics and student perceptions between online and face-to-face cohorts for the Spring 2015 implementation of an online circuits laboratory class.

Spring 2015 Results (MPC):			
Performance	**Online**	**F2F**	**Δ**
Enrollment	9	11	
Retention (% that finished)	89%	82%	7%
Success (% that passed)	67%	82%	-15%
Labs Completed	79%	95%	-16%
Average completion time (hours)	4	2.75	45%
Concept Inventory A (Post)	63%	62%	1%
Student Perceptions (ratings)	**(n=6)**	**(n=9)**	
Impact of labs on understanding	4.3	4.4	-0.1
Sufficient guidance to complete	3.8	4.4	-0.6
Understood objectives before	4.0	3.1	+0.9
Understood objectives after	4.3	4.3	0
Labs helped understand concepts	4.3	3.5	+0.8
Labs taught additional skills	4.7	4.2	+0.5

The results shown in the top section (Performance) of 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 F2F students). The largest discrepancy, 45%, was seen in the average time students reported that 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. 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 likely somewhat diminished by the small sample size.

To gather the student perspective on their lab experience, a comprehensive feedback survey was given to all students, covering the perceived impact of the labs on 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.

Statistics of key findings are shown in the bottom half of Table 2 (Student Perceptions). 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 sense of sufficient guidance to complete the labs was 3.8 (online) and 4.4 (classroom), reflecting a sense that online students feel less supported in their lab activities. Student sense of understanding the learning objectives before the lab was 4.0 (online) vs 3.1 (classroom), a tip in the other direction, possibly due to the labs sometimes being revised after the classroom session to improve the experience for the online students, or that online students are more likely to read the lab handout, or watch the tutorial video, before starting the lab. Student sense of understanding the learning objectives after the lab was 4.3 for both cohorts. The sense that the labs helped students understand concepts in the circuit theory book/lectures was 4.3 (online) to 3.5 (classroom), and that the labs taught additional skills not covered in the circuit theory class was 4.7 to 4.2. These last two items could reflect better learning outcomes achieved when students complete the lab activities individually rather than in teams of 2 or 3 (as in the F2F cohort) in which not all students are necessarily engaged with the labs.

Looking deeper at the data in Table 2, one might observe an interesting divergence between performance and perception, in that the online cohort completed fewer labs and had lower success rates in spite of showing greater appreciation for the labs to clarify concepts and teach additional skills. The significance of this result

Finally, in expressing what they felt were the most effective resources for completing the labs, online students gave the highest value to the TA-developed studio videos explaining each of the lab steps. 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 well received by their intended audience.

The following takeaways from the 2015 implementation guided the 2016 implementation:

- Find ways to make the labs quicker to complete for online students.
- Find ways to encourage greater completion of the laboratories and greater engagement of online students with their classmates.

- Find ways to help online students confirm whether the answers they attained for intermediate steps were correct.
- Some of the labs that followed traditional approaches such as verifying circuit theories and op-amp gain may have been less than inspiring – what kind of activities would elicit more engaging experiences for students in the circuits lab?
- The barrel jack adapters for bringing DC power to the breadboard tended to fall out of the breadboards after repeated use and needed to be anchored with a zip tie. This issue was presented to students at MPC who were enrolled in the Engineering Graphics class, and two groups devised a 3D printed bracket to retain the barrel jacks to the breadboard, potentially allowing for faster and more reliable setup.

4. Results of the 2016 Implementation at MPC

Based on the results from 2015, a number of changes were implemented for Spring '16. These include:

- Abbreviating lab activities by cutting down on the scope of analytical work, particularly in the areas of nodal/mesh analysis and Thévenin's theorem (which had the longest reported lab completion time), since they are redundant with work in the theory class.
- Providing more engaging applications such as a simple "lie detector circuit" to motivate study of voltage dividers and other abstract topics.
- Providing embedded answers for selected steps in lengthy analytical work, and post "Frequently Asked Questions" for online students to refer to.
- Grouping online students into virtual lab groups and encouraging team participation using web conferencing tools.
- Providing breadboards with pre-installed barrel jacks for DC power, anchored with 3D-printed brackets that were designed locally by Engineering Graphics students (Figure 2).
- Providing an optional final project that can contribute toward a student's grade in the circuit theory class.

In practice, not all of the above items were implemented completely, and some of them led to additional confounding factors (discussed below). Nonetheless, the results of this effort, summarized in Table 3, provide an interesting contrast with the results from the Spring 2015 class.

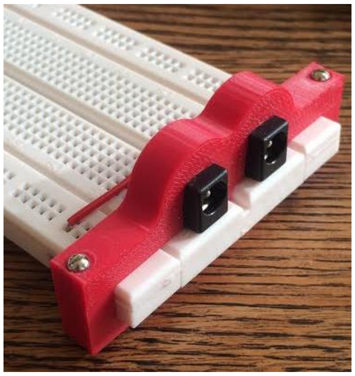

Figure 2. Breadboard with 3D-printed brackets for mounting barrel jacks provided pre-assembled with the Spring 2016 kits.

First, with enrollment, the F2F section more than doubled in size, while the online section remained about the same. Retention statistics are approximately the same, although it was interesting that not a single student dropped in either cohort. However, success between the two cohorts diverged, with the online cohort declining from 67% to 62% and the F2F cohort increasing from 82% to 92% compared to the 2015 implementation. The amount of lab work completed was about the same for the F2F group, but diminished significantly in the online cohort, from 79% to 62%. And in spite of efforts to simplify the lab work and provide checkpoints on work in the labs, it still took about the same additional time (42% vs 45% in 2015) time for online students to complete the labs than the F2F cohort.

Table 3. Comparisons of performance metrics and student perceptions between online and face-to-face cohorts for the Spring '16 implementation of the online circuits laboratory class.

Spring 16 Results (MPC):			
Performance	**Online (n)**	**F2F (n)**	**Δ**
Enrollment	8	25	
Retention (% that finished)	100% (8)	100% (25)	0%
Success (% that passed)	63% (8)	96% (25)	-33%
Labs Completed	66% (8)	92% (25)	-26%
Average completion time (hours)	4 (6)	2.8 (21)	42%
Concept Inventory A (Pre)	74% (3)	40% (18)	-
Concept Inventory A (Post)	78% (3)	66% (18)	-
Concept Inventory B (Pre)	80% (2)	53% (18)	-
Concept Inventory B (Post)	84% (2)	66% (18)	-
Student Perceptions (ratings)	**(n=5)**	**(n=21)**	
Impact of labs on understanding	4.8	4.0	+0.8
Sufficient guidance to complete	3.4	4.3	-0.9
Understood objectives before	3.8	3.8	0.0
Understood objectives after	3.6	4.0	-0.4
Labs helped understand concepts	3.6	4.1	-0.5
Labs taught additional skills	3.8	4.1	-0.3

The concept inventory for 2016 was switched from the previous version in 2015 that was derived from a physics treatment of DC circuits (shown as Concept Inventory A[6]), to a circuits CI coming from a broader electrical engineering perspective (Concept Inventory B[7]). In 2016, both CIs were administered to both cohorts for comparison with the 2015 implementation, and going forward, to future semesters that will only use CI-B. Unfortunately, it was disappointing to observe that less than half of the online students completed both pre- and post-inventories, no doubt because these were not going to affect their final grade in the class. This suggests a strategy of awarding significant extra credit points for completion of the pre-CI and embedding the post-CI within the final exam. The results imply that only the well prepared online students took the CIs (since their scores were considerably higher from the start than the F2F cohort), but that a significant learning took place among both cohorts.

As in Table 2, the top section of Table 3 shows measured statistical performance outcomes and the bottom section shows the results of a student perception survey rating different aspects of the lab experience on a 5-point scale, where 5 is most favorable and 1 is least favorable. Compared to 2015, the results show improved appreciation of online students for the impact of the labs on their understanding (4.8 vs 4.3), but a diminished sense of guidance in working the labs and understanding of objectives before and after (3.4/3.8/3.6 for online 2016 vs 3.8/4.0/4.3 for online 2015). Of course, the very small population size (n=5) of those online students completing the survey also caution against reading too much into these findings since they will be very sensitive to a single person's responses. In contrast, the F2F students presented a basically similar outlook on these same metrics (4.3/3.8/4.0 for F2F in 2016 vs 4.4/3.1/4.3 in 2015).

A reasonable basis for some of differences in results between the F2F and online cohorts might be found in the data in Table 4, which shows the comparative workload between online and F2F students in 2015 and 2016. Clearly, in 2015, the online students were likely more stressed compared to F2F, since with about the same units, they had committed on average to 10 more hours per week of work than the F2F students. However, in 2016, the difference was reduced, and the extra hours of weekly work (8) were partly balanced by fewer enrolled units (5) on average for the online students.

Table 4. Comparisons of student workload between online and face-to-face cohorts, for both implementations of the circuits lab class at MPC.

Student Workload Online	**Spring 2015**	**Spring 2016**
Enrollment	9	8
Average Total Units	12	11
Average Work Hours/week	30	26
F2F		
Enrollment	11	25
Average Total Units	12	16
Average Work Hours/week	21	18

From the instructor's perspective, the 2016 implementation was still very much a work in progress since some of the revisions were met with new issues. For example, the changes designed to improve student engagement with voltage dividers using a "lie detector circuit" seemed to steer students away from the underlying circuit principles that were being exhibited in favor of an experience of being part of an electronic circuit – valuable in its own right, but not fully capitalizing on the rich opportunities for concept formation made possible by this experience.

A more serious problem arose with the 3D-printed brackets used to mount the barrel jacks to the breadboard (Figure 2, above). These brackets were designed and printed by students at MPC and pre-installed on the breadboards before the semester began so that with just a simple act of plugging in a wall adapter, students could bring +12 V and/or -12 V to the breadboard power rails. The intent was to streamline the setup process and reduce hardware construction time, but in practice it appeared that students were mystified by the pre-wired connections and didn't get to fully appreciate the technique of wiring two power supplies in series with a central reference node to obtain the balanced positive and negative supply voltage needed for working with operational amplifiers. Even worse was a phenomenon observed in the F2F section where one of the supply voltages would fail during the op-amp lab and the resulting imbalance would burn up the integrated circuit. Upon further inspection, it was discovered that the barrel jacks were not really "breadboard friendly" as they had been advertised, since the pin spacing was slightly larger than the standard 0.1" breadboard hole spacing, causing the pins to bend slightly upon insertion, with unpredictable results. Another revision to the 3D-printed bracket to rotate the jacks into a more favorable alignment did not fully resolve the problem, and so the jacks were replaced for 2017 with a "barrel jack to screw terminal" adapter that requires more construction by students but also more engagement with the connection of power to the circuits.

Some changes to the 2016 online curriculum, such as the lab on measuring the complex impedance of an AC circuit, were implemented only after difficulties in the F2F delivery were observed. These last-minute changes made it difficult to update the TA-developed videos on a timely basis, and, coupled with the changes to the kit hardware in 2016, tended to undermine their perceived usefulness from 2015. At the same time, the instructor's parallel effort to reorganize the circuit theory co-requisite class to better orient students with the lab class activities and also standardize topic sequences with Cañada College, may have influenced the outcomes and assessments of the lab class. On the whole the revisions did improve the effectiveness of certain labs, and students did appreciate the insertion of expected answers for key steps of the labs, where provided. It was interesting to note that the final CI-A performance in 2016 was stronger than 2015 (66% vs 62% for F2F and 78% vs 63% for online) although the small sample size, especially for the online cohort, contraindicates reading too much into these results.

5. Results of the 2016 Implementation at Cañada College

One of the principal goals for CALSTEP is facilitating access to key lower-division laboratory-based courses in the engineering transfer curriculum. In order to fully meet this goal, the participants are exploring ways to disseminate their online curriculum to other engineering faculty throughout the California Community College system. A trial run in the dissemination process was undertaken with a (non-CALSTEP) faculty at Cañada College in Spring 2016.

Although this was a face-to-face implementation of the labs, the results of this effort, summarized in Table 5, are helpful in comparing learning outcomes between the two campuses using the same lab curriculum and essentially the same circuit theory curriculum, and serve to highlight issues that will arise when other faculty adopt the curriculum for online circuits laboratory classes.

The initiation of this implementation took place rather spontaneously shortly before the start of the spring semester based on the availability and interest of a new faculty hire at Cañada College. Due to time constraints and the 2-week lead of the spring academic calendar at Cañada College, the Cañada College implementation used the 2015 laboratory curriculum and 12 copies of the 2016 version of the circuits lab kits. With 40 students enrolled at the start of the semester, the purely F2F 2016 section at Cañada College was larger than either implementation at MPC (totaling 20 and 33 students in 2015 and 2016) and required a greater degree of sharing of kits between students than at MPC. All students were administered a pre and post concept inventory using CI-B.

Nonetheless, at 93%, retention of the Cañada College section was similar to that of MPC, and the change from the pre- to post-semester scores on CI-B for Cañada College (60% to 73%) is roughly similar to that at MPC (53% to 66%) indicating approximately the same amount of learning even though the students at Cañada College appeared to start out at a higher preparation level than MPC.

Table 5. Comparisons of performance metrics and student perceptions of the face-to-face implementation (no online students) of the online circuits laboratory curriculum at Cañada College in Spring 2016.

Spring 16 Results (Cañada College):	
Performance	**F2F (n)**
Enrollment	40
Retention	93%
Concept Inventory (Pre)	60% (30)
Concept Inventory (Post)	73% (30)
Student Perceptions (ratings)	**(n=33)**
Impact of labs on understanding	3.4
Sufficient guidance to complete	3.4
Understood objectives before	3.6
Understood objectives after	4.1
Labs helped understand concepts	4.0
Labs taught additional skills	3.7

The students at Cañada College were also administered a perception survey rating their impressions on a scale of 1 to 5, similar to that at MPC, and the results are recorded in the bottom section of Table 5. Compared to the 2016 F2F students at MPC shown in Table 4, the F2F students at Cañada College rated some categories less (Impact of labs on understanding [3.4 vs 4.0], Sufficient guidance to complete [3.4 vs 4.3] and Labs taught additional skills [3.7 vs 4.1]), and the others approximately the same. Given the circumstances of the implementation at Cañada College (a new instructor using 2015 lab write-ups with 2016 kits and a higher student-to-kit ratio) it is not surprising that F2Fstudents at Cañada College expressed somewhat lower ratings since they would likely have experienced more confusion in doing the labs than the F2F cohort at MPC.

Taking into consideration the results of the 2016 implementation at MPC and Cañada College, the following takeaways are now guiding the 2017 implementation:

- Online students have difficulty completing the same amount of lab work that F2F students achieve, which is understandable given the lack of instructor supervision and direct contact with a lab partner.
- Online students do appreciate the benefits of labs in helping them understand concepts from the circuit theory class.
- Online students feel noticeably less comfortable with the guidance they are given to complete the labs in comparison to F2F students.
- For some students, the lab activities can seem rote and unrevealing as to purpose or meaning.
- The difficulty of getting online students to complete a pre- and post- concept inventory for the purposes of validating the lab outcomes motivates awarding significant extra credit points for completing the pre- CI.
- Online students working independently are more likely to experience greater frustration in completing circuits lab activities, motivating additional ways of supporting their exploration, such as by including designated checkpoints where students need to verify their work to that point.
- The maintenance of video tutorials is difficult when hardware and lab activities are subject to changes between semesters and sometimes at the last minute.
- Developing curriculum for online labs is an especially messy business, with insights and inspiration for improvement often occurring after debuting in the F2F section.

In addition, many of the following suggestions from the project advisory committee meeting in fall 2016 are being explored for 2017:

- Break labs into weekly pre- and post- activities, and require the pre-lab completion several days before post-lab completion.
- For grading purposes, develop spreadsheet macros that process initial student lab measurements and validate their subsequent mesurements and computations based on their earlier base measurements. This could possibly be deployed during the lab to apply “just-in-time” course corrections when students are about to drift into erroneous lines of thought.
- Require online students to demonstrate key measurements on video to uncover wrong measurement techniques.
- Reduce the lab sequence to 10 experiments with a makeup experiment – where students can redo a prior lab or make a video on a topic they didn’t understand and use this to flag trouble topics.
- Provide a video on the importance of practical work to encourage completion of lab activities.
- Embed short, focused video tutorial segments in the lab handout to guide people through key steps, rather than one long video narrative. This should also make maintenance easier in future semesters since only the impacted video segments related to changing activities or hardware need to be updated.

- Include a design lab halfway through the semester to help students integrate the various concepts from the theory class.

6. 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 circuits labs and support materials was developed and implemented over two successive spring semesters (2015 and 2016) at a community college in Northern California, and disseminated to a second community college in 2016. The labs were designed to support online learners by reducing the complexity of the lab work and provided support with video tutorials. Student learning outcomes and perceptions of the effectiveness of the lab content were evaluated. Although student learning between the two different cohorts was roughly similar, the persistence of greater time requirements for online students to complete their labs is an ongoing area of need, in spite of the resources specifically targeting the online cohort, such as tutorial videos.

Based on these observations as well as the outcomes and feedback from students and advisory committee members, a number of changes will be highlighted for future offerings of the online circuits lab curriculum at MPC, primarily focused on reducing time to completion for labs, providing greater engagement with the laboratory topics and other students in the online cohort, and providing greater checkpoints to keep students from drifting off course. These modifications will take place during the next phase of the project, which will also continue to focus on enhancing the dissemination of these online circuits lab materials to other college campuses to support increased online access for students.

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