AC 2012-3689: TRANSITIONING A LAB-BASED COURSE TO AN ONLINE FORMAT: STRATEGIES FOR SUCCESS

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Transitioning a lab-based course to the online format: Strategies for Success

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Abstract

Lab-based courses are generally not available in an online format because of the need for expensive lab equipment, time consuming technical assistance, and troubleshooting. The recent increase in demand for online instruction extends past current pedagogical methods and is made more problematic with the addition of a lab component. In our previous paper, "Transitioning a lab-based course to an online format"\textsuperscript{1}, we presented the development of our pedagogical framework. This framework is based on our 2010 online course and previous studies in online education. In this follow-on, we complete our study by evaluating the results of our 2011 online circuits course that utilizes the framework proposed in the 2010 paper.

In this paper, we present our finalized pedagogical framework specifically tailored for engineering students in an online environment. This pedagogical framework is well suited as a starting point for instructors looking to explore online education. Data indicating whether student engagement and performance are improved are presented. Development and refinement of the framework through the 2011 course are presented. Results and general information about the Summer 2011 course are discussed.

Introduction

Traditional online courses at Binghamton University have been offered through a non-specialized satellite based approach.\textsuperscript{2} Online classes are simply treated as extensions of an on campus course. In summer 2010, we set out to create a pedagogical model that could be used for our online courses. This model is designed to be tailored specifically for the online setting and replaces the typical satellite model used in online education. In Summer 2010, we applied the satellite model for an electrical circuits course, in which students viewed pre-recorded lectures and worked on the same laboratory, homework, and examinations as traditional students. The Summer 2010 course is used as a benchmark to measure our progress in the Summer 2011 course.

In the design of our methodology, we sought to make key changes to the way a course is taught. We sought to deemphasize the lecture sessions and focus on building problem solving skills and developing students' conceptual understanding. Lectures are shortened and are no longer the central element of learning. Laboratories are no longer time intensive and can be performed without traditional laboratory equipment or with surrogate equipment. Conceptual learning replaces much of the number crunching students perform in a typical course. Our methodology stems from prior research suggesting that less material can result in more learning.\textsuperscript{3,4}
Figure 1 shows a pictorial representation of how a course is organized in our model. Each module is a self-contained unit that emphasizes a different topic. In each module, a student will first view the lecture. Rather than featuring the lecture as the central element to each module, each lecture serves as an entry point to introduce the concept. The lecture length is no longer than 20 minutes. At the end of each lecture, a question about the topic is asked for students to answer in the forums.

After the short lecture, a series of advanced examples are featured in multiple formats. Students are given the option of viewing the advanced examples to practice with. These questions are usually integrated with homework assigned to the student. After the student is satisfied with their
progress, they move onto the laboratory experiment. Unlike a conventional course, each module is closely linked with a relatively short activity that requires the student to apply a fundamental concept learned in the module. Support options throughout the course include suggested reading, synchronous and asynchronous discussion, facilitated by tools such as an interactive whiteboard(synchronous) or forums(asynchronous). Finally, a quiz or similar evaluation provides both student and instructor a means to determine the extent to which they have mastered the material.

Our prototype 2011 circuits course contained 27 modules, 12 experiments, and 19 quizzes. A midterm examination was replaced with a midterm project. The only examination students were given was the final exam, which consisted of a concept inventory and free response questions. The prototype course was given over the period of eight weeks. Students were expected to complete two to three modules per week, allowing for flexibility to accommodate differences in their schedule. The timing of this course could be described as a mix between a traditional course, where there are hard due dates, and a correspondence course where most of the work is usually due at the end of the course.

A large reason for the modularization of material and reduction in actual lecture and laboratory time stems from various research. In the 1980's, Johnstone and Percival indicated that the average attention span was approximately 10-20 minutes. In addition, during an average 45-90 minute lecture, each required refocus further decreases the attention span. It is believed by researchers such as Dr. Carr that attention span has decreased further and that extraneous material on the web presented through hyperlinks overwhelms an individual's cognitive load. In the design of our course, we believe that reducing the amount of material and multimedia content not only agrees with Dr. Carr's view that multimedia and hyperlinks decrease the ability of individuals to understand, but increases the amount of preparation time that the instructor must put forward for the course.

**Evaluation of Students**

Students were evaluated using a variety of different methods. In smaller scale evaluations, students were asked to complete quizzes and experimental laboratories. Larger scale evaluations included a midterm project and final examination. Quizzes designed to verify student mastery were given at the end of each module. Students were given two attempts on each quiz, a method which has been found to encourage students to review and relearn the material. Most students preferred the quizzes to larger examinations.

The midterm examination was replaced with a midterm project. The midterm project in the 2011 course asked students to create a power supply with a linear regulator. The midterm project is included in the Appendix.

Most students responded well to the project and thought that the project contributed to overall learning. It is important to emphasize that all methods of evaluation required extra knowledge
aside from the information presented in the modules. Some students complained that the module quizzes, project, and other required activities did not line up with the lecture. They could not or were unwilling to understand the shift in paradigm in the lecture being an introduction to material rather than the central element in the course. Many students chose not to complete the advanced examples, which would have helped them on the other activities in the course. Some students did poorly on quizzes because they did not try the homework or participate in office hours.

The final examination consisted of the concept inventory, used to compare the online course to the traditional one, and free response questions. Students were given two days to complete the examination. Table 1 below lists the criteria used to evaluate students in the 2011 course.

**Table 1: Evaluation Criteria**

<table>
<thead>
<tr>
<th>Category</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Homework</td>
<td>0%</td>
</tr>
<tr>
<td>Experiments</td>
<td>20%</td>
</tr>
<tr>
<td>Quizzes</td>
<td>40%</td>
</tr>
<tr>
<td>Participation</td>
<td>10%</td>
</tr>
<tr>
<td>Midterm Project</td>
<td>15%</td>
</tr>
<tr>
<td>Final Exam</td>
<td>15%</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
</tr>
</tbody>
</table>

**Figure 3: Student Retention: 2010 and 2011**

<table>
<thead>
<tr>
<th></th>
<th>Students 2010</th>
<th>Students 2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pass</td>
<td>87%</td>
<td>57%</td>
</tr>
<tr>
<td>Fail</td>
<td>13%</td>
<td>14%</td>
</tr>
<tr>
<td>Withdraw/Drop</td>
<td>0%</td>
<td>29%</td>
</tr>
</tbody>
</table>
Student Motivation

In both our 2010 and 2011 online courses, we found that there were many students who had no desire to take our course. These students did the minimum amount of work and added no value to the course. These students were usually non electrical and computer engineering students who needed the course as a requirement to graduate. Other students showed no ability to work independently. However, the level of motivation shown by students was no different from a traditional on campus course.

As the survey results show, students did not feel that the homework assignments helped in the 2011 course. Unlike the 2010 course, homework in the 2011 course was not assigned a grade value. When homework was mandatory, 94% of students indicated that it was helpful. When homework was optional, 63% of students indicated that it was helpful. It should be noted that from observation, many students who felt that the homework assignments did not help did not complete the homework section. However, we do not consider this a flaw in our model as the homework is intended to provide students an opportunity to deepen their understanding of the topic and is not central to the learning.

The problem of student motivation is present all types of formats, including formats such as traditional courses, correspondence courses, and other online models. Our model is designed to engage students with shorter lectures, interesting laboratories, and interesting discussion questions. While we do agree with others, such as Mason, that student motivation is an important element in a course, we will be reviewing the issue in a future course. For this reason, this issue is not further addressed in our study.

Student Survey

Students were surveyed in 2010 and 2011 about how they felt about the course. Even though the percentage of students agreeing that the laboratory assignments helped to improve learning did not significantly increase, it is important to note that students commented in our survey that they
preferred the 2011 laboratories to the labs found in a traditional course. We also experienced a greater number of students submitting completed and correct laboratory assignments. We experienced a decreased number of complaints and negative comments regarding the laboratory section, and more students successfully completed laboratory/experimental assignments than the 2010 course. When each experiment/laboratory was graded, it was found that the 2011 students did significantly better in the laboratory/experiment section of the course, and that the experiment/laboratory section greatly improved their conceptual comprehension.

Table 2: Survey Results

<table>
<thead>
<tr>
<th>Question</th>
<th>% Agreement in 2010 course</th>
<th>% Agreement in 2011 course</th>
</tr>
</thead>
<tbody>
<tr>
<td>I would take course again.</td>
<td>76%</td>
<td>63%</td>
</tr>
<tr>
<td>I would recommend course to others.</td>
<td>72%</td>
<td>82%</td>
</tr>
<tr>
<td>I learned a lot.</td>
<td>86%</td>
<td>72%</td>
</tr>
<tr>
<td>Laboratory assignments improved learning.</td>
<td>68%</td>
<td>72%</td>
</tr>
<tr>
<td>Homework assignments helped.</td>
<td>94%</td>
<td>63 %</td>
</tr>
<tr>
<td>The exams helped.</td>
<td>94%</td>
<td>72 %</td>
</tr>
<tr>
<td>WileyPlus helped,*</td>
<td>86%</td>
<td>-</td>
</tr>
<tr>
<td>The textbook helped.</td>
<td>84%</td>
<td>90%</td>
</tr>
<tr>
<td>The course is comparable to on-campus course</td>
<td>72%</td>
<td>90%</td>
</tr>
</tbody>
</table>

* WileyPlus is an online homework application provided by Wiley. It is designed to supplement their textbook.

Lecture

Lectures were limited to 20 minutes in length in order to fit within our projected student attention span. This would avoid the decrease in material absorption associated with the aforementioned refocusing periods. Lectures were recorded using Camtasia Studio and PowerPoint. We agree with previous studies that indicate the average attention span is limited to 15-20 minutes without subsequent refocusing. Each lecture presents key concepts of a topic and asks one or two questions at the end of the lecture to be answered in forums. More advanced examples were provided in either a PDF file or supplementary video. Students were told that the limited length lectures would contain only the bare minimum material about the topic and that, unlike a traditional course, they would need to work on more on these optional problems.

Reducing the length of lectures increased the number of views that each lecture received compared to the previous 40-60 minute lectures. From the data collected in the 2010 and 2011 study, it can be concluded that 10-20 minutes is an adequate amount of time to present key concepts in the online format.

In the midterm student survey, students commented that the shorter lectures were preferred to the lengthier ones. However, they also commented about the lack of more complex examples and detail. For example, in the resistor section, the formula for resistors in parallel was presented in its original and complete forms without performing the algebraic manipulation to derive the
formula. Some students preferred having this extra information. It was originally thought that more advanced examples provided as a supplementary PDF file or video would be more convenient. At first, students ignored the extra material, but most students quickly realized that they would not perform as well on the quiz if they did not look at the advanced examples.

We conclude that the reduction of lecture time to 10-20 minute videos was successful, especially when additional information is provided for those who wish to see it. Base material is considered the material required to form a conceptual understanding and perform basic operations. For instance, a module focusing on Kirchhoff’s laws would provide an explanation of what Kirchhoff’s current and voltage laws are, how they may be useful to the student, how to analyze the currents entering a node for KCL, and how to analyze the voltage around a loop for KVL. In order to provide this additional material, supplementary videos can be linked to the base video, and the user can be asked whether they would like to see additional derivation steps.

**Laboratory**

One of the most difficult aspects of transitioning a course online is providing a method to conduct laboratory experiments. In the Summer 2010 course, we tried to replicate a laboratory in the student’s home. A USB oscilloscope, sound card function generator, and the same lab supply kit provided to on campus students was used. The power supply was replaced with two 9V batteries. Students performed the same laboratory exercises as on campus students. This approach resulted in increased costs and complaints that the laboratory was not able to be performed at home. Rather than mimic the on campus laboratory experience, we decided to take a different approach.

Our approach focuses on the following basic goals of an online laboratory from our previous paper:

1. Design labs to be less difficult since online students are likely working alone
2. Adapt labs to readily available and less expensive equipment
3. Shorten the length of time required to complete each lab
4. Shorten lab explanations and encourage students to come to their own conclusion
5. Design labs to engage students in understanding one or two basic concepts per lab, to avoid overwhelming students with too much information
6. Design labs to be closely tied with the corresponding lecture

Our design of the laboratory for the online environment focused on these basic principles described in our previous paper:

1. Lab exercises are to reinforce concepts learned in lecture and homework
2. Lab equipment is meant to assist in reinforcing those concepts
3. If a lab exercise, or piece of equipment, does not help reinforce concepts, then it should be replaced or eliminated
Focusing on these goals allowed us to develop short, targeted laboratories that asked the student to utilize the basic concepts learned in lecture and homework. Because of the nature of the online course, laboratory assignments were kept short and focused to align with lectures of the same concept. Additionally, due to prior experience from an analog circuit design course and the Summer 2010 course, experiments were redesigned to be better suited to students working independently. According to the summer 2010 survey results, students commented that the experiments were difficult to perform alone, time consuming, and did not contribute to their ability to understand the course material.

Our lab model utilizes a new lab kit specifically designed for the online course. In this kit, the oscilloscope and function generator are replaced by a sound card, and the power supply is replaced by standard 1.5 and 9V batteries. Replacing the oscilloscope and function generator with a USB sound card significantly reduces cost, but introduces two limiting factors: lower frequency range, and lower voltage range. Focusing on the goals of the laboratory, it is clear that limited ranges are not an issue, as labs are still able to reinforce concepts such as frequency, amplitude, period, and voltage within the reduced ranges.

In our Summer 2011 course, all experiments were coupled with a lecture of the same topic. Experiments took an estimated 10-30 minutes to complete and asked students to demonstrate the concepts they learned in the module. An example can be seen in Figure 5, which shows the Linearity and Superposition experiment, during which students were asked to take current and voltage measurements to verify that the sum of the voltages around a single loop is indeed equal to zero. An example can be seen on the next page.
Figure 5: Linearity and Superposition Experiment

Linearity and Superposition
Experiment 12
EECE 260 Online Circuits

Purpose:
Verify validity of linearity and superposition

Tools:
Breadboard
Multimeter

Materials:
One 9 V battery
One 1.5 V battery
Resistors
1k, 10k, 100k

Task:
\[
V_a = 9V - 1k - 10k - 1k + 10k - 1k
\]

If you need help, you need to contact your instructor or teaching assistants.

Using superposition, calculate \( V_a \) in the above figure. Show your calculations.
Using another method (Any other method. Your choice.), calculate \( V_a \) in the above figure. Show your calculations.
Build the circuit given in the figure above. Take a picture and paste it here…
Measure \( V_a \) with both batteries connected. Record this value.
Measure \( V_a \) with just the left battery connected. Record this value.
Measure \( V_a \) with just the right battery connected. Record this value.

<table>
<thead>
<tr>
<th>Method</th>
<th>( V_a )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superposition</td>
<td></td>
</tr>
<tr>
<td>Other method</td>
<td></td>
</tr>
<tr>
<td>Both batteries connected</td>
<td></td>
</tr>
<tr>
<td>Left battery connected</td>
<td></td>
</tr>
<tr>
<td>Right battery connected</td>
<td></td>
</tr>
</tbody>
</table>

Does your value for \( V_a \) agree for superposition, other method, and both battery connected?
If you add your \( V_a \) values for left battery connected and right battery connected, does it approximately equal \( V_a \) for both batteries connected? Briefly explain why or why not.

By reducing laboratories to simple experiments that ask students to demonstrate that the fundamental laws presented to them in lecture hold true, students are allowed to explore the link
between theory and practice, an experience which was lacking in the summer 2010 course. It is important to note that simplifying these laboratories to short experiments in no way undermines the value of the laboratory section; rather, these experiments increase the validity of the laboratory section by improving its relevance to the course. Students surveyed at the end of the summer 2011 course found the laboratory enjoyable— as opposed to students from summer 2010, who indicated that the laboratory portion of the course produced very little knowledge gain and utilized a disproportionate amount of their time.

Table 3: Required Laboratory Materials

<table>
<thead>
<tr>
<th>Number</th>
<th>Item</th>
<th>Item PN</th>
<th>Supplier</th>
<th>Qty</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7.1 Channel USB External Sound Card Amplifier</td>
<td>B0027EMHM 6</td>
<td>Various</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Breadboard &amp; Wire</td>
<td>438-1046-ND</td>
<td>Digikey</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>Inductor</td>
<td>M10135-ND</td>
<td>Digikey</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>Multimeter</td>
<td>Varies</td>
<td>Digikey</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>Battery Holder 9 V</td>
<td>BH9V-W-ND</td>
<td>Digikey</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>Battery Holder 3 V</td>
<td>BC22AAW-ND</td>
<td>Digikey</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>Capacitor 1uF</td>
<td>P5174-ND</td>
<td>Digikey</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>Capacitor 10 uF</td>
<td>P5134-ND</td>
<td>Digikey</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>Capacitor 100 uF</td>
<td>P5123-ND</td>
<td>Digikey</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>3.5 mm to 3.5 mm audio cable</td>
<td>AUD-1100-06</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>11</td>
<td>Linear Regulator</td>
<td>LM317TFS-ND</td>
<td>Digikey</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>Potentiometer</td>
<td>P3C3203-ND</td>
<td>Digikey</td>
<td>1</td>
</tr>
<tr>
<td>13</td>
<td>1.5 V AA Battery</td>
<td>N/A</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>14</td>
<td>9 V Battery</td>
<td>N/A</td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

As a result of evaluating the summer 2010 course, and in an effort to reduce cost, the USB oscilloscope and function generator were replaced with a USB sound card and the two 9V batteries were replaced with one 9V battery and one 1.5V battery. In the previous paper, we questioned whether reducing a few complex lab experiments to more frequent simpler experiments and using ad-hoc equipment would reduce recall of fundamental concepts. Based on
the results of the 2011 course and comparing those results to the on campus data collected, we conclude that the online students showed performance comparable to or greater than their traditional counterparts. The simplification of labs to basic experiments as well as the use of "ad-hoc" equipment produced no decrease in the understanding of fundamental concepts. It can be qualitatively stated that this reduction in complexity resulted in increased knowledge gain from the laboratory section. This conclusion is in-line with our goal of generating an online course of comparable or improved quality to an on campus course.

Table 4 provides a list of the laboratory components utilized in the summer 2011 circuits course. The total cost of the new lab kit was $34. The lab kit consisted of what would typically be found in an introductory circuits course, with changes in the tools and certain component values. The changes in component value were necessary to stay within the limited range of the sound card oscilloscope and power supplies that the students used.

Table 4: Lab Equipment Used in 2011 Course

<table>
<thead>
<tr>
<th>Number</th>
<th>On Campus Analogue</th>
<th>Online replacement</th>
<th>Equipment Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Oscilloscope</td>
<td>Ozilloscope Software &amp; USB sound card</td>
<td>Low frequency, low voltage, load</td>
</tr>
<tr>
<td>2</td>
<td>Function Generator</td>
<td>Ozilloscope Software &amp; USB sound card</td>
<td>Low frequency</td>
</tr>
<tr>
<td>3</td>
<td>Power Supply</td>
<td>Linear Regulator, 1.5 V and 9 V battery packs</td>
<td>Voltage, non-ideal source</td>
</tr>
</tbody>
</table>

The equipment that was used had frequency and voltage limitations. However, most of the limitations were used as part of laboratory experiments to illustrate key circuit theory concepts. For example, students were asked to input a signal that was higher than the oscilloscope's maximum allowed voltage. This demonstrated the concept of clipping and students were able to recognize (or were eventually told) that the voltage limitation of the sound card limited their ability to measure an accurate signal. The fact that batteries are a non-ideal source was also used to illustrate that many real-world devices exhibit less than ideal properties. Students were asked to short-circuit a battery and measure current through and voltage across the battery. Most students were able to conclude that the battery was not able to provide unlimited current or maintain a constant voltage when shorted and that it was a non-ideal source.

Laboratories for advanced concepts such as operational amplifier circuits and AC circuit analysis were handled through P-Spice, a circuit simulation software package. In the summer 2010 course, we found that students struggled with the advanced labs without someone knowledgeable in troubleshooting to help them. Students surveyed during the Summer 2010 course commented that they did not know how to use the oscilloscope, function generator, or any of the other tools provided to them. In order to mitigate those concerns, a few basic tutorials regarding lab equipment were provided in 2011 and more robust tutorials are planned for the 2012 course. It
should be noted that for many students, it is their first time using this equipment. The typical on
campus course has many teaching assistants to assist students, but we frequently found that
students would not contact online teaching staff for assistance for the laboratory portion.

A point of concern that some faculty may have is the use of a virtual oscilloscope and function
generator. It could be claimed that this equipment is not an accurate representation of their "real
world" counterparts. The user interfaces presented are far simpler than any of the equipment that
students may see in lab. However, the simplified interface may make it much easier for first
time users to make measurements and adjustments. For students at Binghamton University, we
expect that students will see a wide variety of oscilloscopes, function generators, and other lab
equipment as they progress through the program. Additionally, the multitude of different lab
equipment makes it very likely that a student would eventually need to learn how to use a
specific piece of lab equipment on their own anyway. Figure 6 below shows the oscilloscope
software, Oziilloscope by Christian Zeinitz, that was used.10

Figure 6: Oscilloscope Software

Textbook

Most students indicated that the textbook, Circuits by Ulaby, helped improve their
understanding of circuits. Only one out of
ten students responding to the survey
indicated that the textbook did not help
improve their understanding. The student
responses from the previous course using
Circuit Analysis by Irwin and Nelms
showed a similar response. Thus, the
textbook used may have little to no effect on
the level of student learning. It should be noted that Circuits by Ulaby is significantly less
expensive than Circuit Analysis by Irwin & Nelms. Additionally, many circuits texts such as
Pragmatic Circuits by Eccles can be acquired at little to no cost to students from publishers such
as Morgan & Claypool. The only difference is that the more costly texts have more tools to assist
the instructor. The individual instructor should evaluate and choose the text that most closely fits
with their needs.
Table 5: Textbook

<table>
<thead>
<tr>
<th>Text</th>
<th>Benefit</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circuit Analysis [Irwin Nelms]¹¹</td>
<td>Practice Problems, Wiley Plus environment</td>
<td>$180</td>
</tr>
<tr>
<td>Circuits [Ulaby, Maharabiz]¹²</td>
<td>Practice Problems</td>
<td>$90 + shipping</td>
</tr>
<tr>
<td>Pragmatic Circuits [Eccles]¹³</td>
<td>Basic Text</td>
<td>Free*</td>
</tr>
</tbody>
</table>

* Pragmatic Circuits is available to Binghamton University students via the university's subscription to Morgan and Claypool.

Communication

In the 2010 course we set up a forum for students to discuss in, with no guiding questions. The forum was lightly monitored by the professor and teaching assistant. Communication in the 2011 course utilized new strategies that provided for guided discussions and incorporated both asynchronous and synchronous methods of communication.¹⁴ A weekly discussion was held, and teaching assistants and the instructor held office hours for a total of six hours a week. In addition to the discussion, forum and office hours, students were able to reach the teaching staff via email.

Communication was a critical component of our online course. Methods of communication were limited to email, forums, and discussion & office hours through the BigBlueButton whiteboard application. Instant messenger was no longer provided, as it required an excessive amount of time for the staff in summer 2010. It was believed from the data gathered in the summer 2010 course that utilizing an interactive whiteboard would improve communication. While our experience indicates that an interactive whiteboard can be used with great success, we ran into some technical issues. BigBlueButton was utilized both for office hours and the weekly discussion session. At the end of the summer 2010, it was concluded that both asynchronous and synchronous communication methods would be beneficial to students. The data obtained in the Summer 2011 class indicates that that combining both methods is more beneficial than using solely one method.

The simplest to implement method was asynchronous discussion. Prior research indicates that goal instruction in "generating as many reasons as possible" is beneficial.¹⁵ Our observations seem to agree with these findings. We found lower-knowledge students generally answered after the higher-knowledge students. For example, one of our discussion questions asked students to generate ideas of how AC and DC can be used, which resulted in a wide variety of answers. However, it was also found that overly structuring the discussion led to regurgitation of answers. Students simply restated what the posters above them stated rather than formulating their own thoughts if the question asked was too structured. In addition, students often failed to recognize when their classmates had made incorrect statements in the forum. This type of behavior differed greatly from the 2010 forums which were unstructured.
Another communication utility mentioned at the 2011 ASEE conference was Piazza. Piazza is an online service that provides an interactive, asynchronous method for students to ask and answer questions. Piazza is a cross between a wiki and forum where questions are presented by students and faculty, and responses are presented in a forum. We may attempt to use Piazza in the 2012 course.\textsuperscript{16}

Synchronous discussion was difficult to implement. Using BigBlueButton, the class gathered for a mandatory weekly hourly meeting. It was found that most students did not attend the weekly discussion session, and only a few students attended the office hours. Future courses may need to incorporate more discussion time, because the weekly hourly meeting did not provide sufficient time to go over problems. Students were given flexible options regarding meeting times, but still disregarded the discussion session.

The concept of an interactive whiteboard may be desirable, but our use of the BigBlueButton software indicates otherwise. BigBlueButton frequently was slow, voice was unable to be used, and controls were awkward. Most students disliked the use of BigBlueButton because the software application did not perform well.

Although our experience in the summer 2011 course with BigBlueButton was negative, new updates to BigBlueButton have made it a more effective tool. Instructors interested in creating future online courses should also evaluate other available conferencing technologies, such as Adobe Connect and Citrix GoToMeeting.

Both asynchronous and synchronous methods promote our goal of moving away from a lecture-centric course to a problem-solving oriented course. There have been various studies claiming that either asynchronous or synchronous methods are better.\textsuperscript{17} We concluded from the 2010 and 2011 experiences that a combination of both methods helped us achieve our goal.

**Scalability of software and student opinion of software**

Both Moodle and BigBlueButton had difficulty scaling to an increase in the number of users. Performance issues are well documented for Moodle.\textsuperscript{18} However, from the students surveyed, 50\% indicated that the Moodle interface was preferable to Blackboard and 50\% had no opinion. No students agreed that Blackboard was a better interface. It can be concluded that users have a stronger preference for Moodle. Our educational paradigm is better supported by Moodle because courses in Moodle are easily organized by week or topics. Additionally, the modular nature of Moodle's architecture makes it easier to maintain. Adding and removing Moodle components is for the most part, as simple as adding or removing a directory.

**Student Learning outcomes**

Performance of the online course was compared to traditional students using two concept inventories. The same concept inventory was given to traditional students as a basis for
Concept inventories are multiple choice examinations designed to test whether a student has mastered concepts. Each question targets a specific concept and each answer choice within a question is designed to diagnose misconceptions. An example question from the concept inventory is given below in Figure 8.

**Figure 8: Concept Inventory Example Question**

What is the power dissipated by element A?

![Diagram of a circuit with a voltage of 5V and a current of 10A passing through an element A.]

- a) +50 W
- b) -50 W
- c) +2 W
- d) -2 W
- e) None of the above.
- f) 

The concept inventory question above targets the understanding of supplied and dissipated power. Answer choice C indicates that the student does not know how to calculate power. Answer choices B and D indicate that the student cannot distinguish between supplied and dissipated power. By generating distracters such as the former, we are able to tabulate areas that the general student population does not understand and perform corrective action.

The small concept inventory evaluation is a questionnaire consisting of four questions that we developed to illustrate whether students were retaining key circuits concepts. The results of the small concept inventory indicate that students using the online model we developed performed better than, or on par with, students taking the course in a traditional environment. The small concept inventory was given to both on campus sophomores and students in our 2011 circuits course. The concept inventory tested the concepts listed below:

a) Can the student perform a basic voltage division without inverting the resistor or sign?
b) Can the student combine resistors in parallel and series?

c) Can the student correctly identify or solve for an Op Amp problem?

d) Can the student formulate the relationship between voltages given a practical power supply?

Figure 8: Small Concept Inventory Comparison: Online vs. traditional students

As can be seen from Figure 8, traditional and online student performance was very similar. However, the online students fared much better in questions that required analysis, while the traditional students fared better at problems that required memorization. The learning outcomes, Table 6, indicates learning outcome, a short description, and percentage of students from the online and traditional courses meeting the outcome. Each topic represents either a group or a single question pertaining to the topic. The table offers selected learning outcomes and does not include all learning outcomes tested or studied in this project. Additionally, the sample size of the on campus students is significantly greater than the sample size of the online students. The sample size of online students consisted of ten students whereas the traditional student sample size was 78.
## Table 6: Fulfillment of Learning Outcomes

<table>
<thead>
<tr>
<th>Topic</th>
<th>Description</th>
<th>% Online students meeting objective</th>
<th>% Traditional students meeting objective</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PSC</strong></td>
<td>Apply PSC to a circuit to determine whether a circuit is consuming or supplying power.</td>
<td>100%</td>
<td>79%</td>
</tr>
<tr>
<td><strong>Ohms Law</strong></td>
<td>Recognize ohm’s law. Apply ohms law in a circuit with one resistor and one voltage source.</td>
<td>100%</td>
<td>79%</td>
</tr>
<tr>
<td><strong>Resistor Combinations</strong></td>
<td>Compute equivalent resistance, current in series and voltage in parallel. Student will also be able to identify that conductance is inversely proportional to resistance.</td>
<td>100%</td>
<td>81%</td>
</tr>
<tr>
<td><strong>Kirchhoff's Laws</strong></td>
<td>Use KVL and KCL in simplest circuits.</td>
<td>60%</td>
<td>68%</td>
</tr>
<tr>
<td><strong>Voltage and Current Divider</strong></td>
<td>Identify when and how to use the voltage and current divider.</td>
<td>90%</td>
<td>72%</td>
</tr>
<tr>
<td><strong>Loop Analysis</strong></td>
<td>Apply loop analysis to solve a circuit containing at the minimum one current source, one voltage source, and one dependent source with two or more loops.</td>
<td>60%</td>
<td>55%</td>
</tr>
<tr>
<td><strong>Op-Amps</strong></td>
<td>Analyze problem using ideal Op Amp model.</td>
<td>80%</td>
<td>68%</td>
</tr>
<tr>
<td><strong>Thevenin&amp; Norton</strong></td>
<td>Student will be able to calculate the Thevenin equivalent voltage and resistance for: A circuit with independent sources by using the equivalent resistance method. A circuit with dependent sources by using the external source method.</td>
<td>60%</td>
<td>57%</td>
</tr>
<tr>
<td><strong>Inductors and Capacitors</strong></td>
<td>Explain the definition of a capacitor and inductor, as well as their voltage and current relationships. Student will compute equivalent capacitance and inductance in series and parallel configurations respectively.</td>
<td>86%</td>
<td>69%</td>
</tr>
<tr>
<td><strong>RC/RL Circuits</strong></td>
<td>Analyze a first order circuit containing a capacitor, resistor, and voltage source using differential equations and various analysis techniques.</td>
<td>70%</td>
<td>71%</td>
</tr>
<tr>
<td><strong>AC Steady State Analysis</strong></td>
<td>Calculate impedances of resistors, capacitors and inductors in parallel and series.</td>
<td>90%*</td>
<td>48%*</td>
</tr>
</tbody>
</table>

*Students in the on campus section did not yet learn AC analysis at the time they took the concept inventory examination.*
The results of the larger concept inventory indicate that students using our online model performed better or at least on par with students taking the course in a traditional environment. Students taking the course online took the examination via a web interface whereas students in the traditional model used a multiple choice answer sheet. Both groups were given as long as they needed to complete the exam.

In a circuits course, we recommend emphasizing the misconceptions listed in Table 7 below. These misconceptions are based upon results of the large scale and small scale concept inventory evaluations.

### Table 7: Topics to Emphasize

<table>
<thead>
<tr>
<th>Topic</th>
<th>Emphasis</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ground</strong></td>
<td>Emphasize the arbitrary nature of ground and why it is not always &quot;zero&quot;.</td>
<td>Most students could not understand that ground is an arbitrary construct and that ground is not necessarily zero.</td>
</tr>
<tr>
<td><strong>Units</strong></td>
<td>Emphasize the necessity of correct units.</td>
<td>Many student mistakes in the course and the concept inventory involved using incorrect units.</td>
</tr>
<tr>
<td><strong>Kirchoff's Laws</strong></td>
<td>Emphasize KVL and KCL over voltage and current divider.</td>
<td>Students frequently tried to use voltage or current divider in situations where they should have used KVL or KCL. It would not represent a problem if students applied the divider correctly.</td>
</tr>
<tr>
<td><strong>Op Amps</strong></td>
<td>Emphasize the ideal Op Amp model and deemphasize topologies.</td>
<td>Students frequently tried to match the topology of the circuit and failed to solve the circuit correctly. Students memorizing rather than deriving solutions were more likely to get the correct answer.</td>
</tr>
</tbody>
</table>

### Transition & Problems

Although we overhauled our class to match our model in one semester, it is recommended that faculty looking to transition their traditional course to the online environment take their time. It took a considerable amount of time to prepare lectures, homework, experiments, and other activities in the course. An instructor looking to use this model for their online course can start their online course in the traditional satellite model and transition to our model over the course of a few semesters.

Mason indicates that collaboration, rolling intake, tutor workload, motivation of students, and sustainability are the main issues in teaching and learning online.\(^21\) Our methodology does not attempt to completely resolve these issues; however, it does seek to mitigate them. Our model does not take rolling intake into account since we work within the confines of a semester structure. Tutor workload is something that we were able to resolve. In the 2010 course, we were provided with one teaching assistant. In the 2011 course, we utilized two paid teaching assistants. In the future we hope to recruit multiple undergraduates to help tutor in the forums.
and virtual office hours to increase availability and reduce workload on any specific member of the teaching staff. In this online model, it is imperative that there be as many responsive teaching assistants as possible to maximize availability via both synchronous and asynchronous discussion.

A large portion of the problems encountered in our model were due to the fact that many students did not expect the model. Students expected a rigid model where lecture would provide them all of the information they need to pass the course. They expected that all material on quizzes would be covered in the lecture. Students expected that homework would be checked. In essence, students expected to be monitored. Because of the paradigm shift to a model where lecture is treated as a less important starting point, students commented that they felt there was no relation between the quiz, homework, and lecture even though the concept tested was the same.

The last issue that Mason mentions is sustainability. We believe the modularized structure of our design renders the course material easily reusable. Content swapping is very simple once the initial course curriculum is laid out. Moodle was chosen because of its sustainability and modularity. However, the software that we chose may not scale well to larger courses. Our current setup can handle less than 1000 students. An issue that may be of concern is when ten large classes try to submit a quiz all at once. In our implementation, Moodle and BigBlueButton had scalability issues and performance would have to be considered as the number of courses and students increase. Our Moodle and BigBlueButton servers were hosted on a Debian based Dell Optiplex 760 with 4 GB of Ram and a Intel Core2 Duo processor operating at 1.8 GHz.

**Strategies**

A few key elements contributed to the success of the model. We believe an instructor should focus his or her efforts on the following areas:

1. Reduce laboratories to short experiments, asking students to demonstrate fundamental concepts
2. Find new inexpensive and readily available equipment to assist in the short experiments
3. Reduce length of lecture and focus on key concepts, adding extra material in supplemental videos or documents
4. Utilize both synchronous and asynchronous methods of communication
5. Concentrate on examples and experiments. Deemphasize lecture as the central element in the course
6. Create a course specifically for non-majors that emphasize how circuits relates to their major
Conclusion

Our results indicate that the online model used in the 2011 course is successful and can be considered a viable framework for the online environment. New lecture and laboratory formats greatly improved student retention as well as satisfaction. Students were more receptive to the 2011 course flow and structure than to their 2010 counterparts. Our online model used in the 2011 course resulted in increased performance for the more capable students, but reduced retention rates for less capable students. Students taking the online model scored the same or better than the traditional students in our concept inventory tests. As educational pedagogy is an iterative process, we plan to run the same course with the modifications listed in this paper in the summer of 2012.
Appendix

Midterm Project: Build a power supply
Online Circuits
ECE 260
Assigned 6/8/2011, Due 7/20/2011 at 1 AM
Instructor Kevin P. Pintong

The Project:

Introduction
You are an engineer at Mushimoto Industries and have been assigned the task of building a power supply. Below you are given the electrical and physical specifications that need to be met as well as the total price constraints for the components. It is suggested that you work on meeting the electrical requirements first then look for the parts. It is also suggested that you use a website such as www.digikey.com and/or other electronics-vendors when you are searching for the parts that match your schematic. When you have found all the parts that match your design, within a reasonable tolerance to account for real values, it is required that you make a part list. This part list should look like the Bill of Materials (BOM) provided in the examples section below. Finally, you will write a brief report that will discuss your design and your findings.

Groups & Grading
You may choose to work alone or in groups of two. Groups greater than two are prohibited. This project will account for 15% of your total grade.

Submit
Save the file using this format: Milbury_Pintong_260Mid.pdf or Poole_260Mid.pdf if you worked alone.

Your project will consist of:

1. Schematic of the power supply. This will include the components and wiring with clear labels.
   Note: Points may be deducted for messy wiring or missing labels.

2. Bill of Materials that include price, quantity, values, sources, and other pertinent information.
   Note: Please use the example BOM provided as a template or guide on how to complete this.

3. Brief report that includes:
   a. Description: This will include outlines to the project and its requirements.
   b. Design: This will include the justifications for your design choices. Please show calculations, equations, pricing, or any other justifications made to choose a part or design choice. For the justification you will want to mention any alternate designs or parts that were considered and state why you chose the ones being used in your design.
      Note: The design section will be the most important part of the report; so be explicit.
   c. Results: Results from the design you chose. Use calculations based off your components chosen to meet your design and compare them to the given requirements. Also include any limitations met by your design as well as anything else of note.
      Note: Real world parts have a tolerance (they are non-exact), you can ignore these in your calculations.
Requirements:

You will be given an AC/DC converter that is rated at 16 V 3A. In addition to the converter: the casing, connectors, wires, and voltage displays will be provided. You do not need to include these in your BOM or factor them into your price.

Electrical Specifications
1) The power supply must consume less power than the AC/DC converter is able to supply
2) The power supply must have three channels:
   a. Channel one (1) must provide 0-15V, 1 A max current draw
   b. Channel two (2) must provide 0-15V, 1 A max current draw
   c. Channel three (3) must provide 0-6 V, 1 A max current draw
3) All components must be able to withstand the maximum load

Physical Specifications and Features
1) Choose switches so that a single channel at a time can be selected
2) Choose a dial (potentiometer) for the channels that can adjust the voltage in increments of 0.1V
3) Include LEDs in your design to verify which channel is selected
4) Determine any necessary heat sinks and include them in the BOM. Hint: check data sheets

Price Constraints other
1) The whole system is not to exceed $25 in cost
   Note: Cost will be flexible if you can provide reasons on why it cannot be met along with other requirements.
   Bonus points will be awarded to the group that has the cheapest design that can meet specifications.
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7. Personal Conversation(s) with Dr. Jason Loew.


9. Personal Conversation(s) with Dr. Christopher Twigg.


