A Hybrid Approach to a Flipped Classroom for an Introductory Circuits Course for all Engineering Majors

Dr. Steven G Northrup, Western New England University

Dr. Steven G. Northrup, an Associate Professor of Electrical and Computer Engineering at Western New England University, earned a BSEE from the University of Michigan, Ann Arbor, and an MSEE & Ph.D. from Vanderbilt University. Before attending Vanderbilt University, he worked in the defense industry in Whites Sands, NM and in the automotive electronics industry designing climate control systems for Ford Motor Company. At Western New England University, he teaches Intro to Engineering, circuits I & II, senior lab, and embedded controls courses. His research interests are robotics, embedded control systems, and teaching methodologies and effectiveness.

Dr. John J. Burke P.E., Western New England University

John Burke received the B.S.E.E. degree from Northeastern University in 1984, and the M.S.E.E. degree from University of California at Los Angeles in 1986, and the Ph.D. degree from the University of Massachusetts Amherst, in 1993.

Dr. Burke joined the faculty of Western New England University (WNE) in 2000 and since 2004 he has been an assistant professor of electrical and computer engineering. Dr. Burke's primary teaching interests are Electromagnetics, Physics of Semiconductor Devices, High Frequency Circuit Design, Antenna Design and Analog Electronics.

Prior to joining WNE, Dr. Burke was with the EM Observables Division of Mission Research Corporation (MRC) from 1995 to 2000. From 1992 to 1995, Dr. Burke was with the MacNeal-Schwendler Corporation (MSC) Corporation. From 1990 to 1992, Dr. Burke was with Compact Software as a senior research engineer. From 1987 to 1990, Dr. Burke was with the Microwave Electronics Laboratory at the University of Massachusetts. From 1984 to 1986, Dr. Burke was with the Hughes Aircraft Corporation.

A Hybrid Approach to a Flipped Classroom for an Introductory Circuits Course for all Engineering Majors

Abstract:

The use of technology that allows students to view lectures or concept modules outside the classroom has become popular in recent years. The most straightforward and accepted definition of a flipped-classroom was given by Lage, Platt, and Treglia "Inverting the classroom means that events that have traditionally taken place inside the classroom now take place outside the classroom and vice versa"[1]. While many professors and instructors have taken the approach to completely flip the classroom, where the lectures are recorded and the classroom activities are practice problems and perhaps group learning, this paper presents a hybrid approach. Researchers have pointed out that students prefer in-person lectures to video lectures but also prefer interactive activity-based classes to lectures.[2,3] Therefore, the authors of this paper chose to implement and assess a hybrid approach to the flipped-classroom model. Approximately 40% of the lectures were recorded affording time for in-class time problem solving and class discussions of problem solving approaches. The balance of the lecture time was allocated for a traditional lecture style. The time spent in lecture, however, was not a traditional lecture approach. The lectures were interactive where students were required to participate in the problem solving. The lecture classes were small enough, no more than 32 students per classroom, to allow for instructor-student interaction.

This paper presents a detailed discussion of the course delivery – how the classroom time was allocated, how the laboratory time was allocated, and how technology was utilized. A comprehensive summative survey was voluntarily completed by the students. The results of this survey will be discussed.

Background:

Over the past few years, there has been a tremendous interest in the flipped-classroom and many authors have written papers discussing the course method and results. There have also been a few papers that have reviewed the literature and provided summaries of the findings.[2,4] Before reviewing the literature, Bishop and Verleger, found it helpful to define what delivery methods are included in "flipped-classrooms". They "define the flipped classroom as an educational technique that consists of two parts: interactive group learning activities inside the classroom, and direct computer-based individual instruction outside the classroom."[2] Herreid and Schiller use a similar definition but also discuss "Hybrid courses" and "blended courses" (that) have students learning their subject matter via a combination of traditional classroom interactions and some form of internet-based learning"[4] Both papers state that there are mixed results for the learning outcomes from flipped-classroom courses. Many other authors have shown slight improvement in student outcomes[5,6,7,8,9,10] while using the flipped-classroom learning method. But many other authors stated that their results were mixed or that there was no significant difference between student outcomes when comparing the flipped-class room students and traditional classroom students.[11,12,13,14,15] Cavalli in a study of four different engineering classes found that students in two of the courses had neutral to slightly negative outcomes while students in the other two courses "seemed to benefit".[14] Fitzgerald found that there was slight improvement in standardized testing (American Chemical Society analytical chemistry examination) but the data size was "too small to be statistically significant".[15] The student outcomes from in-class exams and student GPA's did not change and student GPAs were not significantly different.[15]

O'Flaherty and Phillips completed a scoping review of the use of flipped classrooms in higher education and with the purpose of completing a "comprehensive overview of relevant research regarding the emergence of the flipped classroom and the links to pedagogy and educational outcomes, (to) identify any gaps in the literature which could inform future design and evaluation" Their results indicated that there was a lot of indirect evidence of improved outcomes and student/professor satisfaction when using the flipped classroom method but that there was a lack of conclusive evidence that the flipped-classroom method affects lifelong learning.[16] While this may be true, the research reviewed for this paper, and this paper itself, did not intend to measure the effect of flipping the classroom on students' propensity toward or skills in lifelong learning.

The background for this paper concludes with review of the relevance of the findings of He, Gajski, Farkas, and Warschauer. Their paper discussed the implementation of a flexible hybrid instruction model for a low-level electrical engineering course. While their focus was different than this paper, it is helpful for understanding the results of this paper. They found that class attendance only predicted student performance for difficult course material and that students with too much time on their hands did not manage their time well. They also found that motivation predicted exam performance "especially when the content is challenging."[17] Finally, and most relevant to this paper, they found that the success of their hybrid format depended upon "student skills and course difficulty."[17]

Introduction:

An introductory circuits course at Western New England University (Springfield MA), with students majoring in all engineering disciplines that are required to take the course, was redesigned to use a hybrid flipped-classroom approach. Research has shown that students prefer in-person lectures to video lectures but also prefer interactive activity-based classes to lectures[2]. In order to cover all the material in the curriculum for the course, it would be difficult to have the course solely activity-based hands-on learning and avoid delivering lectures completely. Since research indicates that students prefer in-person lectures over video lectures, the circuits course was redesigned to utilize a mix of in-person and video lectures and incorporated group problem solving. The lab time was also divided between group problem solving sessions and laboratory work.

This paper presents the structure of the hybrid flipped-classroom circuits course, the methods used in lecture to make them more interactive, a comparison of final exam outcomes from before and after the course design change, and comprehensive summative data from student surveys.

Course Structure Before and After Changing to a Hybrid Flipped-Classroom

Prior to changing from a traditional lecture and lab course, the circuits course had three lectures per week; homework assigned weekly, graded and returned a week later; three exams and a final exam; laboratory work mixed between a three week project, seven labs with brief write-ups, three recitations, and a lab practical exam.   After the course was changed, the lectures were mixed between 70% traditional and 41% video. Some of the video lectures were redundant with the traditional lecture content. The homework method was changed to utilize a weekly homework assignment that was delivered with a detailed solution. Approximately a week later, students took a quiz that was almost identical to one of the homework problems (numbers changed and sometimes slight changes in topology). The laboratory activities were unchanged and still included a mix of lab work and group problem solving. A midterm exam and a final exam were given. Shown in Figure 1 is an excerpt from the course syllabus describing the method of instruction.

Method of Instruction:

1. Lecture classes will be a mixture of in class instruction and recorded lectures. Students will be responsible for checking the course management system classroom for recorded lectures that they must watch before attending class.   Time will be allocated for in-class group problem solving.

2. Homework will be assigned weekly and the solutions will be provided concurrently. Homework is not collected.

3. Approximately once per week there will be a quiz that is based upon one of the homework problems from the previous homework set.

4. They will be a midterm scheduled as a common exam for all four lectures sections. Problems will be similar to quiz problems and or lecture material – full solutions are required.

5. The final exam will also be scheduled as a common exam for all lecture sections. Problems will be similar to quiz problems and or lecture material – full solutions are required.

6. The "lab period" will consist of recitation or lab. Recitation meetings will primarily consist of the students working problems in small groups, with individual instructor or lab TA assistance as needed. There may be discussion of laboratory experiments and their requirements. A portion of the lab time is used for project work. Laboratory procedures and requirements are described in a separate document.

Figure 1: Method of Instruction from the course syllabus.

Shown in the Appendix in Table A1 is the lecture schedule for the fall semester. The schedule was a guideline for content covered during each lecture day, thus the plan was more or less adhered to, with minor adjustments along the way. Time was allocated for in-class practice and lecture material was presented during the class or in a video before the class and sometimes after the class. The reason that lecture material was, at times, presented after the class was that methods were used to make the lectures more interactive. A problem was put on the whiteboard and the steps to solve it were not verbally described by the professor, instead the professor called on students to explain what should be done in each step to solve the problem. Typically, a row of students would be called upon per problem, but if it seemed that a student was not paying attention, she or he would be the next student queried for input. Another method that was used to help the students learn was what could be called "put your pencils down and listen". The professor would go through a problem with the students watching and listening and asking questions. Then after the problem was solved, the students would copy the problem from the whiteboard. Many students seen by this professor cannot effectively listen to a lecture, watch what is written, and write notes at the same time. Therefore, the slower lecture technique was utilized to allow students to listen and watch, and then to write their notes. The main challenge with this technique was the disparate rates at which students copy the problems from the whiteboard. Many of the quicker students had to wait for their peers to finish writing their notes. This issue will be addressed in the survey data section of the paper. Getting back to the video lectures posted after the class. At times, when the content was not covered sufficiently because of the slower in-class lecture techniques, a video lecture was recorded with redundant lecture content after the class – usually posted within a day of the lecture. The video lecture material is summarized in Table 1.

Table 1: Video Lecture Topics

Lecture Number	Topic Covered	Lecture Number	Topic Covered
1	Passive Sign Convention, I, V, & Power	10	Lab 4 Maximum Power: I, V, and P plotting from sim.
2	Power & Tellegen's Theorem	11	Thev. Theorem & Max Power
3	Parallel & Series R Circuit Reduction and dependent sources	12	Thev & Norton Eq. circuits with dependent sources
4	KVL and KCL and sign conv.	13	Max Power, Thev. with dependent sources
5	Voltage & Current Division	14	Digital Circuits Lecture 2
6	Nodal Analysis Lecture 1	15	Transient Analysis
7	Nodal Analysis Lecture 2	16	AC steady-state
8	Nodal Analysis Lecture 3	17	AC steady-state complex power
9	Op-Amp Lecture 3		

Table 2 shows the schedule for the laboratory experiments and recitations that were used for group work with hands-on problem solving. There were 7 lab experiments, 5 recitations where students worked in 2-person teams to solve practice problems or to work on their design project, 2 design project sessions (one for building and testing their design and one for rechecking their work and demonstrating a working project), and 1 lab session for the student's lab practical exam. In all, 14 activities were included in 13 weeks with 36% of the time allocated for hands-on group work and 64% of the time allocated for lab experimentation.

Table 2: Lab/Recitation Schedule

Week	Days	Topic
8/25 – 8/29	M – F	Lab 1: Introduction to Circuit Simulation Software
9/2 – 9/5	Tu – F	Recitation 1: Series/parallel circuits, voltage division/current division
9/8 – 9/12	M – F	Lab 2: Introduction to equipment, resistive circuits
9/15 – 9/19	M – F	Recitation 2: Nodal Analysis
9/22 – 9/26	M – F	Recitation 3: Design Project – Teamwork design activity
9/29 – 10/3	M – F	Lab 3: Op Amps
10/6 – 10/10	M – F	Design Project: Electrical Test
10/15 – 10/21	W – Tu	Design Project: Final Test
10/22 – 10/28	W – Tu	Recitation 4: Network Theorems
10/29 – 11/4	W – Tu	Lab 4: Network Theorems
11/5 – 11/11	W – Tu	Lab 5: Digital Circuits **and** Recitation 5: 1^{st} order transients
11/12 – 11/18	W – Tu	Lab 6: 1^{st} order transients
11/19 – 11/25	W – Tu	Lab 7: AC Steady State
12/1 – 12/5	M – F	Lab Practicum

Final Exam Outcomes: Before and After the change to Hybrid Flipped-Classroom

Student performance data from final exams is used for learning outcome assessment. Because final exams are not returned to students, the final exam from year-to-year is ostensibly the same. Comparison of final median performance on a question by question basis is possible where the questions are the same on the final exam before and after the course was changed to a Hybrid Flipped-Classroom. Data from final exams given in 2014 and 2012 are presented in Tables 3 and 4. Table 5 shows the metric values from 2012 subtracted from the 2014 metric values. A positive difference shows and improvement and a negative difference shows a degradation in outcomes. The average score on the problems improved in 7 of 11 problems, but the median score improved in only 4 of 11 problems. The median score also was unchanged in 3 of 11 problems (2 of these had a median value = 100). The median score also declined in 4 of 11 problems and by a significant amount, -15 to -20 points, in 3 of 11 problems.

The summary statistics show mixed results and cannot demonstrate that the Hybrid Flipped-Classroom method improved learning outcomes. There are some factors that were not controlled that could have affected the exam outcomes. First, the exam in 2012 was given in two parts. The first part was given during the last week of class and the second part was given during the final exam week. The 2014 final exam, however, was given in one sitting and had three hours allocated. Students who chose to take longer, were allowed to use more time. This was possible because the common exam was scheduled for an evening exam time with no exam following. It is likely that fatigue was a factor in some of the declining outcomes.

Table 3: 2014 Final Exam Question Topics and Score Metrics

2014 Exam Question Topic N = 124	digital circuit truth table	2 node super node	Thev -> Rth & max power	Determine Theve Eq Circuit	Op amp, gain, output, output range	1st order trans. and sketch	short answer, circ modeling	1st order transient graph and time const	Transform circ from t to w domain	KVL solution w domain with phasor sketch	AC-ss complex power, P & Q conserved	Exam Score includes a 3 point bonus problem
Problem Number	1	2	3	4	5	6	7	8	10	11	12	Exam Score
Value	5	10	5	10	10	15	7	15	5	10	15	100
Median	100.0	80.0	80.0	85.0	100.0	66.7	85.7	73.3	90.0	100.0	100.0	81.4
Average	97.0	75.4	78.2	77.0	85.6	66.2	87.0	67.8	87.4	89.1	87.7	84.1
Std dev	8.3	25.0	26.9	25.0	19.9	24.5	15.5	18.8	19.4	16.8	20.9	15.1

Table 4: 2012 Final Exam Question Topics and Score Metrics

2012 Exam Question Topic N = 34	ditital circuit truth table	2 node super node	Thev -> Rth & max power	Determine Theve Eq Circuit	Op amp, gain, output, output range	1st order trans. and sketch	short answer, circ modeling	1st order transient graph and time const	Transform circ from t to w domain	KVL solution w domain with phasor sketch	AC-ss complex power absorbed and delivered	Exam Score
Problem Number	9	1	3	4	5	6	8	13a + 13b	10	11	12	Exam Score
Value	5	10	5	10	10	15	6	15	5	15	10	100
median	100.0	100.0	100.0	80.0	100.0	73.3	100.0	73.3	80.0	93.3	85.0	83.3
average	96.9	91.3	79.7	74.5	83.4	79.3	96.1	67.2	70.5	82.8	79.5	81.7
std. dev.	10.3	16.0	34.4	28.8	22.5	16.0	7.9	22.2	25.6	23.9	19.5	13.2

Table 5: Comparison of Final Exam Score Metrics, 2014 Metric Value – 2012 Metric Value

Difference: 2014 - 2012												
Exam Question Topic	ditital circuit truth table	2 node super node	Thev -> Rth & max power	Determine Theve Eq Circuit	Op amp, gain, output, output range	1st order trans. and sketch	short answer, circ modeling	1st order transient graph and time const	Transform circ from t to w domain	KVL solution w domain with phasor sketch	AC-ss complex power Question changed slightly	Exam Score
Value	0	0	0	0	0	0	1	0	0	-5	5	0
Median	0.0	-20.0	-20.0	5.0	0.0	-6.7	-14.3	0.0	10.0	6.7	15.0	-2.0
Average	0.1	-15.9	-1.5	2.5	2.1	-13.1	-9.1	0.6	16.9	6.3	8.1	2.4
Std. Dev.	-2.0	9.0	-7.5	-3.8	-2.6	8.5	7.6	-3.4	-6.2	-7.1	1.3	2.0

Summative Survey Results and Discussion

At the end of the semester, following the final exam, students voluntarily completed a survey that focused on the delivery methods for the course, the student's perception of his or her performance, preference of where to seek assistance, etc… Because the survey was voluntary, some of the students declined (or simply forgot) to participate. About 60% (74 of 124) of the students enrolled in the class filled out the survey. Prior to the survey being given, students were informed that the purpose of the survey was to help the professor improve the course delivery for future students and to hopefully make learning more engaging, efficient, and fun for the future students. There were 39 survey questions and the results of most of these questions results are presented in this section. Some of the questions related to classroom configuration and related issues are not included in this discussion.

The first few questions were designed to see how students perceived their ease of learning before during and after the class. Figure 2 shows that a 54% of students would not have taken the class if it were not required. These students probably did not like their physics E&M class or thought the class would be difficult. Figures 3 – 5 depict the student perceptions about how difficult they thought the course would be or was before, during and after the course.

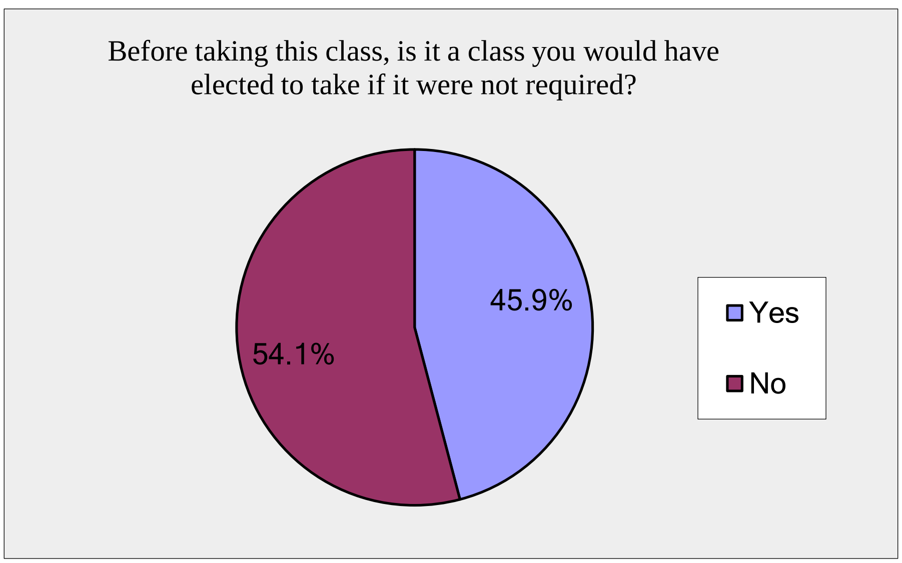


Figure 2: Percent of students who would choose the course as an elective.

Figure 3 shows that before taking the course only 6.8% of the students thought that the introductory circuits course would be easier than other classes they have taken or are taking and 68% believed that it would be more difficult than other courses. During the course, however, students' thoughts about the difficulty of the course improved: 44% of the students stated that the course was easier than they expected it to be and 33% of the students stated that the course was more difficult than they expected. By the end of the course, many more students thought the course was easier than they had anticipated: 45% of students stated that the course was a little easier and 12% stated that it was much easier (up from 5% during the course) and 22% of the students stated that the course was more difficult after they had finished. All the measures show that students' perceptions of the difficulty of the course improved throughout the course. This may be in part due to the delivery methods, but without similar data prior to the change to a hybrid flipped-class room, the delivery methods cannot be shown as causal.

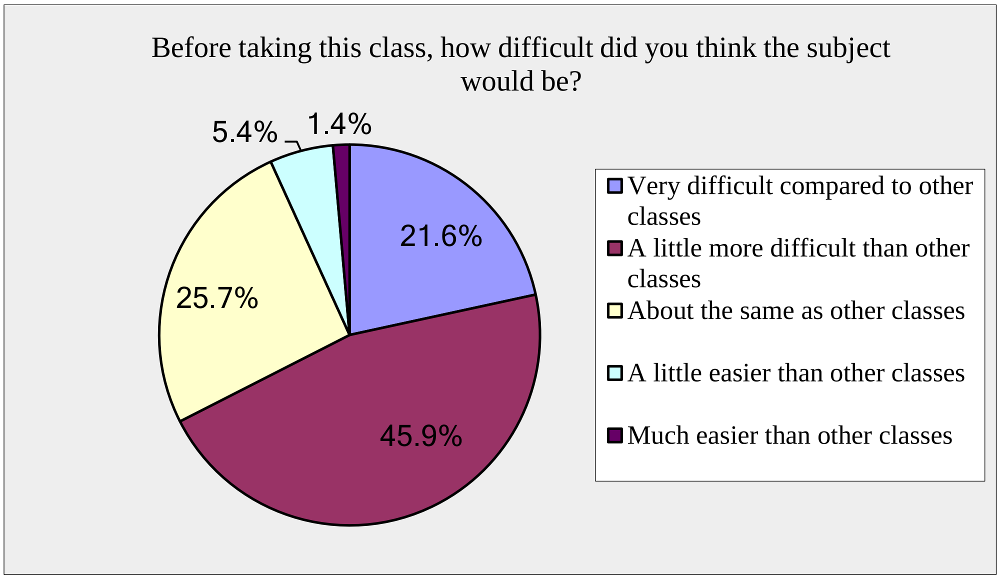


Figure 3: Perception of course difficulty before taking the course.

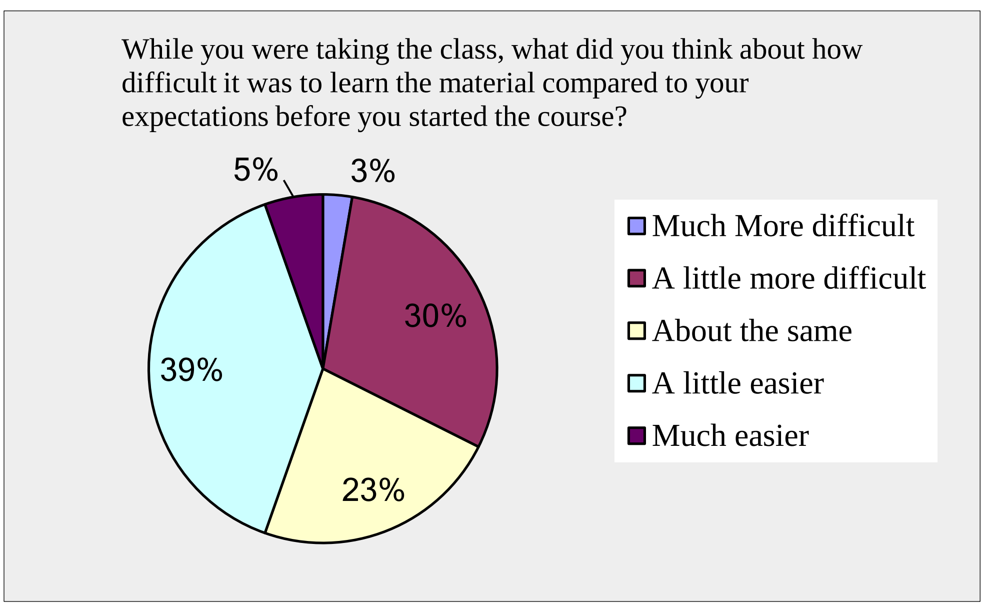


Figure 4: Perception of course difficulty during the course compared to before the course.

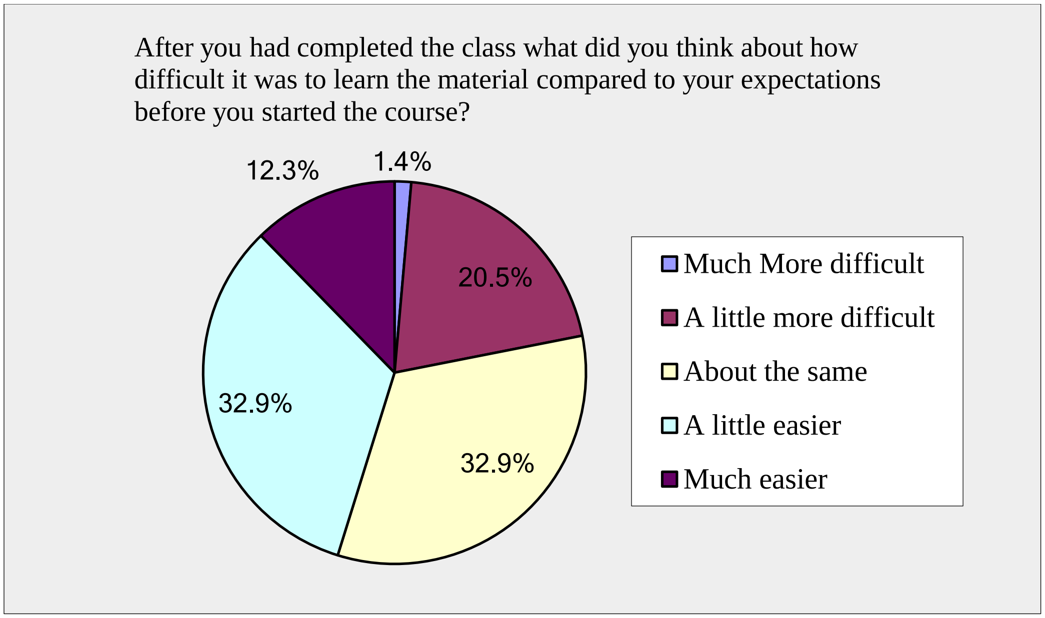


Figure 5: Perception of course difficulty after taking the course compared to before the course.

Students were asked how many, of the 17 available video lectures, they watched and how many times they watched the video lectures a second time. Figures 6 – 9 show the results from these survey questions.

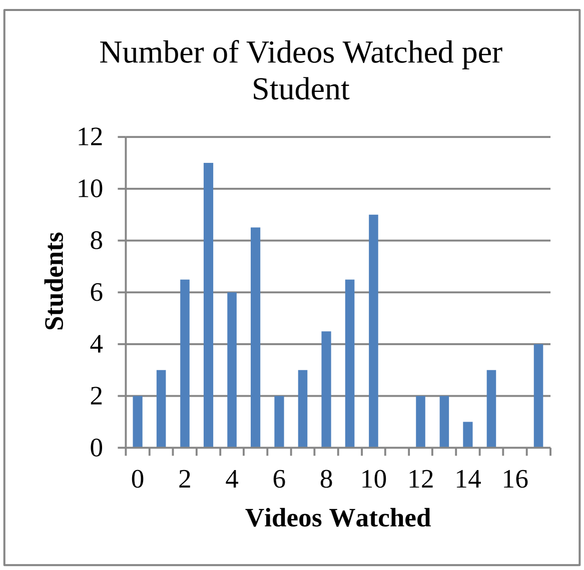


Figure 6: Number of video lectures watched by students

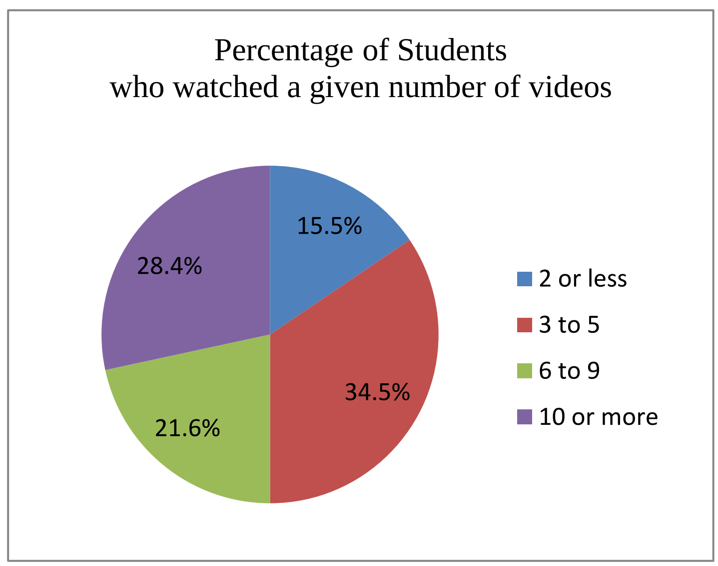


Figure 7: Percent of students who watched a given number of video lectures

It should be clear from the data that many of the students did not watching all of the video lectures. While 72 of the 74 students who participated in the survey stated that they had watched at least one video, 50% of the students watched 5 or fewer video lectures. This may be due to the fact that some course material was covered in traditional lectures, recitations, and in video lectures. The good news is that 28% of the students did watch 10 or more videos. The data in Figure 8 shows that only 22 of 74 students re-watched videos 3 or more times.

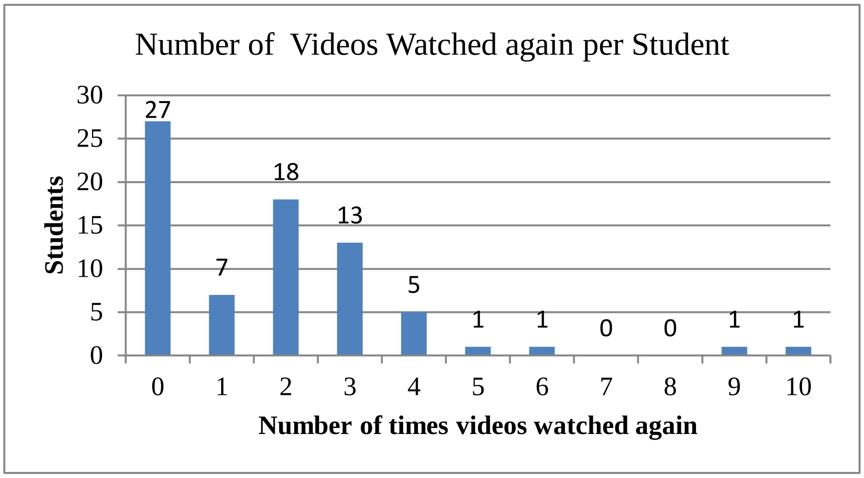


Figure 8: Number of students who watched a given number of video lectures multiple times.

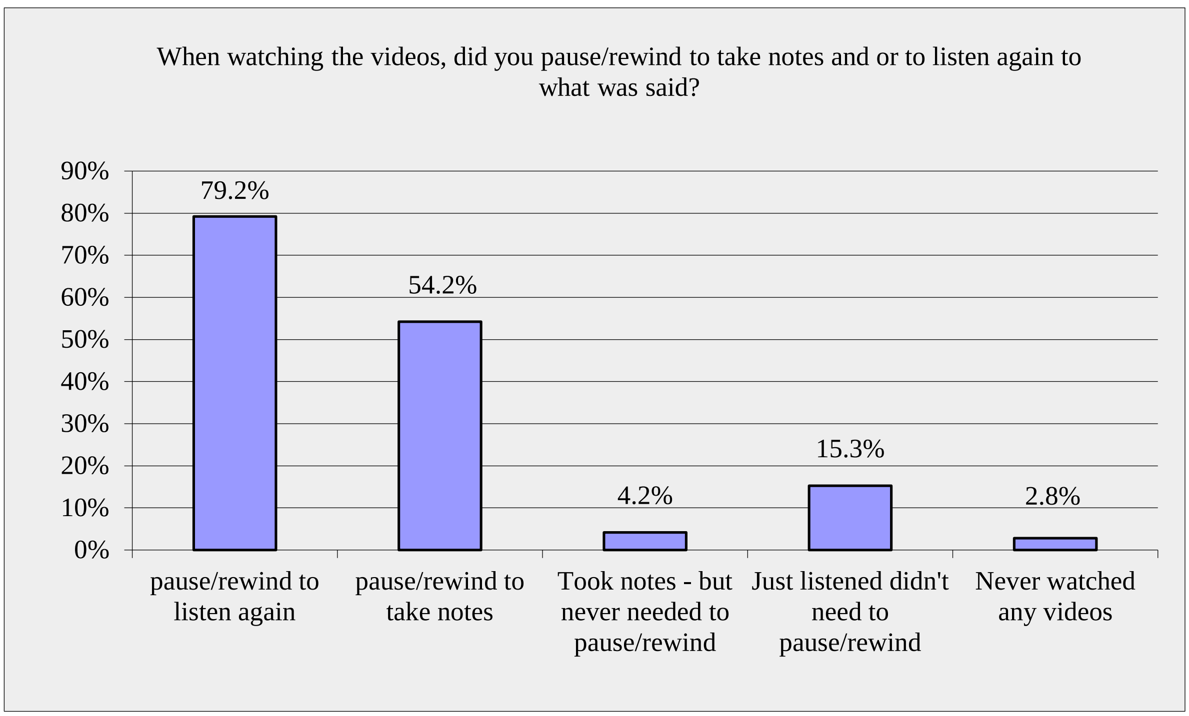


Figure 9: Learning activity while watching lecture videos (% of students who engaged in the activity is shown on the y-axis)

The data shown in Figure 9 suggests that the majority of students, when watching lecture videos, did so with active learning in mind. They either rewound the video to listen again or to take notes. Figure 10 shows perceptions of the usefulness of the video lectures for learning. Only

5.5% of the students reported that the videos were not helpful for learning. 92% of the students reported that videos helped them learn course material. Figure 11 shows that in conjugation with student perception that the videos are helpful to learning, 70% of the students prefer self-paced videos or a mix of videos and in person lectures.

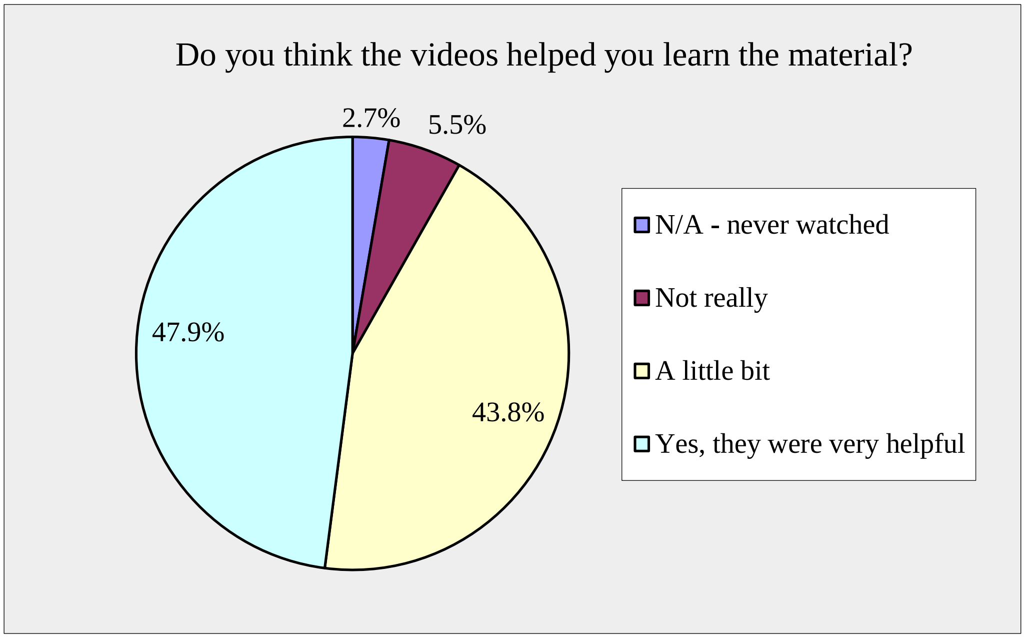


Figure 10: Student perception of helpfulness of videos for learning course material

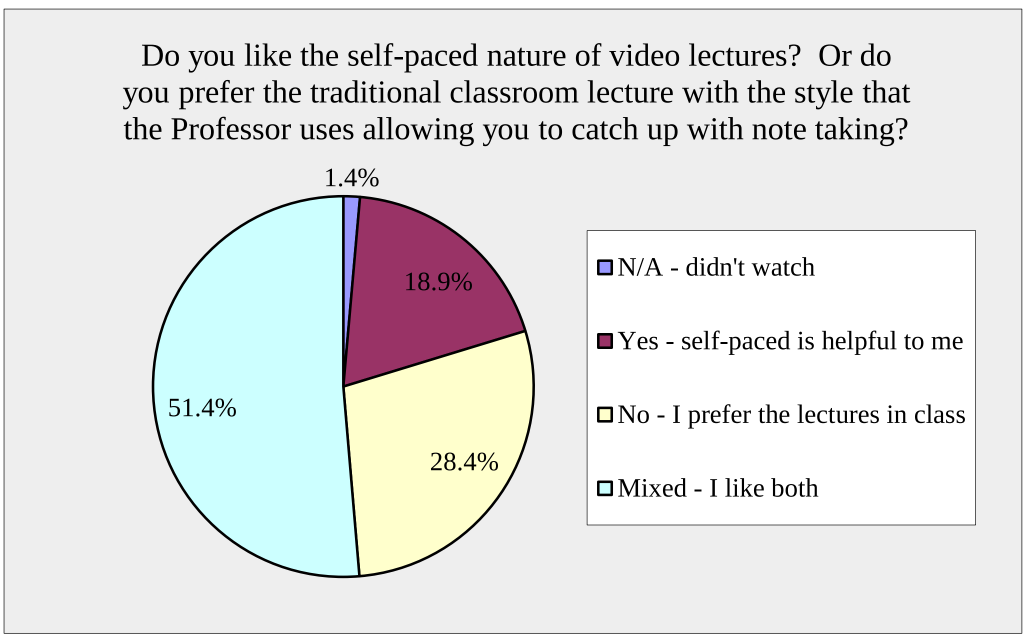


Figure 11: Students' preferences for traditional lectures, self-paced videos, or hybrid approach

Some of the video lectures were redundant with in-class lecture material. The professor wanted to know, in a follow up question to the "self-paced" question, whether videos were helpful for correcting errors in notes that were taken during an in-class lecture. Figure 12 shows the results of this survey question.

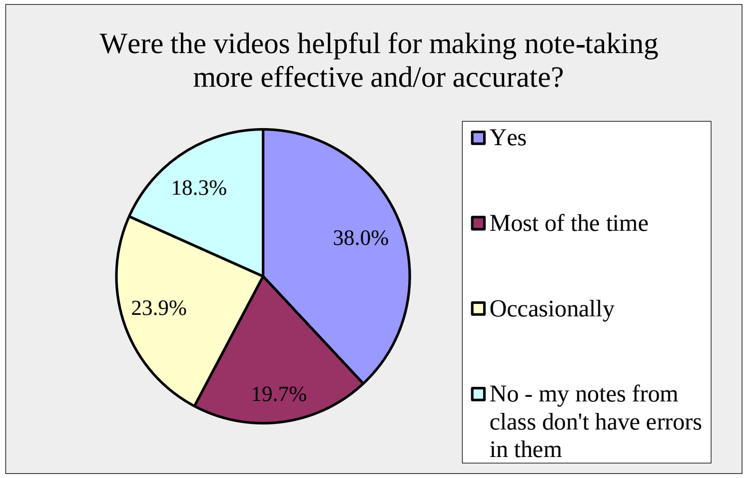


Figure 12: Students' perceptions of the benefit videos for note accuracy

As stated in the "Course Structure Before and After Changing to a Hybrid Flipped-Classroom" section of the paper, the professor would often cover a problem while asking the students to put their pencils down so they could listen and watch. After the professor was finished, he would allow students time to take notes and asked them to think about what they were writing – not just to copy the problem into their notebooks. This method was much slower than a traditional lecture where a professor covers a problem and moves on to the next problem or theory. The professor was curious to know whether there was a negative effect on the students by using the slower technique. The survey data shown in Figure 13 addresses this. Only 4.1% of the students stated that the technique was "waste of their time" and another 9.6% stated that "some of the time" the technique was not necessary. The vast majority, almost 70%, stated that the technique was helpful for their learning.

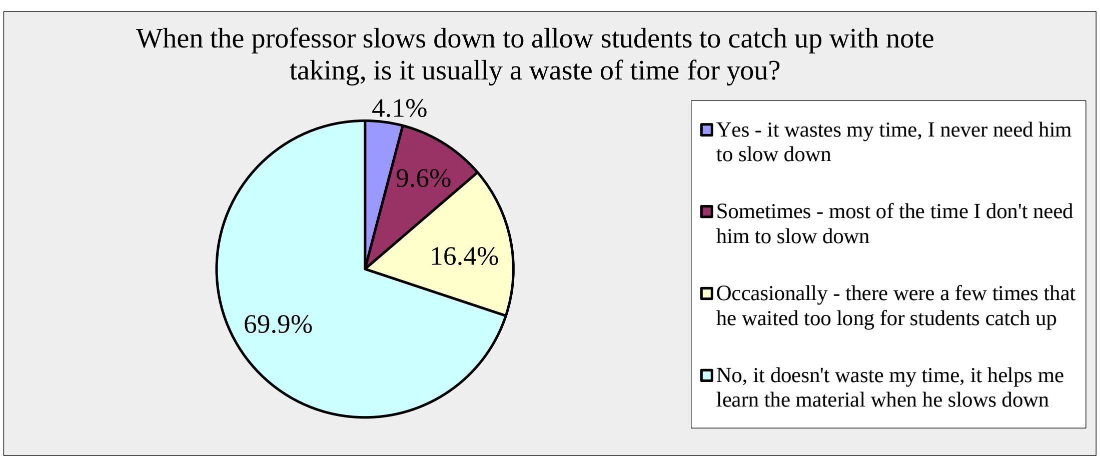


Figure 13: Students' perceptions of the benefit of the professor slowing down to let students catch up with note taking

The professor also wanted to know whether students thought more material should be covered by redundant lecture videos. The responses were open ended and collected and grouped. Shown in Figure 14 are the results for the survey question. The results were a bit difficult to tabulate because of the wording of the question and the open-ended responses. No, probably means that students answered the first question and stated that more material is not necessary. 0% could mean the same thing, "don't need more material" The 41%, chosen by 24% of respondents was a tabulation of students saying "leave the amount the same" So, adding the "No" and the "41%" categories, 17% + 24%, yields 41% of the students stating that the material covered by video lectures was sufficient. The other categories 25%, 50%, 75% and 100% are interpreted as a total percentage of videos lectures. Thus, only a small portion, 15% of respondents, stated that fewer (the 25% category) videos lectures should be used for the class. The fact that 39% of the students stated that more video lectures should be offered is bit strange, given that very few students watched all of the videos available. See Figures 6 and 7 for data on the number of videos watched.

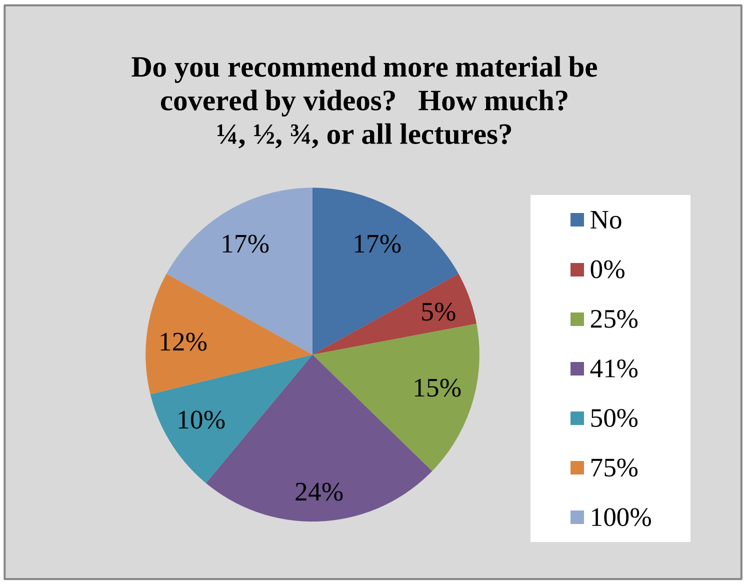
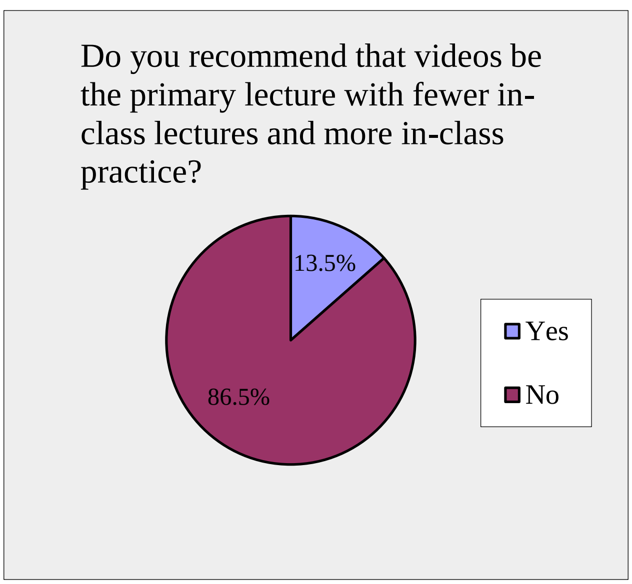
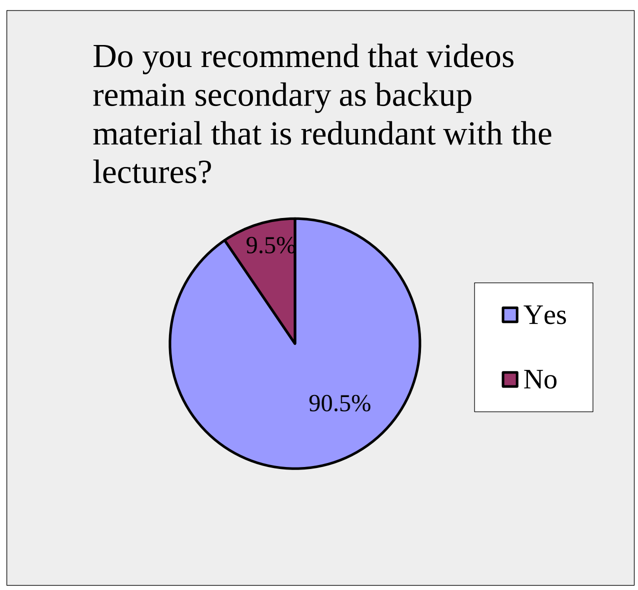


Figure 14: Students' preference for the amount of material to be covered by video lectures





Figures 15a and 15b: Students' preference for video lectures as primary or secondary mode of lectures

While it seems that students want more lecture material covered by lectures, a sizeable majority, 86 to 90% of students prefer that lecture videos not be used as the primary lecture mode. That said, almost 65% of the students recommend a hybrid approach to the delivery of lecture material with utilization of in-class exercises. Figures 15a, 15b and 16 show this data.

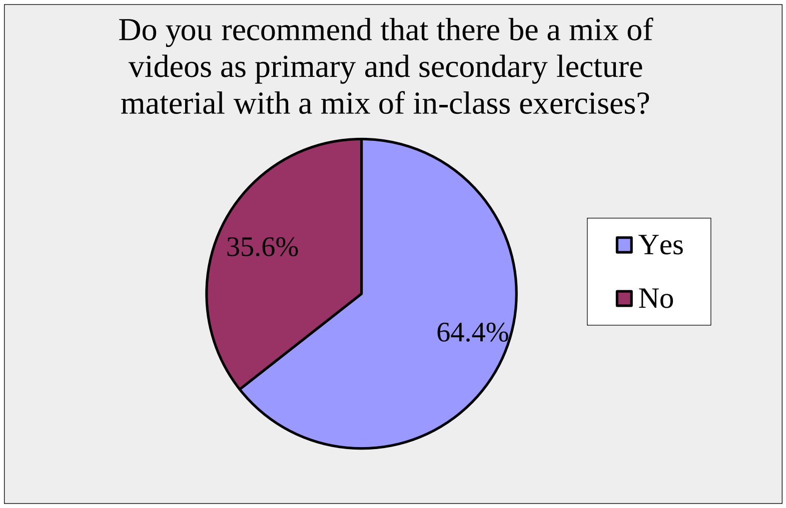


Figure 16: Students' preference for a hybrid approach to lecture material and in-class exercises

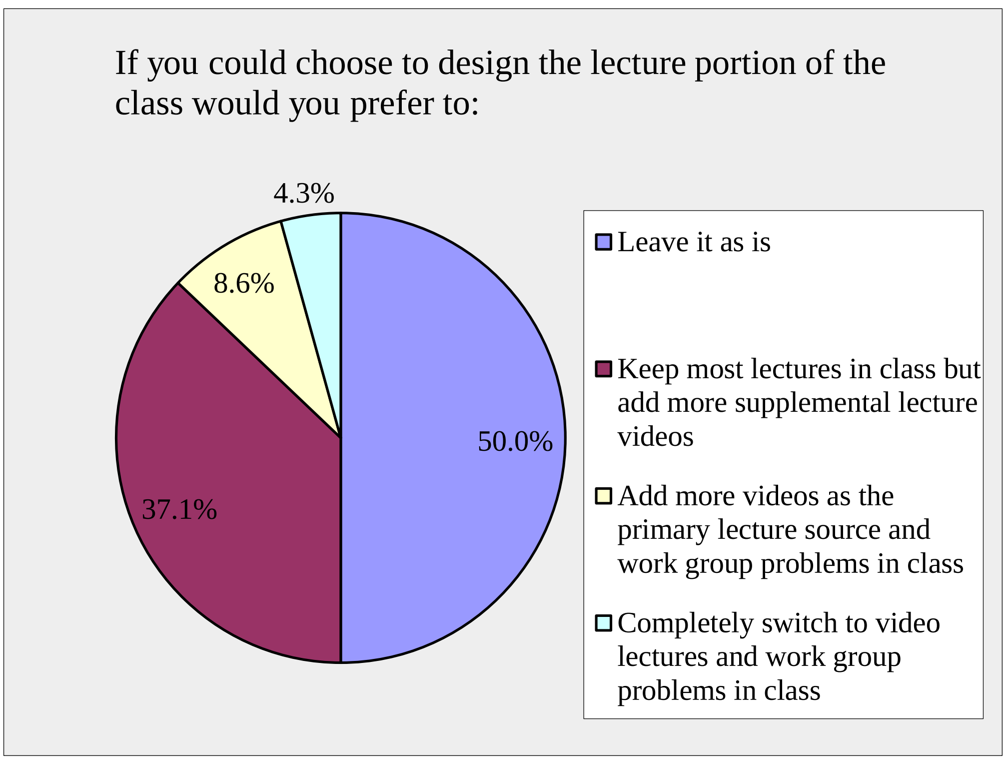


Figure 17: Student preference for a hybrid approach to lecture material and in-class exercises, follow up question.

Data in Figure 17, suggests that half of the students surveyed felt that the hybrid approach to lecture material contained a sufficient number of lecture videos and supplemental videos, but that 37% of the students wanted more supplemental videos. Additionally, 13% of the students wanted more videos as primary lecture material or to completely switch the class to lecture videos. This data is supported by the survey question results shown in Figure 18. 41% of the students surveyed have used other video lectures to help them learn the material for the course. The data depicted in Figure 19 also supports the idea that students want more video learning resources. 87% of the students stated that more videos showing solved example problems would be somewhat to extremely helpful for their learning.

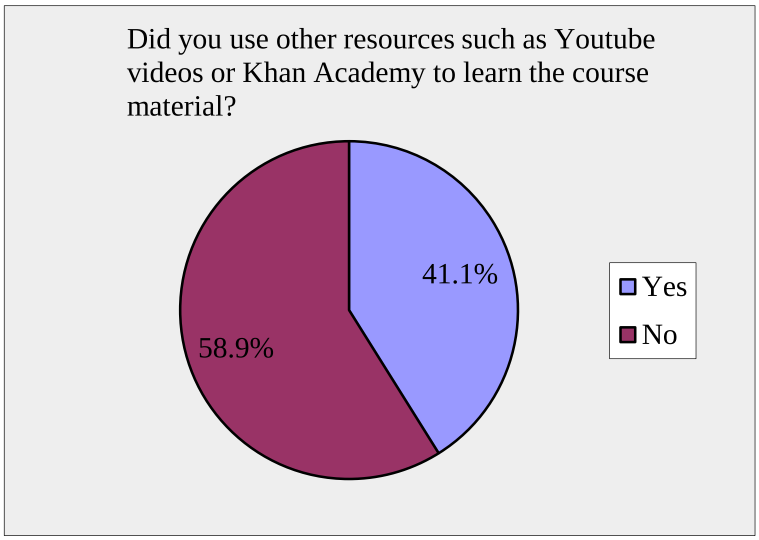


Figure 18: Students' use of external video lectures to learn course material

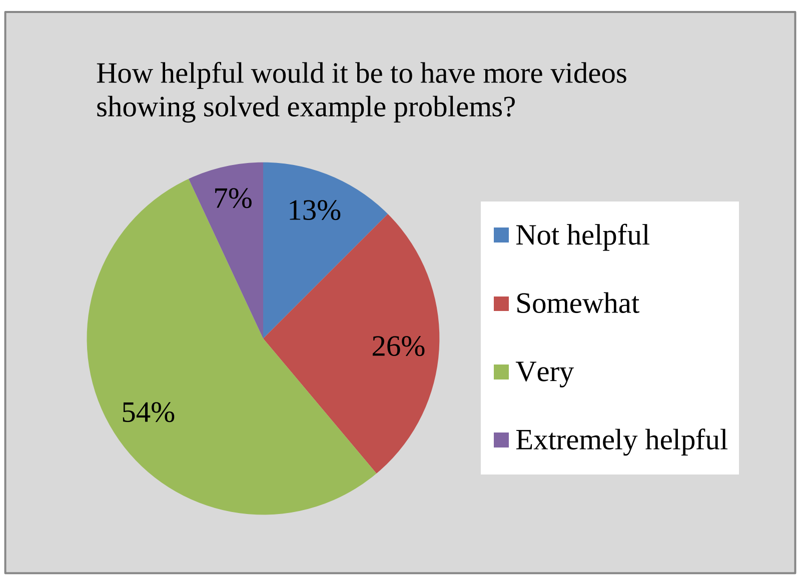


Figure 19: Students' perception of the helpfulness of videos showing example problem solutions

As described in the Course Structure section of this paper, the course included a recitation component that was mixed with the lab experiments. The vast majority of students stated that recitations were very helpful to their learning. Only 2.7% reported that the recitations were not useful. The Course Structure section also described how homework problems and solutions were provided at the same time and that a quiz followed about a week later with a question that was very similar to a homework problem. Students reported that they preferred this method of learning over the traditional method of homework assignment, homework collected, graded, and returned. The professor was concerned that this method may not be effective, so several survey questions were asked regarding: preference for the method, flexibility for time management, and procrastination.

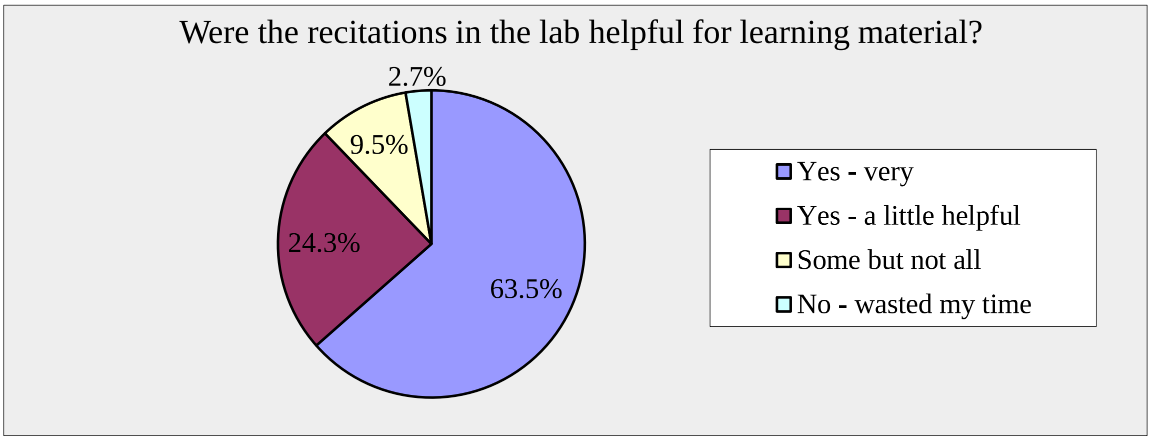


Figure 20: Students' perception of the helpfulness of recitations for learning course material

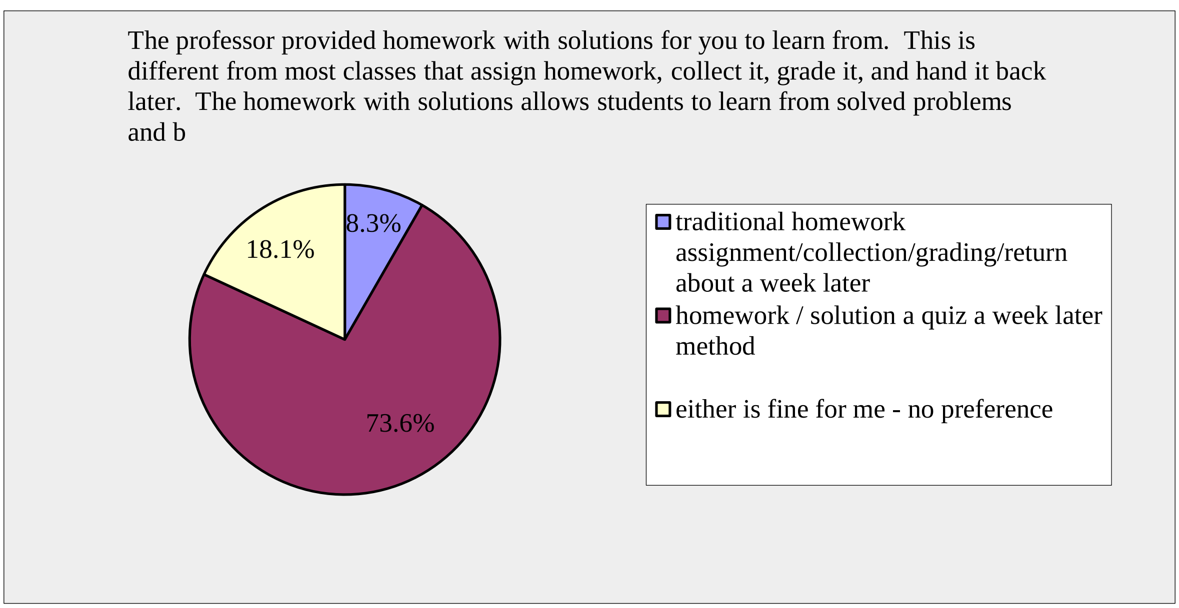


Figure 21: Students' preference for homework learning method – traditional or hw/sol/quiz.

Only a small percentage of students, 8.3%, preferred the traditional method of homework, grading, return the graded homework. A huge majority of students, 74% preferred the homework/solution/quiz method of learning. 18% stated that either method is fine – they had no preference. Regarding time flexibility afforded by having a solution along with the homework assignment, an overwhelming majority of students liked this flexibility, 92%.

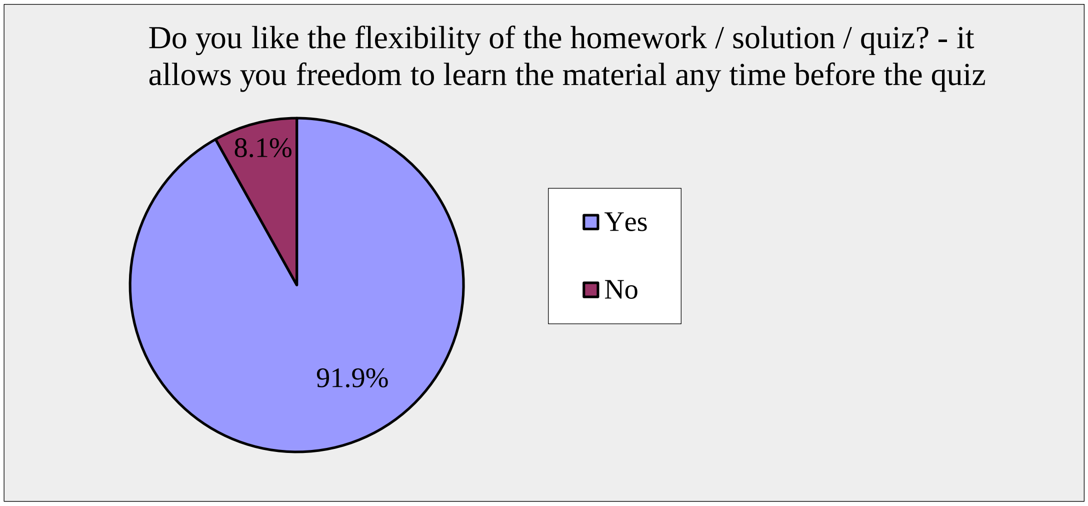


Figure 22: Students' preference for time flexibility of learning from solutions prior to a quiz

As for procrastination, it is quite common for students to procrastinate and leave their work to the last minute. The concern this professor had with the homework/solution method was that students wouldn't do any work until the night before the quiz and at that time they would try to cram the knowledge into their brain. The professor was also concerned that students would find it difficult to do their work and to check their work by comparing their work with the solutions. Figure 23 shows data from the survey question that addressed these concerns to some degree. The procrastination was asked directly, but the preference of the learning from solutions was asked instead of how the students used the solutions. In this survey question, multiple responses were allowed. Shown on the y-axis of Figure 23 is the percentage of students who agreed with the statements.

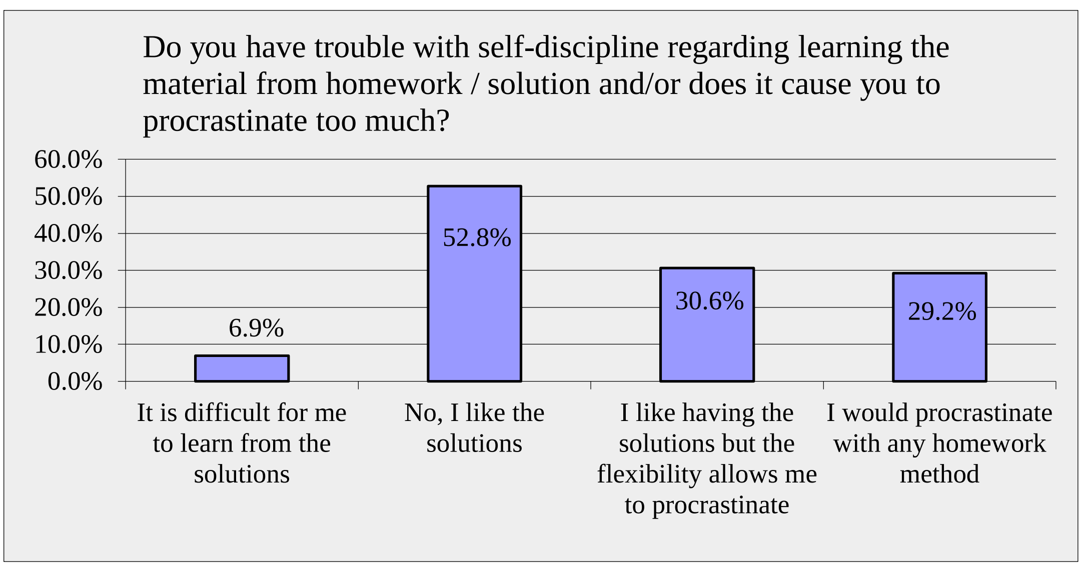


Figure 23: Students' of ease of learning from solutions and their propensity to procrastinate

Most of the students liked having the solutions, 53%, and interestingly about the same percentage of students who stated that having the solutions allows them to procrastinate stated that they would procrastinate with any homework method utilized.

The last survey question covered in this paper asks where the students turn to for help when they are having difficulty learning the material. One of the students pointed out that the professor making the survey did not list "textbook" as an option of where to turn. Perhaps it is naïve, but the professor assumed that the students were attempting to learn from the textbook and the question was meant to see where the students sought help when they did not learn the material from the textbook. The data shows that on average, students would first seek help from classmate, then they would watch a video lecture (or perhaps YouTube or Khan Academy), then they would see the professor, and finally they would go to a tutor or a lab assistant.

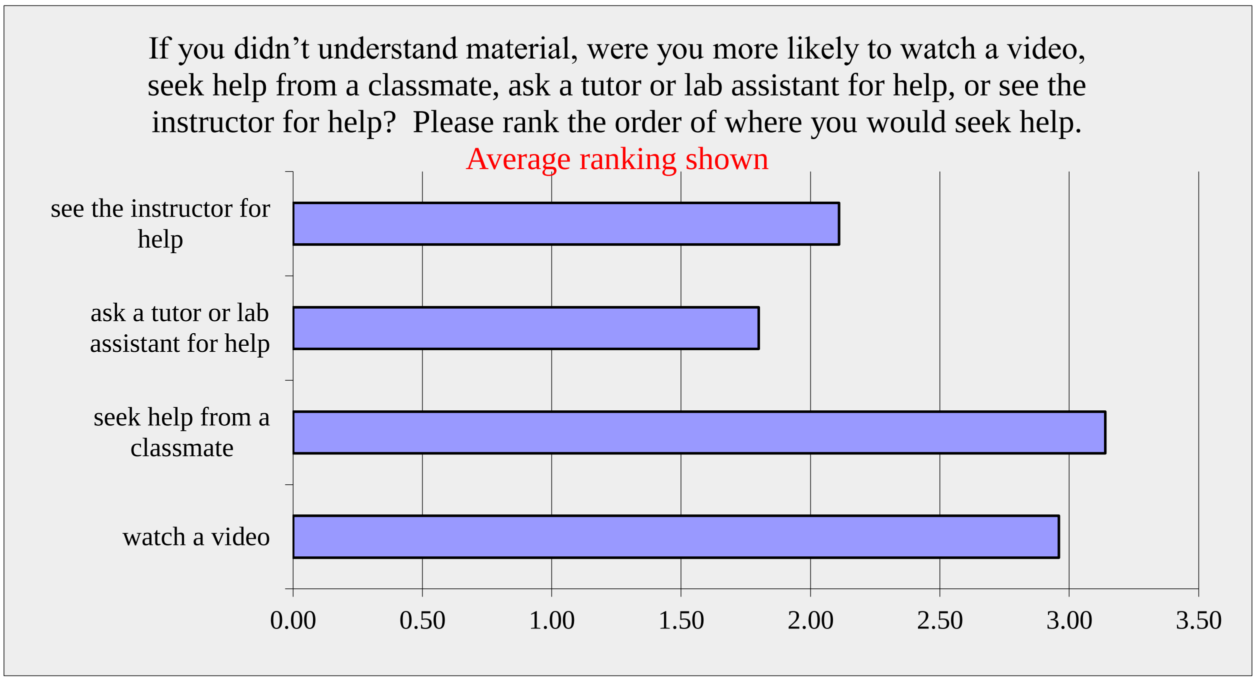


Figure 24: Where students go to get help learning the course material

This data reinforces the idea that the hybrid flipped-classroom model of teaching and learning is working. Students state that they would watch a video as their second choice and the rating was just about as high as student preference for working with a classmate.

Further Discussion and Conclusion

While the outcomes from the 2012 final exam and the 2014 final exam, comparing student performance before and after the introductory circuits course was changed, did not demonstrate that the change was beneficial to the students' learning, the data presented from the survey results show a strong preference for inclusion of video lectures and video problem solving examples in the course. Including videos as primary and supplemental learning sources allows the professor to go over example problems more slowly in class. This allows students to watch and listen more attentively during the presentation of an example problem or theory. Afterwards students are allowed to scribe notes in their notebooks and to think about the problem as they do so. Only a small percentage of students were negatively affected by this technique.

The results from the survey show that while students prefer video lecture material, many of them do not watch the videos. One suggestion that came from an open-ended response was to have the solutions to the homework problems only presented in video form. This would force students to check their homework by comparing their work with the video instead of with a paper solution.

Students also indicated that when they watched video lectures, the rewound the videos to listen again and/or to take notes. There are many universities that have training material available to help students learn how to take notes in a traditional classroom lecture; even prestigious Ivy League schools offer this assistance[18]. When video lectures are available as primary or secondary learning material, students are afforded the opportunity to pause the lecture when they realize they didn't quite understand the explanation.

Students in this course had the opportunity to learn from a many different sources: traditional lectures with interactive slowed portions, video lectures as primary and secondary lecture material, homework assignments with solutions, recitations, and each other. The survey data demonstrates that the vast majority of the students in the introductory circuits course preferred the hybrid flipped-classroom learning method compared to a traditional lecture method. 87% of the students surveyed stated that the class' mix of traditional lectures and video lectures should either stay the same (50%) or keep the most of the lectures traditional but add more supplementary videos (37%). Additionally, 8.6% of the students surveyed wanted more video lectures to allow more in-class exercise time and 4.3% wanted the class completely flipped.

During the spring 2015 circuits II class, the instructor asked the student for anecdotal feedback about the previous class. The circuits II class is only taken by electrical and computer engineering students, so the evidence may not be generalizable. Students primarily stated that when the material was more difficult, they utilized more of the out of class resources to learn the material. They also stated that between themselves and their classmates, they noticed that more motivated, harder working students performed better. One of the "A" students stated that she watched very few videos in circuits I because the material was easy. Now that the material is more challenging, she routinely watches the videos posted for class lectures and YouTube videos. This feedback, while anecdotal, supports the assertions of He et. al. The difficulty of the course has a tremendous impact on the success of the hybrid flipped classroom method. If the material is more challenging, students will probably benefit more from the hybrid flipped classroom.

References:

[1] Lage, M.J.; Plat, G.J.; Treglia, M., "Inverting the classroom: A gateway to creating an inclusive learning environment," *The Journal of Economic Education*, 31(1):30–43, 2000

[2] Bishop, J.L.; Verleger , M.A., "The Flipped Classroom: A Survey of the Research," in *Proceedings of the 120th ASEE Conference & Exposition, June, 2013*., Atlanta, GA

[3] Karnard, A., "Karnad_Student_use_recorded_2013_author.pdf" http://eprints.lse.ac.uk/50929/1/Karnad_Student_use_recorded_2013_author.pdf, accessed on Jan. 31, 2015

[4] Herreid, C.F.; Schiller, "Case Studies and the Flipped Classroom," *Journal of College Science Teaching*, Vol. 42, No. 5, 2013, pp. 62-66

[5] Bates, S.; Galloway, R., "The inverted classroom in a large enrolment introductory physics course: a case study," in *Proceedings of the HEA STEM Learning and Teaching Conference*, April 2012, London, England

[6] Braun, I.; Ritter, S.; Vasko, M., "Inverted Classroom by Topic - A Study in Mathematics for Electrical Engineering Students," *International Journal of Engineering Pedagogy*. Vol 4, No 3, 2014

[7] Chen, M.; Chen, S, "Empirical Study on Flipped Classroom Based on Understanding," *Educational Innovation through Technology (EITT), 2014 International Conference of* , vol., no., pp.92,98, 27-29, Oct. 2014

[8] Hughes, C.; Paulson, S., "Assessing the Impacts of a Hybrid "Flipped" Approach to University Physics," *Bulletin of the American Physical Society*, Vol. 60, No. 1, March 2015

[9] Missildine, K.; Fountain, R.; Summers, L.; Gosselin, K., "Flipping the Classroom to Improve Student Performance and Satisfaction," Journal of Nursing Education, Vol. 52, No. 10, 2013, pp. 597-599

[10] Reyneke, F.; Fletcher, L., "The Impact of an Inverted Traditional Teaching Model on First Level Statistics Students," in *Proceedings of the 9th International Conference on Teaching Statistics*, July 2014, Flagstaff, AZ

[11] Papadopoulos, C.; Roman, S.A., "Implementing and Inverted Classroom Model in Engineering Statics: Initial Results", in *Proceedings of the 2010 ASEE Annual Conference*, June, 2010, Louisville, KY

[12] Gundlach, E.; Richards, A.; Nelson, D.; Levesque-Bristol, C., "A Comparison of Student Attitudes, Statistical Reasoning, Performance, and Perceptions for Web-augmented Traditional, Fully Online, and Flipped Sections of a Statistical Literacy Class," *Journal of Statistics Education*, Volume 23, Number 1, 2015

[13] Haughton, J.; Kelly, A., "Student Performance in an Introductory Business Statistics Course: Does Delivery Mode Matter?," *Journal of Education for Business*, Vol. 90, Iss. 1, pp. 31-43, 2015

[14] Cavalli, M., "Comparison of Student Performance and Perceptions Across Multiple Course Delivery Modes," in *Proceedings of the 121th ASEE Conference & Exposition, June, 2014,* Indianapolis, IN

[15] Fitzgerald, N.; Li, L., "Using Presentation Software To Flip an Undergraduate Analytical Chemistry Course," *Journal of Chemical Education,* Article ASAP, 2015, DOI: 10.1021/ed500667c

[16] O'Flaherty, J.; Phillips, C, "The use of flipped classrooms in higher education: A scoping review," *The Internet and Higher Education*, Vol. 25, April 2015, pp. 85-95.

[17] He, W.; Gajski, D.; Farkas, G.; Warschauer, M., "Implementing flexible hybrid instruction in an electrical engineering course: The best of three worlds?," *Computers & Education*, Vol. 81, Feb 2015, pp. 59-68.

[18] http://www.dartmouth.edu/~acskills/success/notes.html, accessed on Jan. 20, 2015

Appendix

Table A1: Course Lecture Schedule

Monday	Wednesday	Friday
25-Aug	**27-Aug**	**29-Aug**
Current, Voltage, Power (Passive sign convention), Circuit Elements	Power, Tellegen's theorem & in-class practice	Ohm's Law, Passive Sign Convention, KCL
1-Sep	**3-Sep**	**5-Sep**
Holiday	KVL, Passive Sign Convention Reinforcement In-class practice	Resistor Combinations, circuit reduction methods
8-Sep	**10-Sep**	**12-Sep**
Voltage division & Current division In-class practice	Nodal Analysis, simple no dep sources, Calculator Solving In-class calculator solutions	Nodal Anlysis, non-essential nodes. Cramer's Rule and Matlab Solutions
15-Sep	**17-Sep**	**19-Sep**
Nodal Analysis, depedent source, introduce Super nodes	Nodal Analysis, supernodes with dep sources, many examples	Inclass practice nodal practice
22-Sep	**24-Sep**	**26-Sep**
Ideal Op Amp rules, supplies and saturation, Unity Gain - buffer, Inverting, Non-Inverting, Non-Inverting with gain Less than one, transfer function & gain, nodal analysis solution technique	Brief lecture review and In-class practice: Op-amps	Summing Amp, introduce superposition, differential Amp general solution, other examples
29-Sep	**1-Oct**	**3-Oct**
Multiple Stages, inclass practice	Open Loop comparator, Comparator with hysteresis for noise rejection	Network Theorems: Linearity, Superpostion, op-amp examples
6-Oct	**8-Oct**	**10-Oct**
Source Transformation, determining Voc, Isc, & Rth on simple circuits, ladder networks, no dep sources + In-class practice	Thevenin's Theorem to solve problems, Introduce Rth with dep source	Norton and Thevenin's Theorem examples, use superposition to find Voc and Isc

13-Oct	15-Oct	17-Oct
Holiday	Maximum Power Transfer Examples, more Norton & Thevenin Example problems	In-class network theorem practice
20-Oct	**22-Oct**	**24-Oct**
Digital Circuits, logic gates, voltage levels for TTL, CMOS	Combinational Logic, Truth Tables, Examples	Multisim & Examples
27-Oct	**29-Oct**	**31-Oct**
Inductors and Capacitors: Energy storage, series and parallel combinations, differential and integral eqns, current and voltage waveform problems (differentiation & integration)	Continue Waveforms, op amp examples: pure integration (until saturation), differentiation.	First Order Transients: source free solutions and time constant for RC and RL circuits. $\tau = R_{th}C$ or $\tau = L/R_{th}$
3-Nov	**5-Nov**	**7-Nov**
First Order Transients: step function, delta function, ramp function, Step Response for Simple RC Circ.	First Order Transients: differential equations, complementary (or natural or homogeneous) solution, particular (or forced or non-homogeneous) solutions	Brief lecture review and In-class practice
10-Nov	**12-Nov**	**14-Nov**
Lect on complex numbers: coordinate conversions, algebra and complex conjugates. In-class complex number manipulation & calculator practice	Sinusoids & Phasors (show animated gifs) (relate to Euler's eqn & show animation) More practice on Real + j Imag, Coord trans., Calculator & Matlab fundamentals	Phasor Relationships for R, L, C. Impedance and Admittance, Conversion from time to frequency domain, simple example for time --> freq --> freq domain solution (phasor) --> time domain solution
17-Nov	**19-Nov**	**21-Nov**
Review & refresh: Examples for time → freq → freq domain solution (phasor) → time domain sol.. Volt div, I-div, Source transformation	Nodal Analysis (matlab solutions of complex matrices)	Super posiiton, source transformation, Thevenin's Theorem.
24-Nov	**26-Nov**	**28-Nov**
Ave Real Power, Complex Power, & Max power transfer	Holiday	Holiday
1-Dec	**3-Dec**	**5-Dec**
AC Steady State: In-class Practice Problems (Handout)	Final Exam Review and In-class practice	Final Exam Review and In-class practice