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How Flipping Your First-Year Digital Circuits Course Positively Affects Student Perceptions and Learning*

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Given the recent call for engineering faculty to employ more student-centered learning strategies with course objectives that align with real-world, application of content, the current study discusses the implementation and benefits of the flipped classroom in a lower-level engineering course. Using the same course content, student end of course opinion surveys were compared for a traditional lecture (n = 23) and flipped digital circuits engineering class (n = 29). In particular, three items from the student opinion survey were of interest: instructor's teaching helped me learn, accessible to students, and organized course well. It was predicted that student ratings would be more positive on each of the three identified end of course opinion survey items for the flipped class compared to its traditional lecture counterpart. Results supported the study's prediction in addition to providing supplemental findings for the future use of the flipped classroom in engineering and other STEM courses. The multiple benefits of the flipped class pedagogical strategy are discussed with respect to future implementations for faculty teaching STEM courses.

Keywords: flipped classroom; inverted classroom; active learning; electrical engineering; digital circuits; freshmen level engineering courses

1. Introduction

The purpose of the current study was to compare student ratings from a traditional lecture class with a flipped classroom on end of course student opinion survey items that measure perceptions of instructor accessibility and availability as well as course structure. Research suggests that perceptions of instructor accessibility and availability positively affect student-faculty rapport [1], which often result in higher end of course student opinion surveys. The flipped classroom is one such teaching strategy inherently designed for increasing instructor accessibility and availability. Moreover, the flipped classroom provides greater opportunity for deeper learning using active learning strategies. Because the implementation of the flipped classroom in engineering courses across the author's department curriculum is uncommon, student perception of course structure was also of interest.

1.1 Rationale

It has been over 15 years since the publication of Eric Mazur's seminal book, *Peer Instruction: A User's Manual* [2], in which Mazur described a new teaching technique in his introduction to physics class. In lieu of the conventional lecture, Mazur began engaging students in their own learning through peer instruction. Mazur asserts that the traditional lecture typically does not hold students' attention for the entire class period. Because students receive information passively, they have little opportunity for critical thinking or deeper processing of key concepts. As a result, students may be able to memorize and regurgitate facts, formulas, etc., especially in STEM courses, but they may lack a true understanding of the concepts, even at the end of the course. The goal of peer instruction, therefore, is for students to gain a conceptual understanding of course content without sacrificing the attainment of the same basic knowledge they would have been expected to learn in a conventional, lecture course.

When implementing the method of peer instruction, lectures are chunked into smaller units (about ten minutes) that focus on a single, main concept. It is important, however, that students prepare for class by reading the assigned material and complete a three question, web-based assignment prior to attending class because lecture is minimalized [3]. Students are then presented with a "ConcepTest" [2] and asked to think about their answer for 1–2 minutes before sharing their individual answer with the instructor. Students then share their answer with a neighbor for another 2–4 minutes. By the end of this student-to-student conversation, each dyad shares their answer arrived at via consensus publicly. If the majority of the class answers incorrectly,

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the instructor spends additional time explaining the concepts prior to moving forward with the course content. However, since the majority of students tend to answer the ConcepTest correctly *after* the peer instruction as compared to before the peer instruction, content is not sacrificed as some might suspect. In fact, research shows that peer instruction results in greater student learning of both concepts and quantitative problem solving when compared to traditional lecture and distributes greater responsibility and ownership for learning onto students [3]. Additional research, using data from a survey of over 6000 students for an introductory physics course, showed that "interactive engagement" strategies (e.g., peer instruction, concept tests, modeling, active learning problem sets, case studies) resulted in improved problem solving and conceptual understanding compared to traditional lecture [4].

The prevalence of active learning strategies in engineering, as well as other STEM courses, continues to be nil compared to that of traditional lecture despite the ever mounting empirical evidence showing the benefits of active learning on student performance [5, 6]. A recent meta-analysis of 225 studies comparing courses that implemented active learning with traditional lecturing showed that active learning resulted in better student performance on assessments compared to traditional lecture and classes implementing active learning in some capacity had a lower course failure rate when compared to lecture courses [6]. Moreover, students participating in courses where active learning strategies were employed finished the course a half letter grade higher than students receiving information passively in conventional lecture courses [7]. While these data provide encouragement for greater retention rates in the STEM disciplines, the result from this research most relevant to the current study is that "active learning has a greater impact on student mastery of higher- versus lower-level cognitive skills" [6]. While this meta-analysis may be the most recent empirical evidence showing the effectiveness of active learning on student performance, especially in the STEM fields, faculty tend to continue reliance on lecturing as their primary mode of instruction delivery [7].

In the National Academy of Engineering's (NAE) *Educating the Engineer of 2020*, engineering faculty are urged to understand how students learn (i.e., student-centered learning) and align their course learning objectives with the knowledge, skills, and abilities needed by future engineers in the workplace. "In recent years, the Accreditation Board for Engineering and Technology (ABET) has increased the pressure on engineering schools to produce graduates who are prepared to engage in unstructured problem solving and to work in groups" [8]. Furthermore, initiatives by the National Science Foundation (NSF), such as The Higher Education Centers for Learning and Teaching, focus on finding more effective ways of teaching in the STEM disciplines. Sharing these findings about best practices for delivering content knowledge and pedagogical skills with current and future STEM faculty to improve student learning is the ultimate goal, however [9]. It should therefore be no surprise that a call for the creation of engineering instructional development (i.e., faculty development) programs and personnel has also recently been put forth [10].

Given sound empirical evidence for the benefits of active learning on STEM student performance as measured by a variety of assessment methods and recommendations from organizations such as the NAE and NSF for the implementation of active learning strategies in engineering courses, the current study suggests the benefits of one such active learning strategy in a lower level digital circuits engineering course at a midsize public university in the Midwest.

1.2 The flipped classroom

The "flipped" or "inverted" classroom may be one of the "hottest" pedagogical strategies currently pervading the American K-12 and higher educational landscapes. The "inverted classroom," as it was first coined by Treglia et al., capitalizes on the emerging instructional technologies and provides for more time to be spent during class honing critical thinking skills and deeper learning [11]. The Center for Digital Education claims that today's students "expect a classroom experience that helps them develop knowledge for themselves, not just passively receive one-dimensional information. Students want to do something meaningful with content instead of just listening to a lecture" [12]. One of the greatest benefits of flipping is that overall interaction increases: teacher to student and student to student. In addition, flipping allows for the instructor to act more as a "learning coach" instead of the "sage on the stage" [13] as is most common in traditional lecture. Plus, helping students understand that learning is the goal, instead of the completion of assignments, fosters a collaborative learning environment where students willingly help each other learn. An accessible, safe, positive, personalized, and empowering learning environment, like the one characteristic of the flipped classroom, often results in greater student intrinsic motivation for learning [8].

When inverting or flipping the classroom, students are expected to prepare for class by completing pre-assigned readings and, often, but not always, also watch instructor lectures so that class time can be spent completing activities that have typically been assigned in the past as homework. In this way, students enter the classroom with at least one to two exposures to the necessary knowledge needed to apply key concepts in the form of active learning strategies, often in collaboration with peers.

Pre-class lectures can be presented using a course management system platform such as Blackboard or Moodle by simply using Power Point slides with audio narration, video recordings of actual in-class lectures from prior semesters, or newly recorded videos using a webcam with a microphone and posting the video on YouTube. More sophisticated editing software, such as Panopto or Camtasia, allows one to create and edit videos for a more professional presentation of information which can be transferred or updated from semester to semester. While all methods of video production are viable options, research suggests that regardless of the method selected, video recorded lectures should not be longer than 10 to 20 minutes, which is about the attention span of most students [7, 14]. Students then have access to these video recorded lectures 24 hours a day, 7 days a week. Plus, students can take advantage of the pause, rewind, and fast-forward features as needed.

Because course content is delivered prior to and outside of class in the flipped classroom, students are expected to arrive to class with any questions they may have about the content. When students arrive to class with questions about concepts that may still be unclear, the instructor has an opportunity to further clarify concepts prior to their participation in active learning strategies. These active learning strategies are therefore designed to not only reinforce basic knowledge and understanding of course concepts, but to allow for higher order thinking skill development [15]. Much like peer instruction [2], students in the flipped classroom work together during class to help each other gain a deeper level of understanding of the material. In addition, to ensure students complete the out of class preparatory assignments, assessments such as online quizzes are administered prior to class [16]. In a recent study implementing the flipped classroom in an upper-division engineering course, students in the flipped class outperformed students in a comparable traditional lecture course on problem sets involving open-loop analysis, root locus-based design, Bode plot-based controller design, and design problems in general [7]. While these findings are consistent with other studies implementing active learning strategies during class time [3–5, 11, 16], the study also found that students in the flipped class covered more material and progressed through the course at a faster pace compared to the traditional lecture course. This finding speaks directly to the popular misconception that abandoning the traditional lecture format in favor of implementing active learning strategies sacrifices content.

Data show the effectiveness of active learning strategies, and more specifically, the flipped classroom, on student learning. Yet, published research describing the successful implementation of active learning in engineering courses in particular remains minimal. Furthermore, since there has been some scholarly debate regarding the appropriate course level best suited for the flipped classroom [7], the current study builds upon previous research where the flipped classroom was implemented in an upper level engineering course [7] by comparing student learning in a lower level engineering course delivered using either traditional lecture or the flipped classroom. Students in the flipped classroom engaged in collaborative learning, one type of active learning strategy shown to enhance student learning [17], as they solved both computational and application problems during class. On other occasions, peers worked together to complete hands-on laboratory exercises. Students in the traditional lecture course listened to the instructor present the material for 90% of the time and engaged in simple, active learning strategies such as think-pair-share or group discussions the other 10% of the time. Lower than desired end of course student ratings after the traditional lecture course on the following three items, instructor's teaching helped me learn, accessible to students, and organized course well, led to the present study. Based on findings from previous research and the desire to increase and improve student ratings on the three aforementioned items, the purpose of the current study was to compare student ratings from the traditional lecture course with the flipped classroom course. Specifically, it was predicted that student ratings on each of the three identified end of course items would increase for the flipped course compared to the lecture course.

2. Presentation

EGR 190, Digital Circuits, is one of the first engineering courses freshmen engineering undergraduate students are required to take as majors. Class size is approximately 25 students. Students are mostly first year students and do not typically know each other. This 3-credit course is taught twice a week for 75 minutes. The course content includes the fundamental digital circuits concepts such as binary numbers, logic gates, and complex digital logic blocks. The research study is based on two

Table 1. Games that were used in the flipped classroom.

Game	Duration	Learning Objective	Methodology
Jeopardy	45 minutes	Review of the material Peer instruction	Using a 5 × 5 jeopardy matrix with review questions. A group can only get points if every student in the group was instructed by his/her peers.
Bingo	30 minutes	Review Check where the student stands among his/her peers	Students fill in a 5 × 5 matrix on marker boards randomly with 25 correct answers provided by the instructor. First one who fills in a line, then two lines earns a simple gift.

classes that were taught by the same instructor in consecutive academic years during the fall semesters.

2.1 Methods

In order to compare the traditional and flipped classroom techniques both approaches were implemented for the same course content taught by the same instructor.

2.1.1 Traditional lecture

For the traditional style course, the instructor taught the course using lectures with some limited classroom activities. The grading scheme was 30% homework assignments (10 of them), 30% midterms (2 of them), 30% final exam, and 10% participation. In the traditional lecture class, while most of the course material was delivered using traditional lectures, 10% of class time was allocated for group activities such as think-pair-share, trivial competitions, and discussions. The material was covered via lectures and guided problems were given as homework assignments as a means for mastering the material. Traditional classroom students were assigned weekly homework that consisted mostly of one-correct answer problem sets from the textbook. The final project for the traditional classroom was to design an up/down counter. Students were given around two weeks to work on their project assignment outside of class. Most of the students found a conventional circuit from an Internet search and explained the operation of the circuit for the written portion of the assignment.

2.1.2 Flipped classroom

For the flipped classroom course, all course material was delivered via pre-recorded videos and actual class time was used for collaborative problem solving. The grading scheme for the flipped classroom was similar except the 30% homework was divided into 15% homework and 15% online quizzes. The flipped class used the entire class time for collaborative problem solving sessions, hands-on labs, and games. The course material was delivered in two pre-recorded lectures per classroom session (a total of 4 videos per week) by the instructor[1]. Videos were five minutes each. Two to ten question online quizzes per week were assigned via the Blackboard learning management system (LMS) and students were required to complete the quiz before participating in the in-class activities.

Each class session started with the review of the online quiz that students completed the night before. The instructor gave a review of the quiz using a smart board iPad application[2]. After the review of the online quiz, students engaged in applied activities, games (e.g., Jeopardy or Bingo), or worked on a homework assignment in groups of four. Groups were formed based on their ACT/SAT scores and high school GPAs. Each group had at least one high achieving and one below average student while also taking into account factors of diversity (gender, age, and nationality) [18].

Flipped classroom homework assignments were focused on real-life problems including but not limited to sprinkler timing systems and flashing lights. Gaming was also incorporated in the classroom. Brief explanations of the games used are described in Table 1.

The final project for the flipped classroom was to design an up/down counter based light system with several user inputs. The majority of the project was completed during the class while working in groups. However, student projects were all significantly different in terms of their approach and solution.

In both classrooms, students were required to write reflections at the end of each class period and these reflections were combined by the faculty and shared with the students during the following class period. However, only the flipped classroom included further assessment beyond the daily reflections such as instant feedback tools using smartphone based clickers and Google surveys.

[1] Pre-lectures were recorded using Panopto screen casting software, Bamboo tablet, and Plantronics headset with embedded microphone. Videos are then uploaded to YouTube using the Gmail account that was created specifically for this course (egr190central). Each week s videos were also organized in playlists for quick access.

[2] Doceri App was used on the iPad.

Table 2. A summary comparison of the traditional and the flipped classroom in terms of course layout and planning

	Traditional	**Flipped**
Classroom time	Mostly lectures	Mostly collaborative problem solving
Final design project	Up/down counter with one control input	7-segment display up/down counter with three control inputs
Material covered by Midterm 1	30%	50%
Material covered by Midterm 2	70%	100%
Hands-on labs	None	4 (logic gates, counters, etc.)
Homework assignments	One-correct answer problems	Open-ended design problems

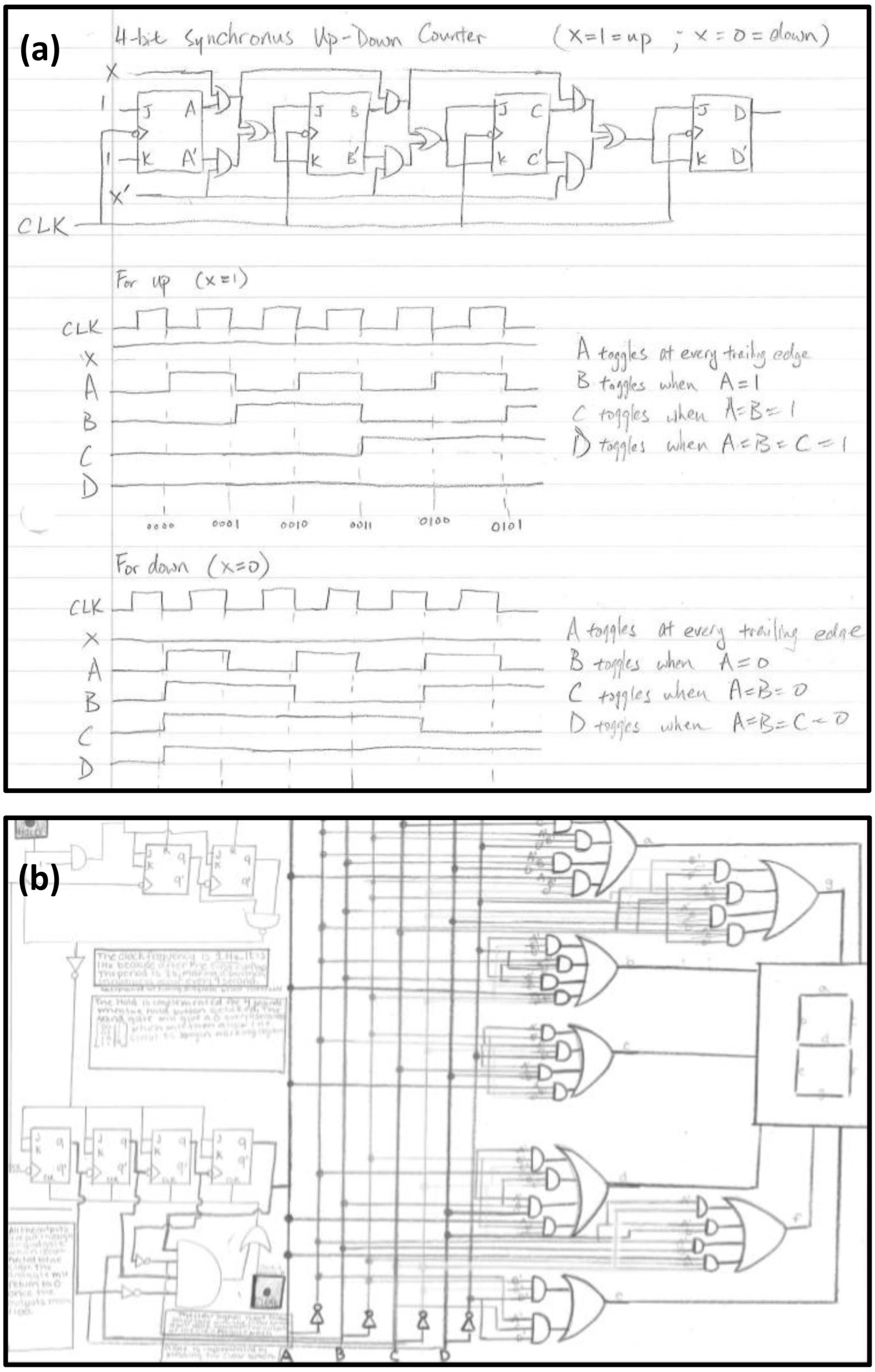

Fig. 1. Complexity comparison of the final design projects of (a) the traditional and (b) the flipped classrooms. Both examples were among the best in each class.

Table 2 summarizes the differences in terms of course material between the traditional lecture and flipped classes. Delivering lectures outside of the classroom resulted in the coverage of more course content. For instance, all of the course content was completely covered in the flipped classroom at the time of the second midterm. Because of this, the traditional classroom's final exam was given as the second midterm exam for students in the flipped classroom. Furthermore, the final project for the flipped class was several times more complicated than that for the traditional class. The final project of the traditional class was to design a 4-bit synchronous up/down counter using JK flip flops. This circuit is one of the fundamental circuit blocks in digital circuits and several implementation examples can easily be found on the Internet. The goal of the project was to get students prepared to understand a design and explain it technically. There was not a significant design concept to the problem. On the other hand, the final project for the flipped class was to design a complete digital system with several functions. The project was to design a 7-segment display that would count from 0 to 9. It had an additional clear and hold functions that needed to be implemented. The design was unique and students had to come up with their own solutions.

Snapshots of the best projects from each class are presented in Fig. 1 to display the difference in complexity of the projects. Fig. 1b shows greater applications of course concepts compared to Fig. 1a (i.e., more functions were implemented with more complexity in the flipped class final project, see Fig. 1b). While the traditional class project had approximately 10 circuit blocks in the design (Fig. 1a), the flipped class project had more than 50 circuit blocks (Fig. 1b). Finally, the flipped class allowed time to conduct hands-on laboratory sessions enabling students to visualize the theoretical material, which provided them a greater understanding of those theoretical concepts. Examples of the hands-on lab sessions include testing logic gates and designing counters using flip flops.

In addition, the group work on the homework assignments allowed more complicated, open-ended, and design oriented problem sets to be assigned in the flipped class, whereas traditional class students only experienced closed-ended and less-complicated problem sets. Representative open-ended and close-ended questions are presented in Table 3.

3. Results

As previously stated, the flipped classroom allowed the course content to be covered more efficiently than the traditional classroom. Table 4 summarizes the content coverage for each of the tests in both classrooms.

To test the study's prediction that student ratings on each of the three identified end of course survey items (noted in bold in Table 5) would increase for the flipped course compared to the lecture course, data from the student opinion surveys (SOS) were compared. Table 5 shows the summary of the responses for both courses. Mean and standard deviation values for overall survey scores are listed. The number of responses for each year varied due to the small fluctuation on student enrollment in the class. The t-score values are also provided. Although there is improvement in the flipped class, the differences were not statistically significant for any of the items ($p > 0.05$). A slight decrease in survey results in terms of instructors' preparedness was observed which might be associated to all the new materials and techniques that were implemented in the flipped class. Detailed information about each question's scores on the SOS is provided in Fig. 2.

For the flipped class, two online surveys administered through Google were conducted during class. Students were instructed to go online either with their smartphones, tablets, or lab computers

Table 3. Example homework questions from the traditional and flipped classrooms.

Close-ended questions (Traditional)	Open-ended questions (Flipped)
EXAMPLE 1: Show the truth table for the following and implement the truth table using AND & OR gates: The system has four inputs. The first two, a and b, represent a number in the range 1 to 3 (0 is not used). The other two, c and d, represent a second number in the same range. The output, y, is to be 1 if and only if the first number is greater than the second or the second is 2 greater than the first.	EXAMPLE 1: Assume that there is a team that is working on solving homework problems in the class. Here are the characteristics of each team member: . . . For a given amount of time-frame, this team solves questions. Would they get the right answer? Design a circuit to answer this question.
EXAMPLE 2: Draw two 6 bit counters using D type flip flops with the following functions: Counter 1 is two times faster than counter 2.	EXAMPLE 2: You will design a sprinkler system. There are a total of 64 sprinkler heads. You need to turn them on one by one because they cannot be turned at the same time. Each sprinkler head will turn on while the one before it turns off. Design a sprinkler circuit that would achieve this function.

Table 4. Content covered by the tests in both classrooms

Content	**Traditional**			**Flipped**		
	Test 1	**Test 2**	**Final**	**Test 1**	**Test 2**	**Final**
Number Systems	X			X		
2's complement	X		X	X		X
Algebraic calculations	X			X		
Minimization of logic functions	X		X	X		
Truth tables	X			X		
Basic logic gates	X			X		
Basic Karnaugh maps	X			X		
Complex truth tables		X	X		X	X
Complex Karnaugh maps		X	X		X	X
Logic function to circuit realizations		X	X		X	X
Adders						X
Decoders		X			X	
Advanced decoders			X		X	
Timing diagrams			X			
Flip flops			X		X	X
Counters						X
Advanced sequential circuits						X

Note: X's indicate content covered.

Table 5. SOS results for both courses. Percentages correspond to the responses who rated the statement as strongly agree. Ratings are scaled from 1 (strongly disagree) to 4 (strongly agree)

	Traditional (n = 21)			**Flipped (n = 23)**				
SOS Items	**% Strongly agree**	**Mean**	**SD**	**% Strongly agree**	**Mean**	**SD**	**t-score**	***p***
Instructor's teaching helped me learn	81%	3.81	0.39	96%	3.96	0.20	1.1829	$p > 0.05$
Treated students with respect	91%	3.90	0.29	96%	3.96	0.20	0.5715	$p > 0.05$
Accessible to students	81%	3.81	0.39	91%	3.91	0.28	0.6969	$p > 0.05$
Organized course well	76%	3.76	0.43	91%	3.91	0.28	0.9854	$p > 0.05$
Presented course well	86%	3.86	0.35	87%	3.87	0.34	0.0679	$p > 0.05$
Seemed well prepared	100%	4.00	0.00	91%	3.91	0.28	–1.5415	$p > 0.05$
Was enthusiastic about subject	91%	3.90	0.29	96%	3.96	0.20	0.5715	$p > 0.05$
Overall Instructor effectiveness	91%	3.90	0.29	96%	3.95	0.21	0.4670	$p > 0.05$

to answer a few questions about the class format. The first survey was conducted at the end of the third week of the semester while the second survey was conducted during the fifteenth week (last week of classes) of the semester. The number of students completing the online surveys from week 3 to week 15 slightly changed ($n = 24$ in week 3 versus $n = 25$ in week 15) due to the attendance on those particular days. It must also be noted that student participation in surveys are voluntary and varies from day to day and class year to class year.

The results of these surveys are summarized in Table 6 and presented in histogram format in Fig. 3. Of the five survey items analyzed for differences from week 3 to week 15, results show that students found the YouTube videos more helpful to their learning later in the term than at its beginning, $t(47) = 1.91$, $p < 0.05$, one-tailed.

4. Discussion

As predicted, student ratings regarding the three pre-identified SOS items (instructor's teaching helped me learn, accessible to students, and organized course well), increased with the flipped classroom when compared to the traditional lecture course, but none of the items reached statistical significance ($p > 0.05$) (see Table 5). While student ratings in the traditional class were overall positive (81%), almost all the students in the flipped class strongly agreed (96%) that the instructor's teaching helped them learn. Students apparently appreciated the more application-oriented course material (hands-on labs, competitions, simulations) in the flipped classroom rather than simply listen to lectures. Moreover, the high-impact teaching practices employed in the flipped classroom model trended towards greater student learning as reported by the students themselves.

As a result of implementing the flipped classroom, student perceptions of the instructor's accessibility increased, although not at a level of statistical significance when comparing means. However, the difference in the percentage of students who "strongly agreed" that the instructor was accessible when comparing the traditional (81%)

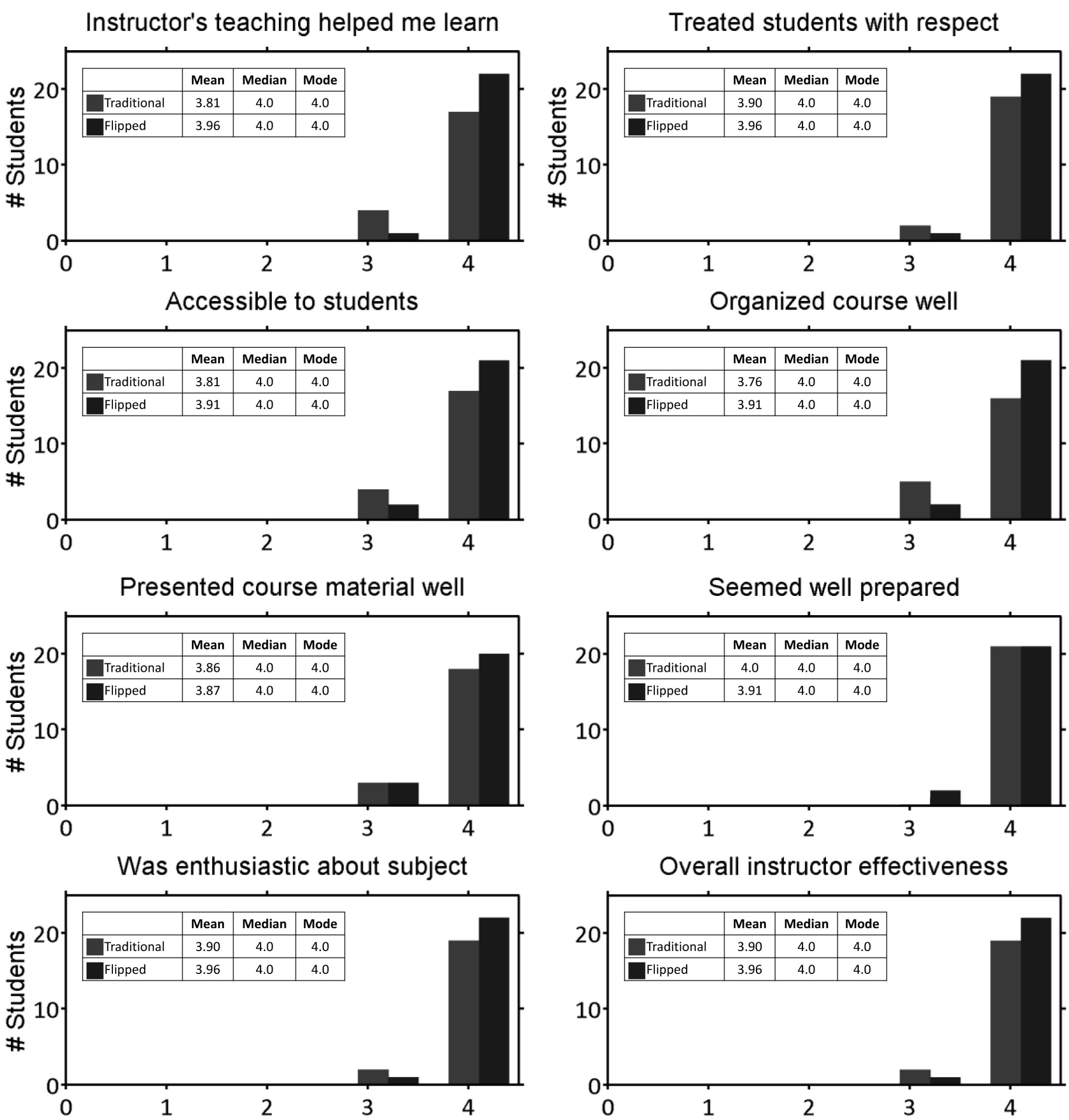

Fig. 2. Comparison of the student opinion survey results for the traditional and the flipped classrooms.

Table 6. Survey results for week 3 and week 15. Percentages correspond to the number of respondents who answered with either ''Agree'' (4) or ''Strongly Agree'' (5). Means were calculated for each item where 1 = ''Strongly Disagree'' and 5 = ''Strongly Agree''

Question	Week 3 (n = 24)			Week 15 (n = 25)				
	% Agree and Strongly Agree	Mean	SD	% Agree and Strongly Agree	Mean	SD	t-score	p
How helpful has the group work been on your learning in this class?	76%	4.38	0.88	83%	4.16	0.94	–0.5984	$p > 0.05$
How helpful were the YouTube videos	*88%*	*4.21*	*0.78*	*96%*	*4.72*	*0.54*	*1.9086*	$p < 0.05$
How often have you read the textbook before a quiz?	8%	1.75	1.22	0%	1.45	0.65	–0.7915	$p > 0.05$
Did you like the course format?	88%	4.58	0.72	96%	4.64	0.57	0.2299	$p > 0.05$
How helpful were the hands-on labs on your learning in this class?	N/A	N/A	N/A	88%	4.44	0.82	N/A	

Note: *Italicized* row is the only item that reached statistical significance at the 0.05 level (one-tailed).

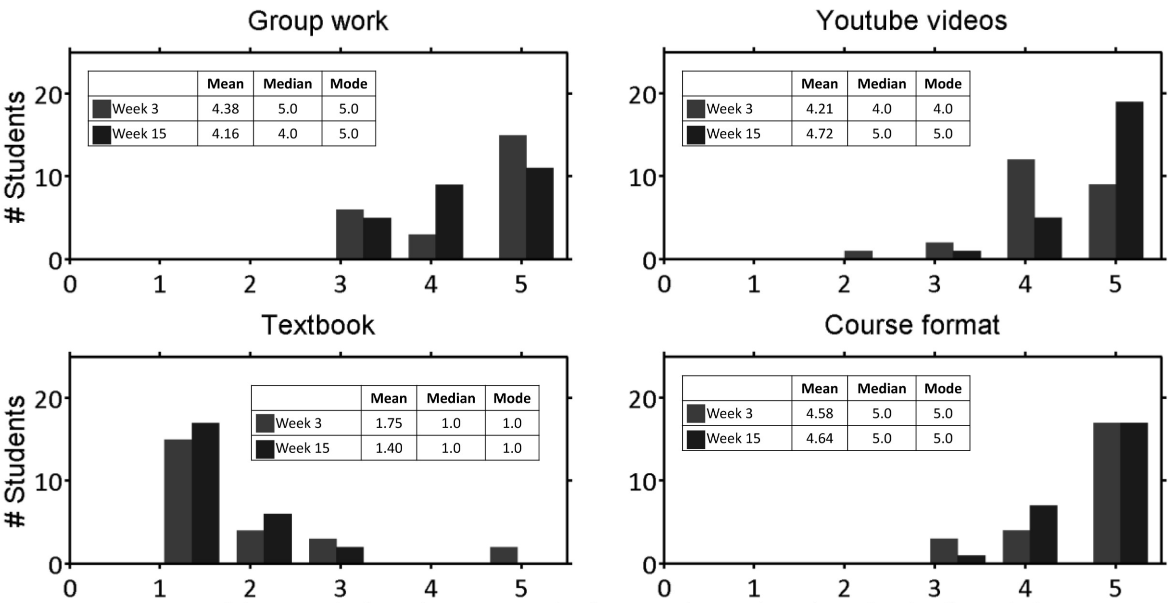

Fig. 3. Comparison of the Google-based survey results from week 3 and week 15 for the flipped classroom.

versus flipped (91%) classrooms still should not be dismissed. For the flipped class, the instructor spent most of the class meeting time interacting with students by answering their questions, providing just in time teaching [19], and helping them understand the concepts through one-on-one instruction when necessary.

Just in time teaching fosters a "teaching-learning team" [19] among students and between students and instructor. Student-student and student-instructor interactions and time on task (using class time to collaborate on active learning activities) have been identified as the top three critical factors for success in college [20]. Furthermore, because just in time teaching encourages all students to participate in and reflect on the learning and teaching process, appreciate perspectives other than their own, apply concepts as they learn them, and connect these concepts to other parts of the course, other courses, and the real-world, it is no wonder students in the flipped course enjoyed the learning experience more so than in the traditional lecture course. And, as a result, students therefore thought that the instructor was more accessible in the flipped classroom (91%) than the traditional classroom (81%) setting. This increased interaction between instructor and students tends to be an essential ingredient for establishing strong faculty-student rapport [21].

Research suggests that student-faculty rapport results in greater class attendance, attention during class, studying for class, enjoying the subject and professor, attending the professor's office hours, emailing the professor, taking another class from the professor, and maybe most important for the STEM disciplines are the results that student-faculty rapport increases the likelihood that students will take another class in that subject in the future and decreases the likelihood that students drop the class [22]. Given that the President's Council of Advisors on Science and Technology charged American educators to increase the number of bachelor degrees issued in the STEM disciplines each year by 33%, the positive effects of student-faculty rapport in the flipped classroom can play a pivotal role in reaching that goal. Other research also shows that active learning as experienced in the flipped classroom versus traditional lecture reduces failure rates in STEM courses [6].

Lastly, because the course content was presented via videos and accessed via online quizzes, the flipped course was perceived to be more organized (91%) than the traditional lecture course (76%), but did not show a statistically significant difference when comparing means. "Information without organization and context does not promote learning" [23]. Research from the online teaching and learning literature shows that "logical course structure and intuitive course navigation supports effective and efficient student learning [24]. One possible reason why organized online course content facilitates student learning is the consistency in expectations provided. According to the Carnegie Mellon Eberly Center for Teaching Excellence and Educational Innovation, one of the seven principles identified for effective teaching based on a summarization of instructional design research is the articulation of explicit expectations regarding learning objectives and policies [25]. By consistently presenting course content online in the form of videos, coupled with a regularly anticipated online quiz, students were provided structure and a clear organizational framework for their learning experience. Future research is needed to discern if using an online learning management system for such course organization purposes contributes to greater student learning or improved performance on assessment measures when compared to organizational methods not involving the use of online technology.

4.1 Strengths of the flipped classroom

With the use of classroom assessment techniques, such as knowledge probes [26], which ask students about their level of preparation for a given lesson or to provide both them and the instructor feedback for their understanding of a current lesson, the instructor was able to cover more material in the flipped class compared to the lecture course, as suggested by previous research [3, 7].

One possible reason for this finding might be because students were encouraged to work/study efficiently on their problem sets during class with their peers. Collaborative learning has been shown to be an effective teaching technique when it comes to students processing material at a deeper level of learning [9]. The research by Prince (2004) and Crouch and Mazur (2001) also reported that active, collaborative learning results in deeper levels of learning when implemented in STEM disciplines [3, 5]. Furthermore, seminal research has shown that cooperative learning improves academic achievement, the quality of interpersonal interactions, self-esteem, perceptions of greater social support, liking among students, student attitudes, and retention in academic programs when compared to individual work [27–29]. Current and past findings regarding the numerous benefits of collaborative and active learning, especially evidenced when using the flipped classroom teaching strategy, speaks directly to the call for "educating engineers for the near tomorrow" [30]. As we enter the era of Globalization 3, where individuals will likely collaborate and compete globally, engineering education steered towards greater problem solving, forward thinking, independent and creative thinking, and working and learning with peers will put future engineers at a distinct advantage upon entering a workplace characterized by highly personalized social relationships where a "shared gain" rather than "team win" mentality will prevail.

Another possible reason the flipped class resulted in greater content coverage compared to the traditional lecture course may be because of the use of several laboratory sessions and games. These two active learning strategies may have therefore served as catalysts for greater understanding of course concepts in the flipped class. Student learning outcomes may either be measured directly or indirectly. While direct measures, such as observations of students performing a task, analysis of assignments designed to test conceptual understanding or student work products, allow for samplings of what students can do, they do not often provide comparable quantitative measures. Indirect measures, such as course evaluations, surveys of student attitudes about course pedagogy and reflections on their learning, on the other hand, provide insight into perceptions students have about their own learning experience [8]. Since "deeper learning" is a concept difficult to quantify, the direct measure of "analyzing student work products" from both the traditional lecture and flipped course was selected. As a result of using this direct measure of student learning, it was concluded that the teaching techniques the instructor used in the flipped class resulted in deeper learning of the material as evidenced by the *complexity* of the final design project for students in the flipped class. Although the traditional lecture students did well on their final design project and met instructor expectations, the complexity of the project in the flipped classroom exceeded that of the lecture course. Specifically, the inclusion of several user input functions to the design was the main difference in the projects. Furthermore, the final projects for the flipped class were more diverse, creative, and applicable to real-life scenarios compared to the more simplistic, cookie-cutter projects of the traditional lecture course. The differences observed in the final products from the traditional versus flipped course align with conclusions presented elsewhere that "interactive engagement courses, are, on average, more than twice as effective in building basic concepts as traditional courses" [4]. These findings appear to extend the research on the effectiveness of the flipped classroom in STEM courses and provide additional evidence for the implementation of this teaching strategy in future STEM courses [4, 7].

In addition to using a direct measure to assess the student learning outcome of deeper learning, indirect measures for student perceptions of their learning experience were also employed. Surveys designed by the instructor administered during the semester coupled with data from institution end of course student opinion surveys shed insight into which aspects of the flipped classroom aided student learning. As can be seen in Table 6, students were a bit skeptical about the course format for the flipped class in the beginning. Specifically, at week three, 88% of students agreed or strongly agreed that YouTube videos were helpful and 76% agreed or strongly agreed that the group work was helpful for their learning. However, this perception changed dramatically by the end of the semester when students thought the YouTube videos and group work was very helpful for their learning (96% and 83%, respectively). Because students were not familiar with receiving lectures outside of class via pre-recorded videos in the beginning of the semester, they began to acclimate to this format by the end and even recognized its benefits for their learning. This finding is not only statistically significant, but key as instructors move forward with the implementation of the flipped classroom in engineering and other STEM courses since delivering pre-recorded lectures via video is the hallmark of the flipped classroom's course design. Furthermore, because lecture content is delivered prior to and outside of class, opportunities abound for more high-impact learning strategies to be employed during class, which enhance student learning. For instance, students in the present study reported that the hands-on labs helped them learn the course concepts (88%) in the flipped class. In sum, the course format characteristics of the flipped classroom were received positively and favored by almost the entire class (96%) by the end of the semester.

4.2 Limitations, recommendations and future directions

Given the small sample sizes for each class ($n = 21$, traditional and $n = 23$, flipped), and the number of t-tests conducted to test for statistical significance for each of the end of term SOS items (a total of eight independent t-tests), it is possible that Type II errors may have resulted. A Type II error occurs when findings are truly statistically significant, but due to certain statistical properties, such as small sample sizes (typically less than 30 respondents per class), results show otherwise. It is therefore recommended that replication of this study be conducted with larger sample sizes per class and in addition to comparing means, statistical analyses also compare the differences in the number of students reporting "strongly agree" for each of the end of term SOS items using non-parametric testing methods.

The primary weakness of the flipped classroom teaching strategy was that the textbook was not utilized much by the students. This was probably due to the successful use of the YouTube videos, which provided students the necessary content. In the future, instead of requiring a textbook, more application-specific reading materials could be provided such as popular science magazine articles and additional online videos (Ted Talks, Khan Academy, etc.).

One challenge for the flipped class was the formation of effective peer groups. Although groups functioned relatively well, group expectations could have been better explained by the instructor earlier in the term. There were times when students tried to focus on their own work more than contributing to the group learning. It is very important to convey the message to students that the main objective of working in groups is to enhance their learning via collaboration. Including some type of peer evaluation is also very important in collaborative learning to ensure individual accountability.

In the digital circuits flipped classroom, the instructor exposed students to more realistic, open-ended case scenarios which reflected more authentic learning and assessment [31] compared to traditional lecture courses and the standard multiple-choice exam or closed-ended problem set. However, some students struggled with these types of problems as they expected to have more structured, one-correct answer problems. In the future, it is recommended that instructors explicitly explain why open-ended questions are more helpful to students' learning in the field of engineering, since the theoretical concepts are most useful when they are applied. Plus, Millennial students tend to appreciate learning that is relevant [32]. Because Millennials have grown up in an era where information was readily accessible and available through Internet search engines such as Google, they tend not to value information for information's sake. Instead, Millennials value the application of information that will be relevant and useful for their chosen careers or daily life. The flipped classroom teaching strategy affords instructors multiple opportunities to connect course content presented outside of class via video modules to in-class active learning activities mirroring the problems students could likely experience in their professional lives.

Another aspect of engineering education is to train students using engineering software. Traditionally, this training does not start before junior year. However, the flipped class in freshmen level engineering had included some software-based circuit design activities that were received well by the students. It is highly recommended that students should be immersed in simulation programs where systems can be tested for their functionality. Furthermore, students can verify their design concepts by using simple yet powerful circuit simulators.

Lastly, the instructor should form additional larger discussion groups to enhance the interactions between student groups not just within groups to promote deeper learning even further. This is particularly important for future engineers as the work environment typically involves multiple facets of opinions and ways of thinking.

This study provides convincing data where the flipped class approach was better than the traditional class in many aspects. However, the scope of the study is relatively narrow due to the number of students and years that were investigated. Therefore, it is recommended that flipped class approaches be studied by looking at several year-long surveys and perhaps student interviews. Another aspect would be to study the retention of the material. Students could perhaps be monitored throughout their education and compared with "control" groups who would not have been exposed to flipped classes.

5. Conclusion

In conclusion, based on the data, freshmen level engineering courses are suitable for flipping. Although students are challenged at the beginning of the class with continuous assignments such as quizzes and video viewings, they eventually liked the course format as it gave them more opportunities to learn and apply their learning to real-life scenarios as a growing engineer. Furthermore, based on the findings from this study, flipped classroom students processed and understood theoretical concepts at a deeper level than traditional lecture students. Although the flipped strategy provided benefits to both instructor and students (e.g., better student-instructor relationship, improved survey scores, faster coverage of the classroom material, etc.), the initial time investment of the implementation was significant. It is therefore suggested that instructors dedicate a summer to prepare the delivery of the course material and have a lighter teaching load during the semester when the flipped course is first implemented. Yet, because flipped courses help organize the course in advance, and once the course material and classroom activities are developed, re-teaching the course becomes easier.

Although students first resist the idea of studying the course content in advance, once they realize the homework is applied in the classroom, and they receive constant feedback from the instructor, they like the flipped course format much better than traditional lecture and understand the application of course concepts better. Thus, it is recommended that instructors be prepared for failures and initial student resistance, but persist with the course layout because of its eventual benefits.

It must be noted here that not only a short-term but also a long-term assessment (longitudinal) studies need to be performed in the future. These studies should focus on student retention and success in the upper level engineering courses. Control groups need to be maintained as well in order to compare the techniques that have been implemented. Student focus groups and faculty and student perceptions can also be studied. Another long-term assessment would be the success of students in performing in their careers.

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