An investigation of students' content understanding, perception changes, and experiences in a flipped precalculus course

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This study reports on the implementation of the flipped classroom in a university precalculus course. Students in the flipped section of the course outperformed their counterparts in two traditional lecture sections of the course on the final exam. In addition, students' perceptions of the usefulness of textbook readings in the flipped section of the course changed for the better during the semester, while their perceptions of the usefulness of clicker questions, lecture notes (PowerPoint slides), and in-class activities changed for the worse. On another note, students' anxiety levels for taking precalculus in the flipped section of the course decreased across the semester. Despite many of the students indicating they would prefer taking a traditional section of the course, they expressed a positive attitude about the format of the flipped section of the course. Students in the flipped section of the course valued discussing and solving homework problems with classmates in the classroom. Student-reported ideas for enhancing the flipped section of the course, recommendations for instruction, and directions for future research are discussed.

Introduction

Although there are variations on the implementation of the flipped classroom (FC), also known as the inverted classroom, there is a consensus view within the research community on the concept of the FC in nearly every discipline of higher education. Specifically, instead of students coming to the classroom (hereafter, class) to listen to a lecture, take lecture notes, and practice content covered in the lecture outside of the class by completing homework assignments-the norm in most traditional classrooms (TC), the reverse happens in the FC (cf., Bergmann & Sams, 2012; Butt, 2014; Davenport, 2018; Lage, Platt, & Treglia, 2000; Love, Hodge, Grandgenett, & Swift, 2014; Strayer, 2012; Tucker, 2012). In the FC, students typically watch or listen to a pre-recorded lecture presentation(s) prior to each class meeting, while class time is reserved for practicing content covered in the lecture recording(s). The practice of content covered in lectures often takes the form of completing problem-based activities and homework assignments in an environment that fosters active learning such as small groups characterized by a lot of student-to-student and student-to-instructor interactions, respectively. Instead of watching or listening to a pre-recorded lecture prior to each class meeting, the students in the present study were required to read instructor-prepared lecture notes (hereafter, lecture notes), selected portions of the course textbook (Sullivan, 2016), and to make their own notes as they read the lecture notes and textbook prior to each class meeting. Details on the implementation of the FC in the present study are presented in the methodology section.

The advent of teaching technologies such as audio and video recording devices has seen an increased adoption of the FC as a new pedagogical approach in many institutions of higher education. Despite the notable increase in the adoption of the FC as a pedagogical approach in many university campuses, several researchers have argued that there is a paucity of research that has examined the impact of implementing the FC on student learning (cf., Green, Banas, & Perkins, 2017; Love et al., 2014). Regarding the FC in the teaching of undergraduate STEM (science, technology, engineering, and mathematics) courses, Love et al. argued that:

> While the flipped classroom model shows promise for improving STEM learning and increasing student interest in STEM fields, discussions to date of the model and its impact are more anecdotal than data driven – very little research has been undertaken to rigorously assess the potential effects on student learning that can result from the flipped classroom environment (p. 317).

The present study provides data driven evidence on the effectiveness (or lack thereof) of the FC approach on students' content understanding in a precalculus course. Students' content understanding was measured by performance on four exams, including the final exam. In addition, the present study examined how students' perceptions of different features (e.g., reading assignments) of the FC changed (or did not change) before and after taking the course. Furthermore, we gathered students' ideas on the different features of the FC that could be changed (and how they could be changed) to improve student experiences and success in the FC. The research questions guiding this study are:

a. How does students' content understanding compare in the TC and in the FC?
b. How do students' perceptions of the FC compare before and after taking a course that uses the FC?
c. What feature(s) of the FC can be improved (and how) to ensure that students have positive experiences and succeed in the FC?

Related literature

Implementation of the FC in STEM courses

Evidence from research shows an increasing use of the FC in the teaching of STEM courses at the undergraduate level. In mathematics alone, several studies have documented the use of the FC in the teaching of linear algebra (Love et al., 2014), differential equations (Yong, Levy, & Lape, 2015), numerical analysis (Johnston, 2017), calculus (Adams & Dove, 2016; Maciejewski, 2016), precalculus (Collins, 2019), college algebra (Overmyer, 2014; Van Sickle, 2016), and business calculus (Zack et al., 2015). A substantial amount of research has examined the implementation of the FC in several other disciplines within STEM, besides mathematics. These disciplines include computer programing (Davenport, 2018), civil engineering (Hotle & Garrow, 2016), biology (Heyborne & Perrett, 2016; Marcey & Brint, 2012; Sletten, 2017), general science (Jeong & Gonzalez-Gomez, 2016), structural dynamics (Baytiyeh & Naja, 2017), engineering physics (Ramirez, Hinojosa, & Rodriguez, 2014), statistics (Khan & Watson, 2018; Winquist & Carlson, 2014), chemistry (Fautch, 2015; Olakanmi, 2017), information technology (Elliott, 2014), information systems (Davies et al., 2013), thermodynamics (Lape et al., 2016), and architectural engineering (Leicht, Zappe, Messner, & Litzinger, 2012).

As previously noted, there are variations in the way different instructors have implemented the FC in STEM courses. Specifically, in addition to requiring students to watch pre-recorded lecture videos prior to coming to class-a common practice in the FC, other instructors have given mini-lectures at the beginning of each class meeting (cf., Fautch, 2015), required students to complete reading assignments before each class meeting (cf., Love et al., 2014; Winquist & Carlson, 2014), used peer learning and tutor assistance during class meetings (cf., Khan & Watson, 2018), and used photographs (Ramirez et al., 2014). In addition, while some instructors have not monitored or offered an inducement for students to watch pre-recorded lecture videos prior to each class meeting in the FC (cf., Collins, 2019), other instructors have given short quizzes either at the end of the lecture videos or at the beginning of each class meeting in an effort to assess students' basic understanding of the material covered in the lecture videos (cf., Davenport, 2018; Fautch, 2015; Winquist & Carlson, 2014). Regardless of the variations in the implementation of the FC by different instructors, a common theme that emerges from the studies that have examined the use of the FC in STEM courses is that active learning in the form of small groups or whole class discussions are encouraged during class meetings (cf., Elliott, 2014), often with the instructor assuming the role of a facilitator as opposed to delivering lectures, a common practice in the TC.

2.2 *Students' content understanding in STEM courses: FC versus TC*

Several studies have used quasi-experimental designs to examine the impact of the FC on students' content understanding in various STEM courses (cf., Baytiyeh & Naja, 2017; Collins, 2019; Davies et al., 2013; Fautch, 2015; Heyborne & Perrett, 2016; Hotle & Garrow, 2016; Khan & Watson, 2018; Love et al., 2014; Marcey & Brint, 2012; Olakanmi, 2017; Van Sickle, 2016; Winquist & Carlson, 2014; Zack et al., 2015). These studies have compared students' content understanding in course sections that have used the FC with students' content understanding in course sections that have used the TC. To date, there have been mixed findings on the superiority of the FC (experimental sections) over the TC (control sections) in improving students' content understanding in STEM courses. In mathematics, a few studies have reported on students in experimental sections of calculus, precalculus, and college algebra outperforming their counterparts in control sections of the same courses (cf., Collins, 2019; Maciejewski, 2016; Van Sickle, 2016). A few other studies have reported on quite the opposite (i.e., students in control sections outperforming students in experimental sections) in calculus, differential equations, finite mathematics, precalculus, and business calculus courses, respectively (cf., Adams & Dove, 2016; Yong et al., 2015; Zack et al., 2015).

Love et al. (2014), who studied students' content understanding in two sections of a linear algebra course, reported that students in the experimental section of the course outperformed their counterparts in the control section of the course on course exams. However, student performance on the final exam was similar in both sections of the course. Love and colleagues argued that while the FC shows promise for improving student learning at the undergraduate level, there is lack of scientific evidence to support the claim that this model is better, in terms of improving students' content understanding, compared to the TC. These researchers argued that "the promise of a flipped environment has not yet been well researched and documented, especially within the context of introductory courses" (p. 323). Persuaded by Love et al.'s argument, the present study seeks to contribute to our understanding of the impact of implementing the FC on students' content understanding in introductory university mathematics courses. Specifically, the goal of our study is to provide scientific evidence on the effectiveness (or lack thereof) of the FC in improving students' content understanding in a precalculus course.

Students' perceptions of the FC in STEM courses

A growing body of research has used survey instruments to gather data on students' perceptions of the FC in various STEM courses (cf., Baytiyeh & Naja, 2017; Davenport, 2018; Davies et al., 2013; Elliott, 2014; Fautch, 2015; Heyborne & Perrett, 2016; Love et al., 2014; Olakanmi; Van Sickle, 2016). Much of this research has generally reported positive student perceptions of the FC. We note, however, that nearly all these studies have examined students' perceptions of the FC in other STEM areas besides mathematics. In fact, we found only two studies that have reported on students' perceptions of the FC in mathematics (Love et al., 2014; Van Sickle, 2016). We further note that in a majority of the studies that have examined students' perceptions of the FC in other STEM areas besides mathematics, survey instruments were given at the beginning, middle, and end of the semester (cf., Davenport, 2018; Elliott, 2014). Consequently, these studies have effectively examined changes in students' perception of the FC changes over time (i.e., one semester).

On the contrary, the two studies that have reported on students' perceptions of the FC in mathematics have only examined students' perceptions of the FC at the end of the semester. Van Sickle (2016) analyzed four items from end-of-semester course evaluations that measured student perceptions in a college algebra course. These items are: (1) "The instructor created an environment conducive to the learning process" (p. 29), (2) "The instructor encouraged my interest in the course" (p. 29), (3) "Overall, the instructor effectively facilitated my learning" (p. 29), and (4) "Overall, I rate the course as excellent." (p. 29). These items were rated by students on a scale of 1 (strongly disagree) to 5 (strongly agree). Findings of this study indicate that students' perceptions of the course were generally negative, especially on Items 2 and 3. In another study, Love et al. (2014) reported that "course perceptions were represented by an end-of-semester survey that indicated that the flipped classroom students were very positive about their experience in the course, and particularly appreciated the student collaboration and instructional video components." (p. 317). Taken together, the findings from Van Sickle (2016) and Love et al. (2014) suggest that students have mixed perceptions of the FC in mathematics courses. In addition, there is a need to examine how students' perceptions of the FC change (or do not change) during the semester in mathematics courses, something that is lacking in these studies. To address this knowledge gap, the present study used a pre- and post -survey instrument to gather data on how students' perceptions of the FC changed in a precalculus course during the course of a 16-week long semester.

Benefits and pitfalls of the FC in STEM courses

A substantial amount of research on the use of the FC in the teaching of STEM courses has reported on instructors and students' perspectives of the benefits and pitfalls of the FC (cf., Collins, 2019; Davenport, 2018; Fautch, 2015; Heyborne & Perrette, 2016; Hotle & Garrow, 2016; Khan & Watson, 2018; Olakanmi, 2017; Ramirez et al., 2014). Among the many benefits of the FC documented in the research literature, students in Davenport's (2018) study "felt that the flipped classroom improved their critical thinking skills and gave them confidence to apply computer programming as an analysis tool outside of the classroom" (p. 30). This researcher argued that the FC affords instructors the opportunity to cover a breath of content, in addition to promoting active learning among students using hands-on problem-solving activities in the class. Olakanmi (2017) asserted that students benefited from watching pre-recorded lecture videos prior to each class meeting and interacting with the instructor and other students when working on in-class activities. Similar results were reported by Fautch (2015) who also argued that the FC helps students to take ownership of their learning. Students in Heyborne and Perrette's (2016) study stated that having pre-recorded lectures enabled them to stay on top of the material, in addition to giving them the flexibility to re-watch the lecture videos anytime they needed to. Ramirez et al. (2014) reported similar benefits.

Concerning pitfalls of the FC, some students have found the FC to be ineffective when the course content becomes more challenging towards the end of the semester (cf., Davenport, 2018; Hotle & Garrow, 2016). Students who have found the FC to be effective for their learning have suggested having brief lectures in the class, in addition to pre-recorded video lectures that students are required to watch outside class (cf., Davenport, 2018). Other students have noted technical problems (e.g., access to the internet), long pre-recorded lecture videos, and lack of instant feedback when watching lecture videos as major drawbacks for the FC (cf., Ramirez et al., 2014). We argue, based on our experience with the FC, that students' failure or inability to complete pre-class assignments (e.g., watching pre-recoded video lectures and reading assignments) could defeat the purpose of the FC in that instructors may have to spend a lot of time teaching and answering basic questions about the lecture content from students who did not complete the pre-class assignments prior to coming to the class. On another note, we posit that it may be difficult to implement the FC in large classrooms. Specifically, it may be difficult to manage group activities in a large lecture classroom or for the instructor to circulate through the class and assist individual students or small groups of students when working on in-class activities. To alleviate these problems, we believe that instructors of large lecture sessions could use the assistance of teaching assistants if that is an option at their institutions.

Methodology

Setting, participants, and precalculus

This study was conducted at a regional campus of a large public research university in the United States. The student population on this campus of the university consist of traditional and non-traditional students. According to Evelyn (2002), non-traditional students are often described as being at least twenty-four years old, having a family to support, or being employed full time. The participants were 132 students, mostly freshmen and represented a wide range of STEM majors, including engineering, information technology, and biology. In addition, they were enrolled in five sections of a precalculus course taught by the same instructor between the fall semester of 2016 and the spring semester of 2019. Twenty-nine students were enrolled in the experimental section of the course taught in the spring semester of 2019. This section met from 4:25 pm to 6:50 pm, two days a week. The other 105 students were enrolled in four control sections of the course. Specifically, the first control section had an enrollment of 19 students and was taught in the fall semester of 2016. This section met from 2:30 pm to 3:35 pm, four days a week. The second control section had an enrollment of 26 students and was taught in the spring semester of 2017. This section met from 7:00 pm to 9:30 pm, two days a week. The third control section had an enrollment of 27 students and was taught in the fall semester of 2017. This section met from 2:50 pm to 4:00 pm, four days a week. The fourth control section had an enrollment of 33 students and was taught in the spring semester of 2018. This section met from 4:25 pm to 6:50pm, two days a week.

The same exams, consisting of three course exams (herein referred to as Exam 1, Exam 2, and Exam 3) and a cumulative final exam, were given in the five sections of the course. There were 10 questions, each worth 10 points on each of the course exams and 15 questions, each worth 10 points on the final exam. The same lecture notes and textbook were used in the five sections of the course. The only difference is that in the control sections, the lecture notes were posted on Canvas, a learning management system (LMS), after each class meeting where as in the experimental section they were posted on the same LMS two weeks before the class meeting where the content covered in the notes was to be discussed.

Precalculus is typically a four or five-credit hour course that is often taken by freshmen who are not prepared to take the first course in the calculus sequence (Calculus I, Calculus II, and Calculus III) at most colleges and universities in the United States. At this university, precalculus is a five-credit hour course. Students majoring in STEM fields at this university usually, after completing precalculus successfully, go on to take some or all the courses in the calculus sequence. With the exception of a few STEM majors, credit earned in precalculus does not count toward most STEM majors offered at this university. Instead, the course serves as a prerequisite for other mathematics courses, especially calculus (e.g., Calculus I), that students take for credit that count toward many STEM majors such as engineering. Students in some non-STEM majors may be able to use credit earned in precalculus to fulfill a university quantitative reasoning requirement. The course covers several topics, namely polynomial functions, rational functions, logarithmic and exponential functions, trigonometric functions and their inverses, conic sections, nonlinear systems, and applications of functions. Student placement in precalculus is determined by a qualifying score (at least 80%) on a placement exam, completion of intermediate algebra (or the equivalent thereof) with a grade of C or better, an SAT Math score of 530 or higher, or an ACT Math score of 22 or higher.

The flipped precalculus section

Contrary to the norm observed in the STEM courses (described in Section 2.1) that have used the FC where students had to watch pre-recoded video lectures prior to coming to class, the students in the flipped section of the precalculus course in this study were required to read lecture notes and sections of the course textbook prior to each class meeting. A check-knowledge quiz (hereafter, CKQ) assessing students' basic understanding of the content covered in the lecture notes and assigned textbook readings (hereafter, textbook readings) was given in the first 10 minutes of each class meeting. A sample CKQ is given in Appendix A. Following the completion of a CKQ, the instructor would spend about 20 minutes discussing solutions to the CQK on the whiteboard, recapitulating main ideas from the textbook readings, and answering questions students had about the content covered in the lecture notes and textbook readings. Sometimes, instead of recapitulating main ideas from lecture notes or textbook readings, the instructor would use clicker questions to engage the whole class in reviewing these ideas.

Students were randomly assigned by the instructor into groups of three or four students, respectively, and spent the rest of class time solving problems prepared by the instructor and assigned homework problems in these groups. As students worked in groups, the instructor circulated through the class, answering questions students had, in addition to assisting (by giving hints) when students would appear to be struggling with solving the problems they were given. Occasionally, representatives from each group would be asked to write their solutions on the whiteboard and to engage the whole class in a discussion of their solutions while the instructor assumed a facilitator role. In the control sections, the instructor began each class by recapitulating content covered in the most recent lecture, followed by a lecture for that day, and concluded with in-class activities that students completed in pairs or discussed as a class. In addition, a quiz was given once a week in each of the control sections. Furthermore, four project assignments were given in the five sections during the semester in which each section of the course was offered. A sample project is shown in

Appendix B. Students were given time to discuss these projects in class and were required to submit a written project report summarizing their results and what they learned from the project a week after each project was discussed in class. Students were required to type their project reports on a word processor (Google Docs), in addition to sharing their Google Docs with the instructor as they worked on the report.

Methods of data collection and analysis

Data for the study consisted of students' scores on Exam 1, Exam 2, Exam 3, and the Final Exam. Quantitative methods were employed to analyze this data. Specifically, means (i.e., class average scores) on each exam, across the five sections, were compared statistically using a one-way analysis of variance (ANOVA) test to determine whether there was an overall statistically significant difference in means. If the results of running a one-way ANOVA test were found to be statistically significant for any exam, a post hoc pairwise comparison test, namely Tukey's Honestly Significant Difference (HSD) test, was run to determine where the differences occurred between sections i.e., to find means that were significantly different from each other. If, for instance, results of running a one-way ANOVA test were statistically significant for Exam 1, a Tukey HSD test was performed to determine which Exam 1 means were significantly different from each other.

Student responses (in the flipped section) to two Qualtrics online survey instruments (see Appendix C and Appendix D) administered at the beginning and at the end of the course constituted the second piece of data for this study. The purpose of these surveys was to gather data on students' perceptions of the FC before and after the course, students' experiences in the FC, students' anxiety about taking precalculus, and student-reported suggestions on how different features of the FC (e.g., lecture notes) could be improved to better meet student learning needs. The first survey was administered on the first day of the course and the second survey was administered on the last week of the course. Qualitative methods were used to analyze the data collected using these survey instruments. To be specific, we used thematic analysis to identify themes (patterns) in the data. These themes consisted of common student perceptions and experiences about the FC identified in the data, in addition to common student-reported ideas on the different features of the FC that could be improved to ensure that students have positive experiences and succeed in the FC. By comparing student perceptions (from the pre-and post-survey instruments) of different features of the course, namely group projects, clicker questions, in-class activities (problems prepared by the instructor), lecture notes, and textbook readings, we were able to determine how student perceptions of these features changed during the semester in which the course was offered.

Results

Students' content understanding: Flipped section versus control sections

To reiterate, by the experimental section we mean the flipped section of the course that was taught in the spring semester of 2019. Results of a one-way ANOVA test revealed that at least one of the means for Exam 1 was different, $F(4, 128) = 3.65,\ p = 0.0076$. Post hoc comparisons using the Tukey HSD test indicated that the mean Exam 1 score for the experimental section ($M = 86.55, SD = 19.81$) was significantly different ($p = 0.0063$) from the mean Exam 1 score for the fall 2017 section ($M = 70.49, SD = 23.90$). In addition, the mean Exam 1 score for the experimental section ($M = 86.55, SD = 19.81$) did not significantly differ from the mean Exam 1 scores for the fall 2016 section, spring 2017 section, and spring 2018 section. Results of a one-way ANOVA test showed that at least one of the means for Exam 2 was different, $F(4, 127) = 4.71,\ p = 0.0014$. Post hoc comparisons using the Tukey HSD test revealed that the mean Exam 2 score for the experimental section ($M = 75.02, SD = 22.74$) did not significantly differ from the mean Exam 2 scores for all the control sections. We note that since the present study examines the effectiveness of the the FC in improving students' content understanding, we do not report Tukey HSD results that pertain to pair-wise comparisons that only involve control sections such fall 2016 and fall 2017. Results of a one-way ANOVA test showed that at least one of the means for Exam 3 was different, $F(4, 127) = 2.73,\ p = 0.0322$. Like in Exam 2, post hoc comparisons using the Tukey HSD test indicated that the mean Exam 3 score for the experimental section ($M = 79.74, SD = 28.07$) did not significantly differ from the mean Exam 3 scores for all the control sections.

Lastly, results of a one-way ANOVA test revealed that at least one of the means for the Final Exam was different, $F(4, 127) = 7.53,\ p < 0.0001$. Post hoc comparisons using the Tukey HSD test indicated that the mean Final Exam score for the experimental section ($M = 131.11, SD = 36.07$)

was significantly different ($p = 0.0008$) from the mean Final Exam score for the spring 2017 section ($M = 91.44, SD = 33.58$). Additionally, the mean Final Exam score for the experimental section ($M = 131.11, SD = 36.07$) was significantly different ($p < 0.0001$) from the mean Final Exam score for the spring 2018 section ($M = 84.92, SD = 32.80$). Post hoc comparisons using the Tukey HSD test showed that the mean Final Exam score for the experimental section ($M = 131.11, SD = 36.07$) did not significantly differ from the Final Exam mean scores for the fall 2016 section and the fall 2017 section. In general, students in the experimental section either equally performed as studnets in the control sections or they outperformed students in the control sections. We note that when compared to all the control sections, the mean score for the experimental section was highest for Exam 1, fourth highest for Exam 2, second highest for Exam 3, and highest for the Final Exam. Arguabaly, the results reported in this section to some extent provide evidence of the effectiveness of the FC in improving students' content understanding in precalculus.

Student perceptions of different features of the FC

Table 1 summarizes how students' perceptions of different features of the experimental section of the course, namely group projects, clicker questions, in-class activities, textbook readings, and lecture notes compared at the beginning and at the end of the course, respectively. Students rated the usefulness of these features on a scale of 1 (least useful) to 5 (most useful). The average ratings in the table are based on 25 students who rated the usefulness of these features in the pre-survey and in the post-survey.

Table 1. Student ratings of different features of the experimental section.

Feature	Average pre-survey Ratings	Average post-survey ratings
Textbook readings	2.88	3.28
Group projects	3.36	3.24
Clicker questions	3.16	2.32
In-class activities	4.2	3.16
Lecture notes	4.24	3.16

Based on Table 1, there was an increase in students' appreciation of textbook readings during the semester. A paired t-test comparison of students' ratings of the usefulenss of the textbook in the pre-and-post survey revelaed that this increase was not statistically significant. We note that students' scores on CKQs generally improved during the semester, suggesting that students not only recognized the importance of reading the lecture notes and textbook, but also completed these reading assignments before each class meeting during the course of the semester. Students' responses to Items 18 and 20 on the post-survey revealed that while students generally supported the use of lecture notes as part of the course, they also had some concerns about this feature of the course. The following is an exemplary comment from a student in response to Item 20: As the semester progressed, did your use or attitude about the instructor lecture notes change? If yes, in what ways and why?

> I used the lecture notes quite frequently throughout the course and for the most part they were helpful. But, for some chapters, they felt very bare and very useless when trying to use them for our homework questions. So, I enjoyed the notes, but they could have been more in depth.

In response to Item 18: What did you like/dislike about using the instructor lecture notes as part of the course? one student remarked, "The lecture notes were great. They helped us with our quizzes [CKQs] and our exams," suggesting that the lecture notes were helpful for some students in the course when preparing for CKQs or exams given in the course. Other students' remarks suggested that the lecture notes helped them understand the content presented in the textbook. In response to Item 18, one student said, "I think the lecture notes are a beneficial tool to students, they offer a different perspective that is in the textbook that you may not see if you look at the textbook by yourself." Other students, however, found reading the textbook to be more helpful for their learning in the course than reading the lecture notes. In response to Item 18, for instance, one student commented, "lecture notes are too vague, better off just reading the textbook, I didn't look at the lecture slides after chapter 5, I just read the book."

The results in Table 1 further suggest that there was a decrease in student appreciation of clicker questions and in-class activities during the course of the semester. We offer two possible explanations for this decrease in appreciation of these features of the course. First, it could be that students found no value in these features as the semester progressed. Second, it is possible that students disliked these features with time because, at times, a significant amount of time was spent on these features during class meetings such that some of the assigned homework problems that were to be completed in class ended up being problems students had to complete outside the class.

Features of the FC needing improvement: A students' perspective

In this section, we report on students' responses to Item 19 on the post-survey: Do you have any suggestions for improving the instructor lecture notes, the course format, or any other aspect of the course? The purpose of this item was to get students' perspective on the features of the course needing improvement, and possibly the nature of this improvement, in the FC as implemented in this study. There are two themes from students' responses to this item. First, a majority of the students indicated that they would have loved for the notes to be more detailed. The following comment exemplifies students' view on the need for the lecture notes to be detailed:

> I would try to go more in depth in the notes, possibly more in depth with the steps when solving problems. The course was planned very well and I enjoyed the syllabus explaining what we would be doing in class every day.

Second, several students (mainly non-traditional students) indicated that they did not like the flipped format of the course. These students suggested that the course be taught in a traditional format to better meet their learning needs. The following comment illustrates how non-traditional students generally commented about the challenges they faced in the flipped format of the course, in addition to stating their preference for a traditional course.

> I think the only downside to the course format is that it isn't as friendly for people who have busy lives outside of school as a traditional class. You are expected to spend however much time is necessary to learn the material on your own so that you can sufficiently comprehend what you are doing in class, rather than learning it in the dedicated class time that you are already committed to on a weekly basis. While the instructor does go over the material in the classroom, it doesn't seem to be quite as

thorough as a traditionally formatted class due to the expectation that we should already know the material from studying outside of class. This can be challenging due to daily quizzes [CKQs] at the beginning of class that are for a grade.

Among other things, the preceding comment suggests that students felt that they had to dedicate more time to the course than they would have to if they had taken a traditional course. Given that this comment was more common among non-traditional students, we argue that this may suggest that the FC is not a good fit for this student population. Two students disliked the clicker questions. In response to Item 19, one student remarked, “clicker problems are not efficient.” In response to the same item, another student commented, “…no clicker questions.” We note that none of the students commented on group projects and in-class activities when responding to Item 19, suggesting that students might not have had issues with the manner in which these features were incorporated in the course.

Students’ attitudes about the course format and precalculus anxiety

Table 2 provides average student ratings on Items 11 through 16 (re-stated below) in the post-survey. These items were used to gather information on students’ attitudes about the course format. The items were rated on a scale of 1 (strongly disagree) to 5 (strongly agree).

11. Studying instructor lecture notes in advance of class and spending class time on other activities (e.g., discussing and solving homework problems, answering clicker questions) was helpful in learning the course material.
12. I prefer the format of this course over the traditional lecture format.
13. Compared to other mathematics courses I have taken, I learned more in this course.
14. Compared to other mathematics courses I have taken, I enjoyed this course more.
15. Compared to other mathematics courses I have taken, I was more comfortable discussing the course content with classmates in this course.
16. Overall, my attitude about the format of the course (instructor lecture notes and in-class activities) is positive.

Table 2. Average student ratings on items about the course format.

Item	Average post-survey ratings
11	3.67
12	2.78
13	3.00
14	3.11
15	3.56
16	3.26

The ratings in Table 2 suggest that although the students in this study prefer traditional lecture courses over flipped courses (Item 12), they valued the structure of the course (Item 11). In addition, the students were more comfortable discussing the course content with classmates in this course compared to other mathematics courses they have taken before (Item 15). In fact, a majority of the students rated Items 11 and 15 with at least a 4 (somewhat agree), while a majority of the students rated Item 12 with at most a 3 (neutral).

Students' responses to Item 3: On a scale from 1 to 5, where 1 means not anxious and 5 means very anxious, how anxious are you about taking precalculus? in the pre- and post- survey revealed that students were less anxious about taking precalculus at the end of the course than they were at the beginning of the course. Specifically, student average ratings on this item in the pre-survey was 3.29 compared to 2.63 on the same item in the post-survey. A paired t-test comparison of students' anxiety levels for taking precalculus in the pre-survey and post-survey revealed that the difference in these average ratings was statistically significant ($p < 0.01$). While we do not know what exactly may have caused a decrease in precalculus anxiety as the semester progressed, we make a speculation based on the ratings reported in Table 2. We speculate that discussing and solving homework problems in the class (Item 12), coupled with the comfort of discussing the course content in the class with classmates (Item 15), may have, in part, contributed to the observed decrease in students' precalculus anxiety during the semester.

Discussion and conclusions

Contrary to the conventional approach of requiring students to watch pre-recorded lecture videos prior to each class meeting in the FC (cf., Collins, 2019; Davenport, 2018; Heyborne & Perrett, 2016; Maciejewski, 2016; Sletten, 2017), the students in the present study were required to read sections of the course textbook, in addition to lecture notes provided by the instructor. Consistent with Love et al.'s (2014) finding that the benefits of the FC may not be evident early in the course, the students in the experimental section of the course equally performed as students in the four control sections of the course in nearly all the course exams (i.e., Exam 1, Exam 2, and Exam 3). Specifically, students in the experimental section only outperformed their counterparts in the control section of the course taught in the fall semester of fall 2017 on Exam 1. On the final exam, however, students in the experimental section of the course outperformed their counterparts in two control sections of the course, namely the control section taught in the spring semester of 2017 and the control section taught in the spring semester of 2018. We note that even though students in the experimental section performed similarly compared to students in two other control sections on the final exam, namely the control section taught in the fall semester of 2016 and the control section taught in the fall semester of 2017, the average raw score in the experimental section was larger than all the average raw scores from the control sections on the same exam. Specifically, the average raw score in the experimental section on the final exam was 131.11, compared to 103.13 in the fall semester of 2016, 91.44 in the spring semester of 2017, 112.56 in the fall semester of 2017, and 84.92 in the spring semester of 2018. Thus, we argue that the findings of this study provide evidence of the effectiveness of the FC (as implemented in this study) in improving students' content understanding in introductory mathematics courses.

Students' perceptions of different features of the FC either changed for better or for worse during the semester. Specifically, students' perceptions about textbook readings improved over time, while their perceptions about lecture notes, clicker questions, group projects, and in-class activities worsened over the course. Student-reported suggestions for improving the FC indicate that providing students with detailed lecture notes would benefit student learning in the FC. We also found that a majority of the non-traditional students preferred the TC over the FC, arguing that overall, the latter course format calls for students to devote more time engaging with the course content outside the class compared to the former format. In light of the unique challenges that are common among non-traditional students, including supporting a family or being employed full-time while also attending college (Evelyn, 2002), we recommend an approach that involves minimizing the amount of work (e.g., reading assignments) students have to complete outside the class and providing mini-lectures at the beginning of each class meeting in an effort to better serve this student population in introductory mathematics courses. Analysis of students' responses to open-ended questions designed to assess students' attitudes about the format of the FC as implemented in this study revealed that while students generally prefer the TC over the FC, they value the opportunity provided by the FC to solve homework problems in the class with classmates. In addition, students reported being more comfortable discussing the course content with classmates in the FC compared to other mathematics courses they have taken. Lastly, students in the FC section were less anxious about taking precalculus at the end of the course than they were at the beginning of the course, suggesting that the FC has the potential to decrease students' anxiety about taking introductory mathematics courses such as precalculus.

Limitations

We conclude this paper by discussing three limitations of the present study. First, when comparing students' content understanding in the experimental section and the control sections, we did not control for several factors, including time of the day when the sections were taught and the instructor's experience over time. With regard to the instructor's experience, for instance, it could be that on the exams where students in the experimental section of the course outperformed their counterparts in the control sections of the course, this was a mere reflection of the instructor's increasing effectiveness in teaching the course and not necessarily an indication of the FC's superiority in improving students' content understanding compared to the TC. Second, while this study provides useful insights on different features of the course that students found to be beneficial in the FC (i.e., textbook reading), as well as features that need improvement (e.g., lecture notes), it is not easy to determine what and how various aspects of the textbook (e.g., expository sections and examples) students found to be beneficial for their learning in the course from survey responses. In addition, one cannot fully ascertain from survey responses how the features of the course identified by students as needing improvement in the FC could be improved. To better understand these issues, one would have to conduct follow-up interviews with students, something we did not do in this study. Third, this study found that students' precalculus anxiety decreased during the semester. Finding out how certain features of the course may have led to the noted decrease in precalculus anxiety would require follow-up interviews with students. Thus, future research might use structured interviews with a larger sample of students to further explore this, and other issues observed in this study.

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Disclosure statement

The author declares that there is no conflict(s) of interest.

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Appendix A: A Sample Check Knowledge Quiz given in the Flipped Section of the Course

NAME: ____

Check Knowledge Quiz 10

1. $s = \log_k t$ is equivalent to $s^k = t$ if $k > 0$ and $k \neq 1$. [**True/False**]. [2 .5 points]

2. If $\log_r x = log_r y$, then $x = y$ if x, y, and r are positive and $r \neq 1$. [**True/False**]. [2.5 points]

3. If $y^a = y^b$, then $a = b$ if $y > 0$ and $y \neq 1$. [**True/False**]. [2.5 points]

4. Solve $4^{2x+1} = 16$. [2.5 points]

Appendix B: A Sample Project given in the Flipped and Control Sections of the Course

(Adapted from Moran et al., 1996)

Project 4-Daylight and Seasonal Affective Disorder (SAD)

Background

The seasons affect everyone's moods to some degree, but some people are so strongly affected by the amount of daylight that they experience mild to severe depression during the part of the year when the hours of daylight are shortest. This condition is termed seasonal affective disorder, or SAD. A typical person with SAD feels depressed for two or three months, sometime between the end of October and late February. She (women are affected more often than men) may experience a lack of energy and a craving for carbohydrates, and she may respond by oversleeping, overeating, and withdrawing from society.

An estimated 6% to 8% of the population of New England suffers from full-blown SAD. Unlike the traditional treatments for other forms of depression, an effective therapy for SAD has the patient sit in front of bright lights every morning. More information on SAD can be found at: http://www.ncpamd.com/seasonal.htm

In this project, you will find a function that can be used to estimate the amount of daylight that a person with SAD might be "missing" when compared to March 21, the first day of spring. An equinox occurs twice each year at two specific moments in time when the center of the sun is located vertically above the earth's equator. This happens around March 20 or 21 and around September 22 or 23 each year. The word equinox comes from the Latin words for 'equal' and 'night' because at the equinox the night and the day are equally long.

Your functions will depend on how far north of the equator you are! You will use your functions to estimate the rate at which the amount of daylight is changing at various times of the year.

Project: Daylight and SAD

Over the course of a year, the length of the day-that is, the number of hours of daylight, calculated by subtracting the time of sunrise from the time of sunset-changes every day. Below is a table giving the length of day, rounded off to the nearest tenth of an hour, for Boston, latitude 42° N.

Hours of Daylight in Boston, United States (latitude 42° N)

Date	Day	Hours of Daylight	Date	Day	Hours of Daylight
1/2	2	9.2	7/5	186	15.2
1/10	10	9.3	7/13	194	15.0
1/18	18	9.6	7/21	202	14.8
1/26	26	9.8	7/29	210	14.5
2/3	34	10.1	8/6	218	14.3
2/11	42	10.4	8/14	226	13.9
2/19	50	10.8	8/22	234	13.6
2/27	58	11.1	8/30	242	13.3
3/7	66	11.5	9/7	250	12.9
3/15	74	11.9	9/15	258	12.5
3/23	82	12.3	9/23	266	12.1
3/31	90	12.7	10/1	274	11.8
4/8	98	13.0	10/9	282	11.4
4/16	106	13.4	10/17	290	11.0
4/24	114	13.8	10/25	298	10.7
5/2	122	14.1	11/2	306	10.3
5/10	130	14.4	11/10	314	10.0
5/18	138	14.8	11/18	322	9.6
5/26	146	14.9	11/26	330	9.5
6/3	154	15.1	12/4	338	9.3
6/11	162	15.2	12/12	346	9.2
6/19	170	15.3	12/20	354	9.1
6/27	178	15.2	12/28	362	9.2

Plot these points (day of year versus hours of daylight) on your calculator. Plot two years' worth of data so that you can see the pattern repeating itself. For example, in the second year, day 2 becomes day 365 + 2 = 367. So day 367 has 9.2 hours of daylight. The shape you see should look like a rough approximation of a sine wave.

1. (a) Find a formula for this curve using the sine function. Once you have an equation, enter it into your calculator in Y= and see how well your equation matches the plotted points.
(b) Interpret the **midline** and **amplitude** in your function in terms of the natural phenomena. You might want to consider the significance of March 21 (as described in the background) as the first day of spring.

Seasonal Affective Disorder (SAD) appears to be even more prevalent farther north. Below are some data for Reykjavik, Iceland, latitude 64° N.

Hours of Daylight for Reykjavik, Iceland (latitude 64° N)

Date	Day	Hours of Daylight	Date	Day	Hours of Daylight
1/2	2	4.5	7/5	186	20.5
1/10	10	5.0	7/13	194	19.9
1/18	18	5.7	7/21	202	19.1
1/26	26	6.5	7/29	210	18.3
2/3	34	7.3	8/6	218	17.4
2/11	42	8.2	8/14	226	16.5
2/19	50	9.1	8/22	234	15.7
2/27	58	9.9	8/30	242	14.8
3/7	66	10.8	9/7	250	13.9
3/15	74	11.7	9/15	258	13.1
3/23	82	12.5	9/23	266	12.2
3/31	90	13.4	10/1	274	11.4
4/8	98	14.3	10/9	282	10.5
4/16	106	15.1	10/17	290	9.7
4/24	114	16.0	10/25	298	8.8
5/2	122	16.9	11/2	306	8.0
5/10	130	17.8	11/10	314	7.1
5/18	138	18.6	11/18	322	6.3

5/26	146	19.5	11/26	330	5.5
6/3	154	20.2	12/4	338	4.9
6/11	162	20.7	12/12	346	4.3
6/19	170	21.0	12/20	362	4.2
6/27	178	20.9	12/28	362	4.3

2. (a) When you plot these points, you will see that they do not seem to lie nearly so close to a smooth sine curve as Boston's points did. The Reykjavik data are less precise and, therefore, you must not take any single point too seriously. Nevertheless, you should find a sine function that fits the data, taken as a whole, fairly well.

(b) Interpret each constant in your function in terms of the natural phenomena.

(c) What features of the graph remain substantially the same as the graph of the Boston data? Which constants control those features? What features of the Reykjavik graph makes it different from the Boston graph? Which constants control those features? Interpret these similarities and differences in terms of the natural phenomena.

3. Your next task is to investigate the rate at which the amount of daylight is changing at various times of the year for the city of Boston.

(a) During the month of April, the amount of daylight appears to be increasing each day. Using your function and an interval of time h = 0.01 days, calculate the average rate of change in the amount of daylight for April 10th, 15th, and 20th. What are the units for this rate of change? Interpret the meaning of these values in terms of the graph and in terms of the problem situation. What do these three values tell you about the shape of graph over the interval from April 10th to April 20th?

(b) During the month of October, the amount of daylight appears to be decreasing each day. Using your function and an interval of time h = 0.01 days, calculate the average rate of change in the amount of daylight for Oct. 10th, 15th, and 20th. What are the units for this rate of change? Interpret the meaning of these values in terms of the graph and in terms of the problem situation. What do these three values tell you about the shape of graph over the interval from Oct. 10th to Oct. 20th?

(c) Examine the region of the graph where the greatest number of daylight hours occurs. What is the approximate rate of change for that region? Explain how you can read this information from the graph without having to do any calculations.

Project Report

Your project report should explain how you decided on the value of each constant in the Boston length-of-day function and how you modified that function to write one for Reykjavik. Mention any difficulties you encountered in attempting to fit a sine curve to the data. For each city, you must include a graph that shows the data points and your function *on the same set of axes.* Discuss the differences and similarities between the graphs of the two cities. Explain what information these functions might provide about seasonal affective disorder, including (among other things) the effect of latitude. Interpret the rates of change that you found for the city of Boston. What conclusions can you draw about the function by looking at all three rates of change?

Appendix C: Pre-survey Questions Given in the Flipped Section of the Course

(Adapted from Love et al., 2014)

Demographic Questions

1. What is your academic standing?

Freshman Sophomore Junior Senior

Other:_________

2. What is your major?

Mathematics Engineering Other: _________

Precalculus Anxiety

3. On a scale from 1 to 5, where 1 means not anxious and 5 means very anxious, how anxious are you about taking Precalculus?

Attitudes about precalculus

For the following questions, use a scale of 1 to 5 where

1. Strongly disagree
2. Somewhat disagree
3. Neutral
4. Somewhat agree
5. Strongly agree

4. Precalculus is relevant to my education.

5. Precalculus is relevant to my career.

Attitudes about instructor lecture notes

6. Instructor lecture notes are useful for education in general.

For the following questions, use a scale of 0 to 5 where

0. Not Applicable
1. Strongly disagree
2. Somewhat disagree

3. Neutral
4. Somewhat agree
5. Strongly agree

7. In my past courses, studying instructor lecture notes **before class** was useful.

8. In my past courses, instructor lecture notes helped me learn the material being presented.

9. In my past courses, reviewing instructor lecture notes when studying for exams was useful.

10. Overall, I had a positive opinion of the instructor lecture notes in previous courses.

Attitudes about the Course Format

11. In my past courses, studying instructor lecture notes in advance of class and spending class time on other activities (e.g., discussing and solving homework problems, answering clicker questions) was helpful in learning the course material.

For the following question, use a scale of 1 to 5 where

1. Strongly disagree
2. Somewhat disagree
3. Neutral
4. Somewhat agree
5. Strongly agree

12. Overall, my attitude about the format of a course using instructor lecture notes and in-class activities is positive.

13. Please rank the following items from 1 to 5 where 1 is least useful and 5 is most useful.

__________ Textbook readings

__________ Instructor lecture notes

__________ Clicker questions

__________ In-class activities

__________ Group projects

Open Ended Question

14. What do you like/dislike about using instructor lecture notes as part of a course?

Appendix D: Post-survey Questions Given in the Flipped Section of the Course (Adapted from Love et al., 2014)

Demographic Questions

1. What is your academic standing?

Freshman Sophomore Junior Senior

Other:_________

2. What is your major?

Mathematics Engineering Other: _________

Precalculus Anxiety

3. On a scale from 1 to 5, where 1 means not anxious and 5 means very anxious, how anxious are you about taking Precalculus?

Attitudes about precalculus

For the following questions, use a scale of 1 to 5 where

1. Strongly disagree
2. Somewhat disagree
3. Neutral
4. Somewhat agree
5. Strongly agree

4. Precalculus is relevant to my education.

5. Precalculus is relevant to my career.

Attitudes about instructor lecture notes

6. Instructor lecture notes are useful for education in general.

7. Studying instructor lecture notes **before class** was useful.

8. The instructor lecture notes helped me learn the material being presented.

9. Reviewing instructor lecture notes when studying for exams was useful.

10. Overall, I have a positive opinion of the instructor lecture notes.

Attitudes about the Course Format

11. Studying instructor lecture notes in advance of class and spending class time on other activities (e.g., discussing and solving homework problems, answering clicker questions) was helpful in learning the course material.

12. I prefer the format of this course over the traditional lecture format.

13. Compared to other mathematics courses I have taken, I learned more in this course.

14. Compared to other mathematics courses I have taken, I enjoyed this course more.

15. Compared to other mathematics courses I have taken, I was more comfortable discussing the course content with classmates in this course.

16. Overall, my attitude about the format of the course (instructor lecture notes and in-class activities) is positive.

17. Please rank the following items from 1 to 5 where 1 is least useful and 5 is most useful.

_________ Textbook readings

_________ Instructor lecture notes

_________ Clicker questions

_________ In-class activities

_________ Group projects

Open Ended Questions

18. What did you like/dislike about using the instructor lecture notes as part of the course?

19. Do you have any suggestions for improving the instructor lecture notes, the course format, or any other aspect of the course?

20. As the semester progressed, did your use or attitude about the instructor lecture notes change? If yes, in what ways and why