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Evaluation of a Flipped, Large-Enrollment Organic Chemistry Course on Student Attitude and Achievement

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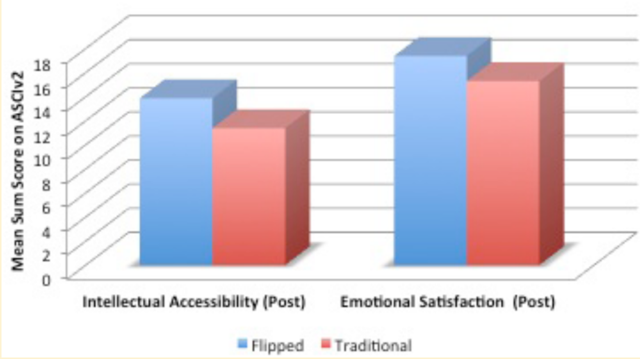
Supporting Information



ABSTRACT: Organic Chemistry is recognized as a course that presents many difficulties and conceptual challenges for students. To combat the high failure rates and poor student attitudes associated with this challenging course, we implemented a "flipped" model for the first-semester, large-enrollment, Organic Chemistry course. In this flipped course, lectures were replaced by short videos, which were delivered via a course management system, and class time was reserved for problem solving and other active learning activities. We assessed the impact of the flipped course on course grades and failure rate compared to historical course data. The results showed that there was a statistically significant improvement in A and B grades and a decrease in failure/withdrawal rates for the flipped course. We also assessed students' attitudes toward the course using a valid and reliable instrument, the Attitude toward the Subject of Chemistry Inventory Version 2 (ASCIv2). The results showed a statistically significant increase in students' emotional satisfaction and intellectual accessibility for the flipped course compared to those for traditional lecture courses. The flipped format of the course provided students with increased access to course material, which increased time for in-class group learning and discussion. We believe that this aspect of the course format led to a reduction in cognitive load, thereby increasing students' emotional satisfaction and intellectual accessibility in the course. Our results demonstrate that the flipped course model can be adopted for challenging, large-enrollment courses.

KEYWORDS: *Second-Year Undergraduate, Curriculum, Organic Chemistry, Chemical Education Research*

FEATURE: Chemical Education Research

■ INTRODUCTION

Organic Chemistry is one of the most challenging science courses.[1,2] Biology, Chemistry, and other Life Science majors require this course to pursue their undergraduate degree and to continue in science-related career paths. For many students, this course has become a barrier to successfully pursuing their desired career. The failure and withdrawal rates for Organic Chemistry have been known to be quite high, approaching up to 50% in some cases.[3,4] Also, students have difficulties dealing with the large volumes of material and understanding the challenging concepts associated with the course.[5−9] Despite these challenges, lecture is still the typical mode of instruction for the majority of science courses, including Organic Chemistry.[10] In the traditional lecture model, students attend class, take notes, and then work on homework and other problem-solving activities outside of class without immediate feedback.

To overcome some of these disadvantages of the lecture model, we implemented a flipped classroom model. In this flipped course, students received their first exposure to the material via a video lecture before coming to class, while class time was reserved for brief lectures and cooperative problem solving. As they worked on the problems, the students received immediate feedback from the instructor and teaching assistants (TAs). Students also engaged in peer-led team learning (PLTL) sessions once per week. PLTL is a nationally recognized practice that provides an environment in which students can further engage in problem solving and discussion among their peers.[11,12] We envisioned that the flipped classroom format would free up more time to implement PLTL in the course.

Flipped Classroom

There has been considerable interest in educational circles regarding the flipped classroom method.[13] The flipped classroom is based on inverting instruction, such that traditional classroom activities become homework, and what is traditionally homework is done in the classroom.[14] According to Bergman, one of the pioneers of the flipping method, the flipped classroom is designed to allow students to take responsibility for their learning, to encourage student-centered learning, and to continually engage students in the learning

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process.[15] There are now more examples in the literature of flipping college-level courses in chemistry. The majority of studies on the flipped classroom in chemistry have been on courses with less than 60 students;[16−18] two of these have been for large-enrollment Organic Chemistry courses.[16,19] These studies have reported the benefits of the flipped classroom on student learning and achievement.[16,17,20−23] A review of the flipped course method in undergraduate chemistry has recently been published by Seery.[13] Below we summarize some of the main points on the implementation and assessment of the flipped classroom in chemistry.

In general, the majority of reports on flipped classroom implementation in the literature include three distinct parts: prelecture assessments, in-class activities, and after-class assignments. The prelecture activities are consistent with each other. Students typically would view video lectures lasting an average of 10−20 min before class to encourage them to come to class prepared and more engaged. In addition, some instructors provided students with extra lecture notes or worksheets to complete before the class session.[16,24,25] In some cases, the online course materials were organized with a schedule to ease student adaptation and help them plan their time accordingly.[16,23,25] Also, the majority of instructors who implemented the flipped model required a quiz or other similar activity to encourage students to complete the prelecture assignment.

During the face-to-face class time in flipped classrooms, prelecture materials were connected to in-class activities by problem-solving sessions by all authors. Most authors used the "Just in Time" method,[26] in which students' difficulties with the prelecture activities or quizzes dictated the concepts that were discussed in class.[27,28] Problems given during class were similar to either prelecture practice problems or the quiz questions designated as difficult by the students.[16,17,27] As such, students can connect their prior knowledge with what they have learned during the class. Most authors also required some type of group work in class. These activities encouraged students to complete prelecture materials and attend class.

The majority of the flipped classroom implementations reviewed did not report the implementation of any postclass assignments. Only two authors, Flynn[16] and Smith,[28] have reported implementing after-class assignments. Flynn assigned more complex problems that required further thinking on the topics discussed in class, and Smith assigned online homework from the textbook that students completed.

Evaluation of the impact of flipped classroom in previous reports typically examined student satisfaction and learning gains. All the studies used some type of student feedback in their evaluation. An analysis of students' open-ended responses on the flipped classroom indicated that students appreciated the ability to access the course material at their own pace. Despite this, the majority of students watched the required prelecture video before class.[23,25] Also, since the material was organized in advance with built-in questions and problems, students had multiple opportunities to engage with the course material. It was also noted that switching from traditional classrooms to flipped classrooms might require an adjustment period for some students; a minority of students reported difficulty in organizing their time or that they just have a preference for traditional lecture format.[27,28]

Most studies on the flipped classroom have assessed its impact on student exam scores and grades. These reports generally show a shift toward higher grades and a decrease in withdrawal rates. However, reports of the impact of the flipped course on American Chemical Society (ACS) exam scores are mixed. In one case, there was a moderate difference in the ACS scores for the first implementation of the flipped course but no difference for the second implementation.[29] Another study on flipping a large general chemistry course showed a significant difference in ACS Exam scores compared to control groups.[21] More recently, Eichler and Peeples also reported that there was no difference in final exam scores between the flipped and nonflipped courses.[17]

The general consensus is that flipped courses in undergraduate chemistry lead to improvements in student learning and that it is a tool to encourage active learning practices. However, there is no prescription as to what should be done with in-class time when implementing the flipped method, and there are mixed results of its effectiveness.[13] To this end, there is still a need for additional and diverse studies that provide details on how the flipped classroom model was implemented, insight into how student attitudes impact their success, and hints toward a theoretical basis for the success of the flipped course format. These types of data are especially needed for challenging, large-enrollment courses. As noted by Weaver and Sturtevant, "...details of how the course is taught and carried out will vary the types of effects it has on students."[21]

■ THEORETICAL FRAMEWORK FOR THE IMPLEMENTATION

Considering prior reports on the flipped classroom,[16,17,23] we designed our implementation based on two theoretical frameworks: social constructivism and cognitive load theory.

Social constructivism is guided by the principle that "student understanding is actively constructed through individual and social processes."[30] This theory recognizes the influence of social interactions in facilitating students' conceptual understanding. For example, group-based discussion and activities are often components of the flipped classroom model. These activities are also driven by the student-centered learning theory of Lev Vygotsky, which purports that learning occurs in a social context. Vygotsky proposed the "zone of proximal development" that encourages the use of scaffolding by more knowledgeable persons to help students go from what they cannot do, to what they can do.[31] In the flipped course presented here, the in-class activities typically involved students working in groups with guidance and feedback provided by the instructor and teaching assistants. Students were encouraged to discuss the problems and work together. As such, they were able to construct their own knowledge and build deeper understanding of the material.

Cognitive load theory (CLT) can also be appropriately applied to the flipped classroom model. Other authors have already implied that CLT may be an underlying theoretical explanation for the success of flipped classroom pedagogy.[32,33] The premise of CLT is that the working memory can only process a limited number of items at a time.[34,35] The working memory is used to temporarily store new information to interact with the long-term memory in order to learn or perform cognitive tasks. The implication of CLT is that if the new instructional materials and tasks overwhelm the learner's working memory, the ability to process new information can be hindered.[36] Therefore, CLT provides reasoning for designing instructional experiences and material that reduces cognitive load. The very nature of learning organic chemistry includes many representations, terminology, and language that are

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completely new to the learners that may overwhelm their working memory.[37] We envisioned that, with the flipped course model, students would have the ability to watch the lecture multiple times, stop when needed, and rewind to help clarify concepts better. This ability to watch the lectures at their own pace may increase their ability to process this new information and increase engagement and focus during face-to-face class time. The videos also provided step-by-step examples of organic chemistry mechanisms and problem solving that have been reported to impact cognitive load.[38]

■ METHODS

Study Setting

This study was conducted at a large, urban, research institution in the southeast United States in the Fall of 2015. The institution has 24,862 undergraduates and 32,000 total students enrolled. The student population is diverse: African-American/Black (39%), White (35%), Asian (14%), Hispanic (9%), and two or more (5%); 36% of our students are male, and 64% are female.

The chemistry course of interest in this study was the first-semester Organic Chemistry course (O-Chem I). This course is a large-enrollment course of up to 212 students and primarily consists of biology, chemistry, and pre-health-professional majors. The demographics of students in the flipped and traditional O-Chem I courses in Fall 2015 are shown in Table 1.

Table 1. Demographics of Flipped and Traditional First-Semester Course (Fall 2015)

Demographic	Flipped Course (%)	Traditional Course (%)
African-American/Black	36	47
Asian	30	24
White	21	20
Other	13	9
Female	70	65
Male	30	35

Description of the Traditional Course Structure

Organic Chemistry at this institution is a four-credit course in which lecture is delivered in three 70 min periods per week. Classes are held in a large theater-seating style auditorium. Over the last five years, content delivery in the course ranged from exclusively writing on the whiteboard or document camera to a mixture of PowerPoint slides and writing on the document camera. Typically, there is limited time for students to work on problems in class and receive feedback; instructors may only have time to work out a few example problems during the lecture. Also, students receive either paper or online homework problems or worksheets (not for credit) to do on their own outside of class.

In the traditional course structure implemented in Fall 2015, the instructor used Power Point lectures about half of the time and the document camera the rest of the time. The instructor used the document camera to work out problems step-by-step for the students. Students' interactions with the instructor were primarily in the form of questions students asked throughout the lecture, and online homework via access to Pearson was required. The instructor provided 4 h of office hours each week to further interact with students on any questions or challenges they may have had. The format of this course was typical of traditional courses at this institution in the last five years.

Description of the Flipped Course Structure

The first author implemented the flipped course in first-semester Organic Chemistry (O-Chem I) in Fall 2015. The students did not know about the flipped nature of the course until they had already enrolled in the course. This course was also taught in the theater-seating style auditorium. Figure 1 shows an overview of the flipped course structure. Ideas for the course structure and organization was adopted from the flipped Organic Chemistry course implemented and reported by Alison Flynn.[16]

Before Class. Students were required to watch video lectures before coming to class. The videos, the accompanying notes, and the learning objectives for each chapter were organized and posted on our online course management system, Desire2Learn (D2L). The students were strongly advised to take notes and write down any questions they had as they watched the video material. After watching the video, they completed an online quiz via the Learning Catalytics (LC) platform.[39] LC is a web-based platform marketed by Pearson that can also be used for quizzing or polling students inside and outside of the classroom. Students answered questions posted to LC via any laptop computer or smart devices such as a cell phone or tablet. All students had access to their own devices for in-class work. The instructor had iPad tablets available for any student who may not have a device, but these were never utilized.

The postvideo quizzes included up to three questions related to concepts in the videos and one open-ended question for students to describe or comment on anything about the video content that was unclear.[40] This step was used to increase the students' preparation for the face-to-face discussion. In general, 80−95% of the students watched the videos and completed the postvideo quiz before class. The number of times a video was

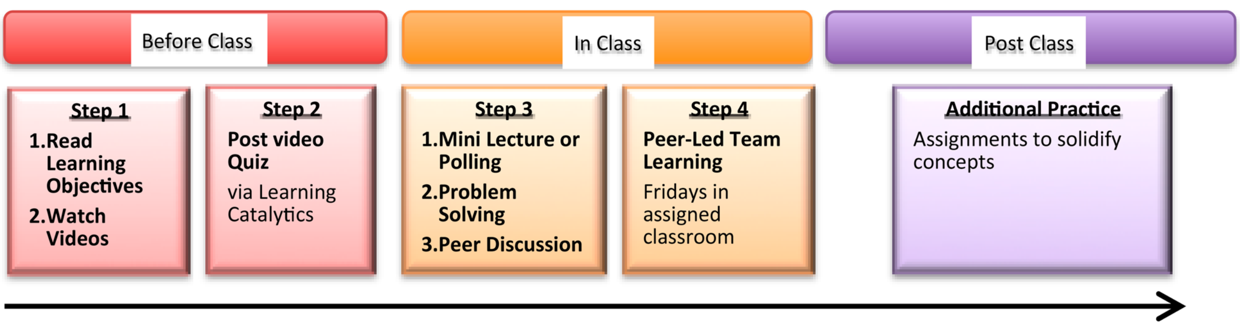

Figure 1. Overview of flipped course design.

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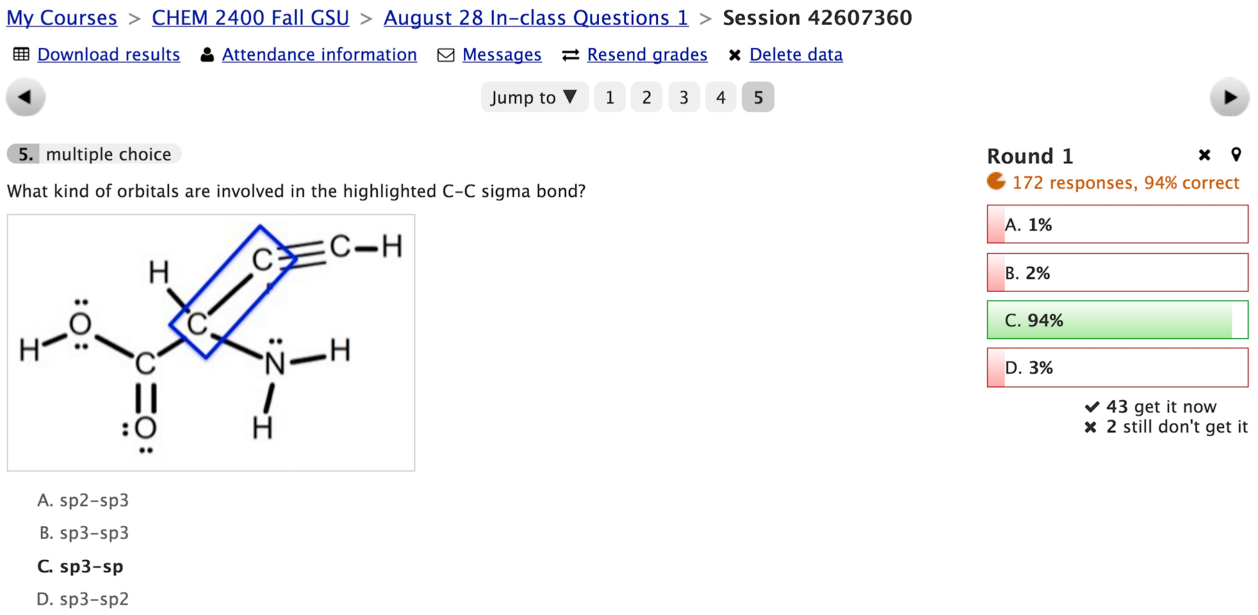

Figure 2. Screen shot of the instructor's view of an in-class Learning Catalytics quiz. The results on the right side of the figure can be made visible to students with or without showing the correct answer.

viewed ranged from 247 to 595 views, which suggests that students watched multiple times. To help focus the in-class discussion, the author looked at the students' responses to the LC quiz and their comments on the reflection question before class.

An iPad tablet with an app called Explain Everything was used to create the videos.[41] The app was easy to use and did not require any additional software. With this app one can record over uploaded PowerPoint presentations or PDF documents. Also, free-hand drawings and writing could be done using a stylus to demonstrate Organic Chemistry reactions and mechanisms. The videos were then directly uploaded from the app as a YouTube video. The YouTube video was embedded into D2L for easy student access. Forty instructional videos, which amounted to 8 h and 22 min of recording time, were created. Individual videos ranged from 4 to 20 min in length, and the average duration of the videos was 12 min.

In Class. Each class began with a brief lecture (15–20 min) and/or warm-up LC quiz that students answered using their smart devices or laptop computers. The lectures primarily focused on the content that students had difficulty with on the video quiz or had expressed concerns about in their open-ended comments. After the introductory lecture, students worked on problem worksheets in groups of no more than four students. The students discussed the problems with each other while four teaching assistants (TAs) and the instructor walked around the classroom to address any questions or concerns from students. After each section of the worksheet, the instructor stopped and asked the class to respond to LC quiz questions to monitor their progress in understanding the material (Figure 2). These LC quizzes were similar to the types of problems on the worksheet. If students had challenges with a concept, they were asked to discuss with a fellow students or the instructor would explain further or do additional example problems. Course credit earned for LC quiz questions ranged from 100% participation to 100% accuracy. 100% participation was assigned to new material that we were going over for the first time. Students received 50% participation/50% accuracy if a similar question was already asked on the same concept that day. 100% accuracy was assigned to problems that we covered in previous lectures. The worksheet problems were not graded, but the answers were discussed and posted after class. Resources for additional practice were also posted to D2L; however, graded homework problems were not provided. The instructor also provided four office hours weekly.

PLTL. Students engaged in PLTL workshops on Fridays, except on weeks in which there was an exam. PLTL was implemented according to best practices.[11] Peer Leaders were selected that received a B or better in the course. After an initial 2 h orientation, the Peer Leaders received weekly training by the first author that included discussion of learning theories, questioning techniques, group dynamics, and problem-solving strategies. In addition, we discussed the PLTL workshop problems 1 week in advance of meeting the students. The Peer Leaders also provided weekly reflections of their experiences facilitating the workshop sessions. Students were randomly divided into groups of about 12 students per peer leader. Students worked in pairs or groups of four during the PLTL workshops. The workshops were designed with challenging problems that were meant to solidify the concepts covered in the course during the week and to encourage additional discussion and interaction among the students. Answer keys for PLTL workshop problems were not provided. Each PLTL workshop was worth 20 points: 5 points for a readiness quiz; 5 points for bringing the textbook, lecture handout, or lecture notes; and 10 points for participation in the discussion.

A comparison of the grading schemes of the flipped and the traditional O-Chem I courses is shown in Table 2. The allotment of different components of the course to the final grade was similar for both courses; however, the LC quizzes and PLTL in the flipped course replaced the credit for quizzes and homework in the traditional course.

The first author, who implemented the flipped course, and the instructor of the traditional course (in Fall 2015) have both been teaching the first-semester Organic Chemistry course for

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Table 2. Grading Scheme of Flipped and Traditional O-Chem I Courses

Course Weight	Flipped Course	Traditional Course
55%	Best 3 of 4 exams	Best 3 of 4 exams
30%	Final exam (ACS)	Final exam (ACS)
10%	LC In-class quizzes	In-class quizzes
5%	PLTL	Online homework

one year. The semester exams for both courses were not identical; however, both courses used the same exam format and addressed the same concepts in each exam. Also, both instructors provided students with past exams to use for study.

RESEARCH QUESTIONS

To assess the impact of the flipped course, we sought to answer the following research questions: (1) What are students' attitudes toward Organic Chemistry in the flipped course compared to those of students in the nonflipped course? (2) What are students' perceptions of the flipped course format? (3) What is the rate of failure/withdrawal in the flipped course compared to that of traditional courses? (4) What is the rate of A, B, and C grades in the flipped course compared to that for traditional courses?

STATISTICAL ANALYSES

In this study, we assessed student attitude, failure/withdrawal rates, and final grades of the flipped course compared to those of traditional courses. SPSS software version 21 was used for all statistical analyses.

A multivariate analysis of the variance (MANOVA) model was used to determine if there were statistically significant differences in students' attitudes, as determined by the Attitude toward the Subject of Chemistry Inventory version two (ASCIv2), between the flipped course and all the other nonflipped Organic Chemistry courses in Fall 2015. A MANOVA model is typically used when there are two or more groups and two or more dependent variables. Z-test of proportions[42] was used to determine if there were statistically significant differences in the withdrawal/failure between the flipped course and the traditional first-semester Organic Chemistry courses from 2010 and 2015 at the same institution. Finally, chi-squares tests of independence[42] were used to determine if there was a statistically significant difference in the percentage of A, B, and C grades between the flipped course and traditional first-semester Organic Chemistry courses from 2010 and 2015 at the same institution.

IRB APPROVAL

The study received an "exempt" status by the Institutional Review Board of our Institution.

RESULTS

RQ1. What Are Students' Attitudes toward Organic Chemistry in the Flipped Course Compared to Attitudes of Students in the Traditional Courses?

We used students' responses to the ASCIv2 to address this research question. The original ASCI was developed by Bauer[43] and then modified by Xu and Lewis to a shortened version known as the ASCIv2.[44] The ASCIv2 is an eight-item questionnaire, which uses a semantic differential scale that allows students to say how they feel about chemistry between two polar adjectives on a seven-point scale (Figure 3). The ASCIv2 has two subscales, intellectual accessibility (IA) and emotional satisfaction (ES). Items 1, 2, 3, and 6 load on to the IA subscale, while items 4, 5, 7, and 8 load on to the ES subscale.

Previously, authors showed that the ASCIv2 could be used to observe the impact of a curriculum intervention on student attitude toward chemistry and that a pre/post-ASCIv2 can be used to assess how a particular course influences students' attitudes toward the subject of chemistry.[44,45] To our knowledge this is the first time that the ASCI or ASCIv2 is being used to examine students' attitude in the flipped classroom.

A pre/post administration of the ASCIv2 was implemented in Fall 2015. The survey was given to students in the flipped and traditional O-Chem I courses. To further assess if the attitudinal outcomes were course- or instructor-related we also administered the ASCIv2 to both sections of the second-semester Organic Chemistry courses as well. One section of the second-semester course utilized lecture via prepared notes on the document camera, six sessions of PLTL for the semester, and a short group learning activity about once per week (O-Chem II Active). The other section was a traditional lecture course where the instructor exclusively wrote on the white-board (O-Chem II Traditional).

The first administration of the ASCIv2 was within the first 2 weeks of the semester, and the final administration of the questionnaire occurred 1 week before the final examinations. Of the 658 students in all four O-Chem courses, 432 completed both the pre and post survey. The survey was hosted on Qualtrics, a web-based survey software.[46] Students were given the option of receiving three points of course credit for participating in the survey; those who chose not to participate

CHEMISTRY IS:

1. Easy	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Hard**
2. Complicated	1	2	3	4	5	6	7	**Simple**
3. Confusing	1	2	3	4	5	6	7	**Clear**
4. Comfortable	1	2	3	4	5	6	7	**Uncomfortable**
5. Satisfying	1	2	3	4	5	6	7	**Frustrating**
6. Challenging	1	2	3	4	5	6	7	**Not challenging**
7. Pleasant	1	2	3	4	5	6	7	**Unpleasant**
8. Chaotic	1	2	3	4	5	6	7	**Organized**

Figure 3. Attitude toward the Subject of Chemistry Inventory version 2 (ASCIv2).[43,44]

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in the survey were offered an alternative assignment to receive the same course credit.

Items 1, 4, 5, and 7 were recoded in order for higher scores to represent positive aspects of students' attitudes before proceeding with the statistical analysis (Table 3). The mean and standard deviations for each item in the scale are shown in Table 3. Descriptive statistics on the item for each of the four Organic Chemistry courses are provided in the Supporting Information (Tables S1–4).

Table 3. Item Means for Pre and Post Administration of ASCIv2 (N = 432)

Items		pre		post	
		Mean	Std Dev	Mean	Std Dev
1. easy[a]	hard	2.74	1.30	2.88	1.50
2. complicated	simple	2.80	1.31	3.02	1.47
3. confusing	clear	3.68	1.43	3.95	1.63
4. comfortable[a]	uncomfortable	3.62	1.40	3.89	1.56
5. satisfying[a]	frustrating	3.81	1.61	3.75	1.78
6. challenging	not challenging	2.29	1.41	2.36	1.45
7. pleasant[a]	unpleasant	3.81	1.43	3.86	1.59
8. chaotic	organized	4.55	1.49	4.57	1.63

[a]These items were recoded before statistical analyses.

The reliability of the two subscales on the ASCIv2 as indicated by Cronbach's alpha was above the acceptable 0.7, as reported in previous publications (Table 4).[44,45]

Table 4. Cronbach's Alpha for Results for Pre and Post of ASCIv2

Cronbach's Alpha	Pre (N = 432)	Post (N = 432)
Intellectual accessibility	0.77	0.75
Emotional satisfaction	0.79	0.81

Data Analysis of ASCIv2

Descriptive statistics showing the mean sum scores for the two subscales of the ASCIv2 for all four O-Chem courses are shown in Table 5. To determine if attitudinal differences existed between the flipped course and the other courses, a MANOVA was developed. We elected to run a MANOVA instead of multiple t tests because the subscales, ES and IA, were highly correlated ($r = 0.512$, $p < 0.001$). Gain scores (post minus pre) for ES and IA were used as the dependent variables for the MANOVA. We also considered that the prescores could affect the gain scores. However, there was no statistical difference between IA pre scores ($F = 0.393$, $p = 0.758$) or ES pre scores ($F = 0.411$, $p = 0.411$) for any of the courses.

Table 5. ASCIv2 Sum Averages for Flipped and Other O-Chem Courses

Mean (Std Dev)	O-Chem I (Flipped) N = 134	O-Chem I (Traditional) N = 160	O-Chem II (Active) N = 57	O-Chem II (Traditional) N = 81
IA pre	11.6 (4.1)	11.4 (4.2)	11.8 (4.5)	11.5 (4.1)
IA post	13.9 (4.6)	11.4 (4.7)	11.6 (4.3)	11.3 (3.8)
ES pre	15.9 (4.5)	15.5 (4.2)	16.1 (5.6)	15.8 (5.0)
ES post	17.4 (4.9)	15.3 (5.3)	16.4 (5.7)	15.1 (5.1)

The results of the MANOVA indicated that there were significant differences between the courses for IA gain ($F(3, 428) = 7.764$, $p < 0.001$) and ES gain ($F(3, 428) = 3.813$, $p = 0.01$). The p-values of less that 0.05 indicated that the result was statistically significant at the 95% confidence level. More specifically, posthoc procedures showed that the IA gain score of students in the flipped O-Chem I course was significantly higher than the gain scores of students in all the other O-Chem courses. The ES gain for students in the flipped O-Chem I course was significantly higher than the traditional O-Chem I and both O-Chem II courses. However, the difference in ES gain for the flipped course was not significantly different than the O-Chem II active course (Figure 4). The results of the MANOVA (see Supporting Information Table S5) also indicated a small to medium effect size (based on eta squared) for ES (0.03) and IA (0.05). This is based on Cohen's suggested effect size for eta squared, with small (=0.01), medium (=0.03), and large (=0.14).[47] Thus, we can conclude that students in the flipped course felt more emotionally satisfied, and the course material was more intellectually accessible to them compared to students in the traditional courses.

RQ2: What are Students' Perceptions of the Flipped Course Format?

We administered an end-of-course survey that had items regarding aspects of the flipped course. We analyzed students' responses to the following question: "What do you think about the flipped-classroom method used in this course?" Individual students' responses to this question were first coded as positive (72%), negative (10%), mixed (10%), or neutral (8%). Neutral comments were those in which students stated they had no opinion or did not know what was meant by "flipped". Examples of these comments include the following: "I don't know what's the flipped method" or "It was neither beneficial nor harmful". Mixed comments were those that contained both positive and negative views of the flipped course. An example of a mixed comment follows: "I do like the "flipped" method. However, as the semester progress and the material got more difficult, the "flipped" method got overwhelming to handle the amount of information we had to retain."

All the authors discussed these codes and came to an agreement on the negative, positive, mixed, and neutral assignments. Next, all of the students' comments, except those assigned as neutral, were further coded into themes. The initial codes were generated by the second author. Another researcher applied these codes to all of the comments. The percent agreement between the two coders was 96%. Table 6 summarizes the themes and example quotes of the students' responses. The majority of positive comments referred to students' liking the ability to rewatch and clarify concepts using the videos. Other positive comments referred to students addressing the benefits of in-class problem solving, desiring that the flipped method be implemented in other challenging courses, and the usefulness of seeing the material before coming to class.

For most of the negative comments students simply stated that they did not like the flipped method without providing any further explanation. Those that gave reasons disliked the flipped method because they found it not as effective for more difficult course material, it was not their preferred learning style, or they had difficulty managing their time in the course (Table 6).

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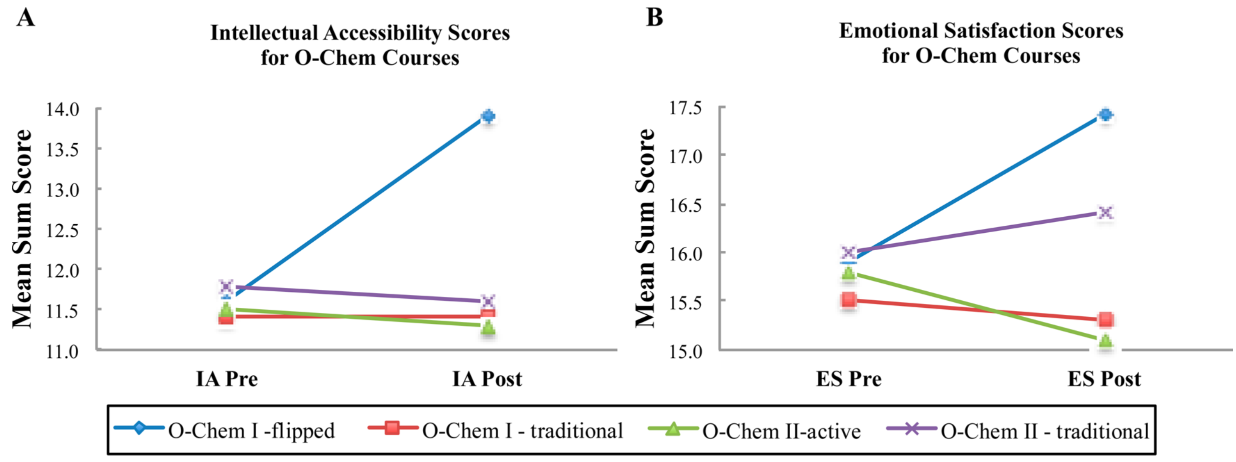

Figure 4. (A) ASCIv2 survey results for intellectual accessibility (IA) subscale. (B) ASCIv2 survey results for emotional satisfaction (ES) subscale.

RQ3: What is the Rate of Failure/Withdrawal Rate in the Flipped Course Compared to That for Traditional Courses?

We used Z-tests of proportions to compare the failure rate of students in the flipped course to the traditional first-semester Organic Chemistry courses at our institution between 2010 and 2015. Failure is defined as a C− or below in the course. A grade of C− is defined as failure because students cannot move on to the second-semester course if they did not earn a grade better than a C−. We found that there was a significant difference in the withdrawal/failure rate of the flipped classroom compared to the traditional O-Chem I course for Fall 2015 and the average withdrawal/failure rates for Fall semesters (2010−2015), Spring semesters (2010−2015), and all semesters (2010−2015). The unadjusted p-values were adjusted for multiple testing with the Bonferroni correction of $p < 0.0125$ (Table 7).

RQ4: What Is the Rate of A, B, and C Grades in the Flipped Course Compared to Those for Traditional Courses?

We compared the percent of A (A+, A, A−), B (B+, B−), and C (C, C+) grades of the flipped course compared to nonflipped first-semester Organic Chemistry courses from 2010 through 2015. A chi-square test of independence was performed to compare the percent of A, B, and C grades between the flipped course and other first-semester Organic Chemistry courses from 2010 to 2015. The analysis revealed that there was a statistically significant increase in the percent of A grades in the flipped course compared to the traditional O-Chem I courses in Fall 2015 and all courses in Fall 2010−2015. There was also a statistically significant increase in B grades in the flipped course compared to all the semesters compared. However, there was no significant difference in the percent of C grades for the flipped course compared to any of the nonflipped courses in previous years (Figure 5).

■ STUDY LIMITATIONS

The data for this study is not based on results from a single instructor that directly compares flipped to traditional instruction side by side in the same semester. In other words, we did not use a control/parallel design. Since student GPA can be an indicator of success in the course, we compared the incoming GPAs of students in the flipped course (3.16) with those in the traditional O-Chem I course (3.05) using an independent t test. There was no statistical difference between the two courses ($t = 1.96$, $p = 0.051$). Also, a comparison of the Fall 2015 student evaluations for both instructors on four key statements showed that students' perception of the instructors in both courses were similar (no statistical difference) (Table 8). Therefore, the improved results for students in the flipped course were not significantly based on an instructor effect.

An additional limitation is the ACS Exam score data. We did a preliminary comparison of the ACS raw score out of 70 of both O-Chem I courses (flipped and traditional) in Fall 2015. An independent t test showed that there was no statistical difference between the average score of the flipped course (34) and the traditional course (33). Although the exams are similar, in terms of the concepts covered, this is only a preliminary finding because each course used a different version of the ACS exam. Moreover, the 2014 version of the exam used by the flipped course is not yet normalized so the two versions of the exam cannot be directly compared at this time. We hope to further examine the impact of the flipped course on ACS Exam scores in the future.

This flipped course included PLTL as a required activity almost every week. PLTL, on its own, has been shown to improve student course outcomes in chemistry.[11,12] In general, the students in this study had a positive view of PLTL. In response to a survey item regarding PLTL (Table 9), 75% agreed or strongly agreed with thefollowing statement: "I believe that attending PLTL workshops improves my grade." However, in response to a similar survey item regarding aspects of the flipped classroom, approximately 92% agreed or strongly agreed with the following statement: "participating in Learning Catalytics questions in class helped me understand the material better." Also, 94% agreed or strongly agreed that "Doing problems in class is effective at helping me learn organic chemistry." Of note, Chan and Bauer used a fully randomized design to investigate the effect of PLTL on student achievement and attitude; the ASCI was used as one measure of student attitude.[48] These authors found that there was no difference in ASCI scores for PLTL and non-PLTL groups. In fact, there was a small but significant decrease in attitudes throughout the semester. In our case, students' attitudes increased significantly. At this point, it is not feasible to disentangle PLTL from this flipped course implementation, without an additional control study. We can only say that more students found aspects of the flipped course more beneficial than PLTL, and it is possible that these positive effects are primarily attributed to the flipped course format.

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Table 6. Students' Comments Regarding the Flipped Format

Positive Comments	
The ability to rewatch and clarify using the videos	"I thought this was a great method because I had the lectures readily available to me and it helped a great deal having the material 'in-hand' before taking the exams. This method definitely worked for me and I would highly recommend continuing with it."
	"I think the 'flipped' method was very effective for this class because in most other classes we go and we have lecture and we're are unable to access that information again unless we took very good notes. However, with this method we have the lecture at our fingertips at anytime and we are able to go back and try to understand anything in the videos that we did not previously understand. Then we can bring in our questions that we didn't understand during class."
In-class problem solving is beneficial	"I like this method of teaching rather than the traditional way since I generally have questions on problems not lectures. Doing problems in class allow me to ask those questions among peers or to the professor."
	"It also kind of forces us students to review content before coming into class so we can have a general idea of what we are talking about, then leaves time in class to practice problems we otherwise would not be able to do in a traditional lecture, and, knowing myself and other students, we most likely wouldn't practice as many problems, and such a diverse amount of problems, at home as we do in lecture."
Challenging courses should be flipped	"Every challenging class should have this method."
	"...I highly suggest that for hard courses such as organic classes, it should be flipped."
Usefulness of seeing the course material before coming to class	"I really like the flipped method. I know all classes say you have to read to expose yourself to the material before coming to class, but the videos were so much better. They explained things very thoroughly and made is so much less intimidating. I've been doing surprisingly well in the class and I think the videos have a lot to do with it."
Negative Comments	
Not good for more challenging material	"It was really good for easier material but was ineffective for harder concepts like mechanism and pretty much the second half of the class."
Not preferred learning style or prefer lecture	"All people learn in different ways, the flipped class format is more efficient in some aspects, though quick and efficient is not always the best in terms of trying to completely understand a topic difficult to a large majority of students."
Time management	"At first I was excited about it because I would have all the notes/lectures available to me all the time on the Web site. As the semester went on though, I noticed that the fact that they were always available caused me to fall behind in keeping with the schedule so I was lost when we were working through problems in class because I hadn't watched the videos. Overall though, it was a good learning experience and taught me how to prioritize my time in order to stay on track."

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Table 7. Failure/Withdrawal Rates for Flipped Course Compared to Historical Data (O-Chem I)

Semester	*N*	Failure and Withdrawal[a] (%)	*Z*-score	*p*-value[b]
Flipped course (Fall 2015)	212	22		
Traditional course (Fall 2015)	212	41	4.80	0.0010
Spring (2010–2015)	1374	32	2.93	0.0034
Fall (2010–2015)	2290	34	3.75	0.0018
All semesters (2010–2015)	3664	34	3.65	0.00026

[a]Failure is grade C− or below. [b]Significance at $p < 0.0125$.

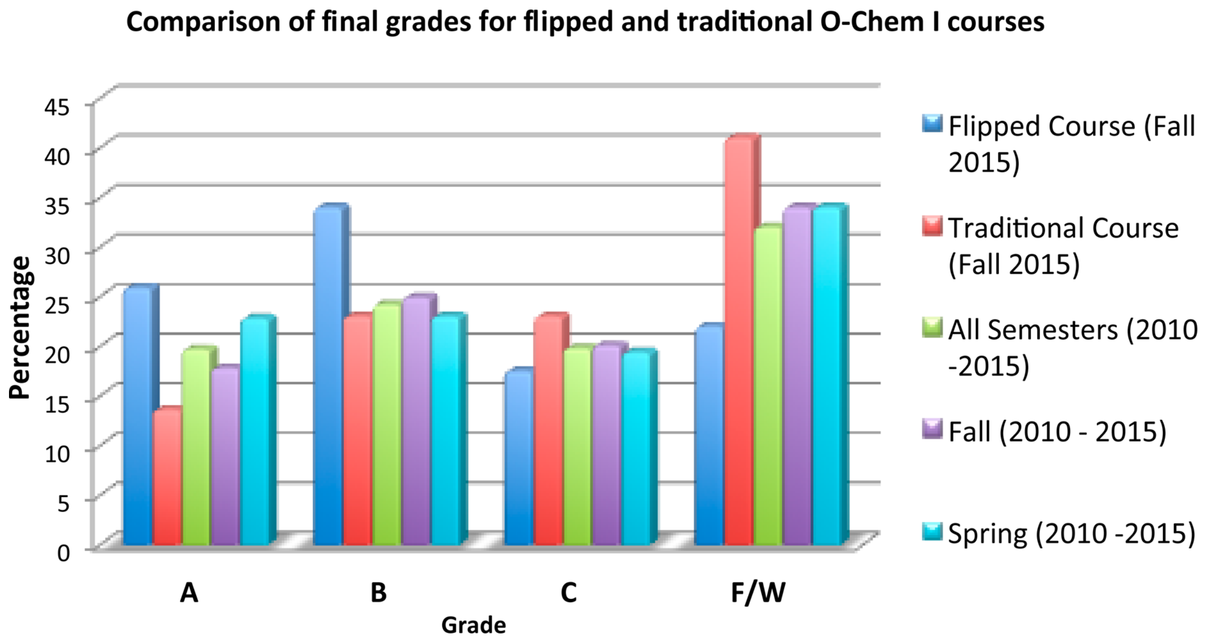

Figure 5. Comparison of the final grades for first-semester Organic Chemistry (2010–2015). F/W = failure/withdrawal. $\chi^2 = 43.68$, $p < 0.05$.

Table 8. Comparison of the Average Instructor Evaluation Scores for First-Semester Organic Chemistry in Fall 2015

Statement[a]	Average Rating out of 5 (Std Dev)	
	Traditional (*N* = 118)	Flipped (*N* = 142)
Was well prepared	4.4 (0.9)	4.4 (1.1)
Used class time effectively	4.4 (0.9)	4.2 (1.2)
Motivated me to learn	4.1 (1.2)	4.2 (1.3)
Considering both the limitations and possibilities of the subject matter and course, how would you rate the overall teaching effectiveness of the instructor	4.1 (1.1)	4.3 (1.1)

[a]5 = very descriptive to 1 = not at all descriptive; 0 = N/A.

A final limitation is that this study was implemented at a single institution. However, the diversity of this institution in terms of ethnicity and gender is an advantage. Additionally, more than 50% of our students are Pell eligible.

DISCUSSION

In this study, we sought to understand the impact of the flipped course on students' attitude toward Organic Chemistry and their success in the course. Our results showed that the flipped course had a moderate but significant impact on students' attitude toward the Organic Chemistry course, as indicated by the ASCIv2. Thus far, reports on students' attitude toward the flipped classroom have primarily relied on students' comments and instructor evaluations.[13] Very few studies have measured affective variables or student attitudes using a valid and reliable instrument.[49]

Previous studies have established that there is a relationship between attitude and achievement in chemistry. For example, Chan and Bauer used the ASCI along with other assessments of students' affective characteristics to identify at-risk students in General Chemistry courses. Overall, the study found that there were significant differences in exam performance between the high and low affective groups, with the high affective group performing significantly better than the low affective group.[50] In

Table 9. Student Responses to Survey Items on Flipped Course and PLTL

Survey Item (*N* = 172)	Strongly Disagree (%)	Disagree (%)	Agree (%)	Strongly Agree (%)	Not Applicable (%)
I believe that attending PLTL workshops improves my grade	3.5	19.0	42.3	33.1	2.1
Participating in Learning Catalytics questions in class helped me understand the material better	0.7	7.0	47.6	44.1	0.7
Doing problems in class is effective at helping me understand/learn organic chemistry	1.4	3.5	40.1	54.2	0.7

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another study, Brandriet et al.[45] used the ASCIv2 questionnaire to investigate changes in the attitudes of students in General Chemistry courses that include weekly POGIL activities. Their results showed that students' post-test scores on the ASCI strongly correlated with final course grades and final exam scores. Despite the fact that POGIL involved students working in small groups to discuss problems, they only observed a small but statistically significant difference in intellectual accessibility and no significant difference in the students' emotional satisfaction. In our study, only the flipped course showed a statistically significant increase in intellectual accessibility compared to the other four O-Chem courses. In addition, there was a statistically significant increase in emotional satisfaction compared to three of the four O-Chem courses. Our results had a small to medium effect size, which suggests that these results have some practical significance. As hinted by students' comments (Table 6) and reported by others, these increases may be attributed to a reduction in cognitive load.[23] That is, having access to the videos gave students more time to rewatch and process the course content at their own pace. Instructors typically encourage their students to read the textbook before coming to class, but few students actually do. The flipped format makes it more likely that students would have seen the material before coming to class, which reduced the cognitive load for the face-to-face sessions and increased learning and affected students' attitude positively. Also, students in the flipped course had multiple opportunities to test their knowledge through LC quizzes conducted after video lectures and during class time, and there is evidence that increased quizzing or testing produces a "testing effect." That is, the process of preparing for and doing a quiz can increase learning and lead to better exam outcomes.[51]

Students' responses to open-ended survey questions regarding the flipped course corroborated closely with the findings of others summarized in the review by Seery.[13] A more recent article by Weaver and Sturtevant[21] also had similar findings that students responded positively to the flipped course. In their case, students also provided suggestions for improvements. Students did not give any suggestions for improvements in our study. However, it is clear from these and our findings that students like the flipped method, especially the availability of the video lectures. Many of our students also rated the in-class activities such as the LC quizzes and in-class problem worksheets highly. We believe that a combination of the guided nature of the video lectures along with the active and engaging in-class environment led to students' positive attitude toward the course.

The flipped course discussed here showed a reduction in failure/withdrawal rates and an increase in the percentage of A and B grades when compared to traditional O-Chem I courses. In general, a higher percentage of students received A or B grades in the flipped course (60%) compared to the traditional courses (44%). It is possible that students who would have received a C or lower in a traditional course had higher grades in the flipped course.

Students' higher grades in the flipped course were primarily due to higher scores on midterm exams during the semester and not necessarily their final exam scores. This trend was also observed in a previous flipped general chemistry course.[17] In essence, the authors proposed that the nature of the flipped course allowed students to process the content and new information at their own pace. As such, there were gains in short- to intermediate-term learning for students in the flipped course. However, the authors did not observe long-term gains for the final exam. We believe that this idea may explain our results as well and that the in-class LC quizzes also played a role in improving students' shorter-term learning gains.

■ CONCLUSIONS

We believe that this first implementation of a flipped course at this institution was a success. However, implementing this type of course for the first time can be challenging. The author received an internal grant from her institution that provided summer funding to work on the video lectures and prepare for the course. As an alternative, it may be best to start by flipping only a few topics at first and build up toward flipping the entire course. Additionally, instructors can utilize freely available material from online sources such as Khan Academy or YouTube instead of make their own videos. We believe that the use of graded postvideo quizzes is necessary to motivate students to watch the videos. For large-enrollment courses, like the one discussed here, the use of a tool like Learning Catalytics to poll the class is critical for tracking students' understanding during in-class time in an efficient way. In addition, the use of the postvideo quiz gave students' an incentive to watch the video before coming to class.

Other authors have pointed out that students may have difficulty adjusting to the flipped course format. In our comments from students, a few noted that they had this challenge. The instructor made an effort to help students organize their time and improve their study skills in the flipped classroom. The instructor used class time after the first exam to introduce students to the study cycle as described by Saundra McGuire.[52] Students were encourages to preview, attend class, review, and engage in intense study sessions often. These ideas were reiterated weekly to students in the instructor's posts on the online course management system.

There are still many aspects of flipped courses in chemistry that warrant further research. We agree with other authors[13,16] that the next step in research on the flipped classroom is to assess the mechanisms by which the in-class activities are impacting students and how the students are engaging with the material, the TAs, and each other. In this study, it is evident that the flipped course had an impact on the affective domain, which may also include the constructs of motivation, self-efficacy, and metacognition. These aspects and their relationship to cognitive load and students' achievement are worth further investigation.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.6b00367.

Descriptive statistics for individual items on ASCIv2, results of MANOVA for ASCIv2 gain scores, and examples of in-class worksheets (PDF, DOCX)

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Notes

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