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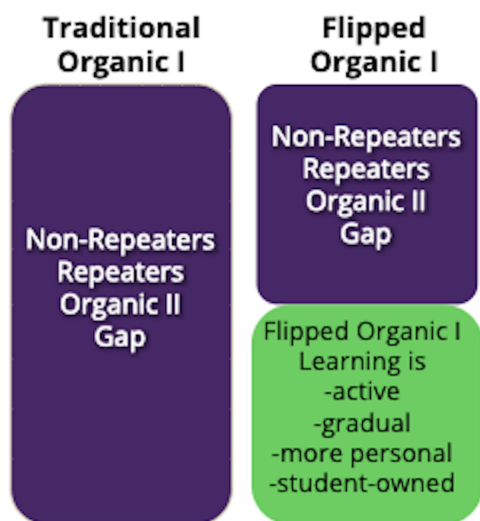
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ABSTRACT

Converting a first-term, accelerated summer organic chemistry course to a flipped format reduced the achievement gap in the flipped course and in the second-term traditional lecture course between Non-Repeaters taking an accelerated course to “get ahead” and Repeaters taking the course to “get back on track.” The difference in final exam performance in the second-term course was nearly halved, the GPA gap in both courses was reduced, and the gap in passing rate for the second-term course was eliminated. First-generation students who took the first-term course in the flipped format experienced a final exam score boost in the second-term course regardless of repeater status. While most students responded positively to the flipped course structure, repeating students held a stronger preference for the flipped format. These findings provide guidance on how to create courses that promote equity, access and retention of diverse students in STEM.

GRAPHICAL ABSTRACT



KEYWORDS

Second-year Undergraduate, Organic Chemistry, Constructivism, Student-Centered Learning,

25 Learning Theories, Chemical Education Research

INTRODUCTION

First-generation, low-income, PEERs (Persons Excluded from science because of Ethnicity or Race), and women are entering science, technology, engineering, and math (STEM) majors, yet a disproportionate number graduate in non-STEM disciplines.¹⁻⁴ Only forty percent obtain a STEM
30 degree within six years.³ One of the most challenging introductory science courses is organic chemistry, with failure and withdrawal (DFW) rates often higher than other lower division STEM courses.^{5,6} Traditional lectures continue to dominate at larger universities, in which students passively take notes and complete homework after class, with minimal opportunity for immediate feedback, peer interaction, or collaborative problem solving.⁷ This style of instruction promotes independent learning
35 and thus is a cultural mismatch for certain students in STEM who rely on interaction with their peers and are more successful when part of a community of learners (first-generation, low-income, PEERs and women).⁸⁻¹⁰ Thus, partial or complete flipped instruction has increased to address these concerns.¹¹ In general, flipped instruction refers to any course where content delivery is completed before class through videos and textbooks, freeing up class time for student-centered, active

learning.¹¹ Frequently larger classes include an electronic response system and/or peer leaders to: gauge completion of pre-class work; formatively assess students during learning activities; facilitate peer-peer interaction; and increase engagement.¹²⁻¹⁴

FLIPPED INSTRUCTION

Numerous studies on flipped instruction in undergraduate STEM courses show positive results.

These studies typically focus on outcomes in the current course, rather than long-term benefits. Less is known about the effects of flipped instruction in large enrollment, organic chemistry courses at large, public research universities when taught in an accelerated summer term. This study implemented a course redesign in an accelerated summer Organic Chemistry course that includes ethnically and financially diverse students.

Flipped Instruction in Large General and Organic Chemistry Courses

Several studies of large, flipped general chemistry courses have reported positive outcomes, including increased grades and decreased DFW rates (Table 1), affirming that flipped instruction may be especially beneficial to certain subgroups of students.^{12,15-17} A subset of these studies identified differing outcomes for different student groups. He, Holton, and colleagues found that only sophomores and female students seemed to benefit from the flipped instruction, as measured by both final exam outcomes, and post-course performance (even though there were numerous technology challenges).¹⁸ Comparing flipped and traditional general chemistry courses, Ryan and Reid found a small increase in final exam scores for students performing in the lower third of the class based on pretest scoring.¹⁹ Deri et al. demonstrated a decrease in DFW rates and an increase in course grades compared with historical trends of traditional lecture general chemistry courses enrolling up to 1,000 students per class across two campuses of a large, urban, public university.²⁰ Importantly, this work indicated larger gains for first-generation college students with lower SAT scores and coming from lower-performing high schools. In a recent study of a large general chemistry course, Bancroft et. al, found that a flipped format closed the performance gap between Black and Latinx students and their White and Asian counterparts.²¹ The few studies on flipped learning in organic chemistry affirm an advantage for students that might not otherwise succeed (Table 2).²²⁻²⁵ Crimmins and Midkiff found students in a flipped course scored higher on the final exam and earned overall higher course grades

compared with the historical traditional course; students in the 25th and 50th percentile experienced the greatest benefit.²⁵

70 **Table 1. Findings of Studies on Flipped Large General Chemistry Courses**

Study Authors	Course Structure	Course Enrollment	Findings
Yestrebsky ¹⁵	fully flipped	415	Small increase in course grades
Eichler and Peeples ¹²	partially flipped	452	Increase in course grades, decrease in DFW rate
Bokosmaty, et al. ¹⁶	partially flipped ^a	208-867	Increase in course grades, decrease in DFW rate
He, et al. ¹⁷	fully flipped	334	Increase in final exam scores, no increase in study time
He, Holton, and colleagues ¹⁸	fully flipped with technology challenges	313	Increase in final exam scores and post-course performance for sophomore and female students
Ryan and Reid ¹⁹	fully flipped	117-206	Small increase in final exam scores for students in lower third of class
Deri, et al ²⁰	fully flipped	20-1000	Increase in course grades, decrease in DFW rate, larger gains for potentially less well-prepared entering college
Bancroft, et al. ²¹	fully flipped	124	Performance gap closed between Black and Latinx students and White and Asian students

^aIncludes introductory and general chemistry courses.

Table 2. Findings of Studies on Flipped Large Organic Chemistry Courses

Study Authors	Course Structure	Course Enrollment	Findings
Flynn ²²	fully flipped	17-400	Small increase in final exam scores, decrease in DFW rate.
Rein and Brookes ²³	partially flipped	192-222	No change in exam scores or DFW rate. Small positive change in course evaluations
Mooring, et al. ²⁴	fully flipped	212	No change in exam scores, increase in A and B grades, decrease in DFW rate, positive effect on emotional satisfaction and intellectual accessibility

Crimmins and Midkiff ²⁵	fully flipped	395	Increase in final exam scores and course grades, greater benefit to students in 25th and 50th percentiles
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Persistent Effects of Flipped Instruction

Studies on longer term effects of flipped instruction are minimal (Table 3). In a study by Hibbard, a small but statistically significant increase in student performance on the cumulative ACS standardized exam was observed after a full year of a semi-self-paced flipped general chemistry course format.²⁶ He, Holton, and Farkas found that students in a partially flipped general chemistry course showed an overall positive effect on end of course motivation and post-course grades, approximately half a letter grade higher on average.²⁷ A differentiated effect was seen, whereby students for whom traditional instruction was not successful, showed higher motivation increases and higher gains in post-course motivation after participating in flipped learning. Eichler and Peeples reported a GPA increase in organic chemistry courses for the least academically prepared third of a cohort of students after a full year of flipped general chemistry courses.²⁸

Table 3. Persistent Effects from Flipped Chemistry Courses

Study Authors	Course (Type)	Course Enrollment	Findings
Hibbard, et al. ²⁶	General Chemistry (semi-self-paced, flipped, full years sequence)	20-37	Increase in student performance on cumulative ACS standardized exam
He, Holton, and Farkas ²⁷	General Chemistry (partially flipped)	223	Half letter grade increase in post-course grades. Higher gains for certain subgroups of students
Eichler and Peeples ²⁸	General Chemistry (partially flipped, year-long sequence)	250-300	GPA increase in organic chemistry sequence for students with initially lower GPAs

Studies of flipped courses have increased in recent years, but studies describing large organic chemistry courses in a flipped format with diverse student populations are less common. Furthermore, no studies to date have examined the long-term effect of a flipped organic chemistry course taught at an accelerated pace, with a focus on students repeating the course after an unsuccessful attempt. The current study implemented flipped instruction in an organic chemistry course as a means to increase

long term student achievement and is unique in that it focused on an accelerated summer course with a diverse student enrollment, including many students who had previously failed the course and enrolled in the summer course to “get back on track.”⁸

95 THEORETICAL FRAMEWORK

Two bodies of research on student performance and persistence framed this work: culturally responsive teaching and social/academic integration. It is well known that undergraduate STEM courses at large research universities do not have equitable success rates; certain groups of students, first-generation, low-income, PEERs (Persons Excluded from science because of Ethnicity or Race) and women, experience higher DFW rates.³ One explanation is cultural mismatch — certain groups of students are disadvantaged because of conflicts between implicit expectations for autonomy in American higher education and cultural identity.^{10,29–31} Culturally responsive teaching creates a learning environment that accommodates students’ interdependent learning norms, tapping into students’ prior experiences and knowledge to increase student performance and persistence.^{32,33} For example, in a culturally responsive classroom, the instructor serves as facilitator. For the flipped course in this study, the instructor provided in-class, collaborative activities including working problems on paper, using model kits to investigate three-dimensional structures, and acting out chemical processes. This embodies culturally mediated instruction by facilitating interdependent learning norms that rely on peers helping one another. As a result, students are empowered, in control of their learning, and able to function as a community, matching their cultural norms. By providing a culturally responsive learning environment for students, they are able to integrate socially and academically, which is known to contribute to persistence.³⁴ Tinto’s model of social and academic integration assumes students who persist in college and graduate participate in school culture.³⁵ Unfortunately, strategies for increasing social integration are frequently extra-curricular, co-curricular, or supplemental to classroom instruction. This study sought to increase social and academic integration within the classroom by employing culturally responsive teaching, thereby improving student performance, persistence, and matriculation into STEM careers.^{31,36} The flipped model employed in this study creates the sense of belonging that previously was only available outside of the classroom, and all students have access to integrate into the college culture. Flipped instruction

combines the informal social integration with the formal academic integration to take advantage of the one time all students are guaranteed to benefit. For students repeating a course, who are trying to “get back on track” during an accelerated summer term, using culturally responsive teaching to promote social and academic integration may help reduce the achievement gap in performance and persistence.

RESEARCH QUESTIONS

To determine whether a flipped format in an accelerated summer organic chemistry class is associated with a positive effect on student performance and persistence, we sought to answer the following questions:

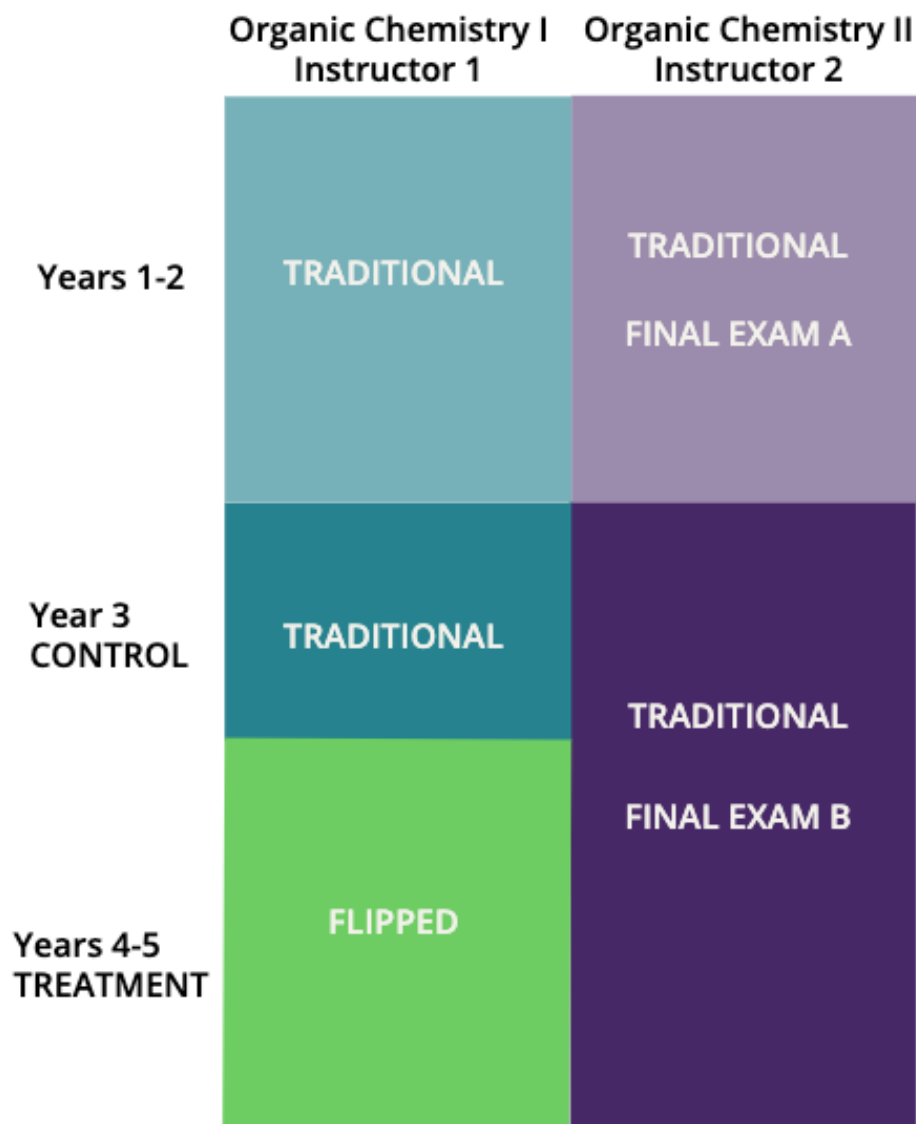
- How do students’ academic performance in an accelerated Organic Chemistry II (OCII) course compare between students who took the flipped, accelerated Organic Chemistry I (OCI) course and students who took the traditional, accelerated OCI course?³⁷
- Will a flipped, accelerated OCI format reduce the achievement gap in OCI and OCII for students who have unsuccessfully attempted OCI during a regular academic term?
- What were students’ perceptions of the course structure and their own skill development in the flipped OCI course?

METHODS

Participants and Setting

This study was approved by the Institutional Review Board as exempt (IRB 2012-8939 and IRB 2018-4211). The current study included five consecutive accelerated summer terms from 2009 to 2013, at a large public research university in the western United States with a diverse student population.³⁸ In the final year of the study, students self-reported as 43% Asian, 22% Hispanic/Latinx, 16% non-resident, 11% white, 4% other (Black, Pacific Islander, and two or more races), and 4% who declined to state. Additionally, 49% of the students self-reported as first-generation college students and 35% were identified as low-income based on self-reporting in admissions files. First-generation status was defined as neither parent completing a 4-year degree (i.e. students with the highest level of education being “some college”, “high school”, or “some high school”). Students who did not self-report income were assumed to be non-low income students. The student population at the time of the study was 50% male and 50% female based on self-reported responses to a binary choice question about biological sex at time of admission.

Each summer, Instructor 1 taught OCI in the five-week Summer Session I, while Instructor 2
150 taught OCII in the five-week Summer Session II term (Figure 1). In both accelerated courses, students
met for two-hour sessions three times a week. Instructor 1 used traditional face-to-face instruction
from Year 1–3 and implemented fully flipped instruction in all class meetings in Years 4 and 5.
Traditional lecture format for OCI included narrative lecture during which the instructor used a tablet
to fill in notes on slides and work example problems in class. Students were provided with the skeletal
155 notes in PDF format before class, and 3–5 clicker questions were given in each two-hour class meeting.
Students were encouraged to discuss responses with their peers. Instructor 2 used a similar
traditional lecture format in OCII during all years, including intermittent clicker questions. Students
purchased a bound notes packet that contained descriptive information, some pre-drawn structures,
and space for students to draw supplemental structures along with the instructor during the lecture.
160 During Years 3–5 (OC I: $n_3 = 219$, $n_4 = 259$, $n_5 = 210$), enrollment in Organic Chemistry I courses was
consistently higher than in Year 1 and Year 2 (OC I: $n_1 = 171$, $n_2 = 140$), and met the standard criteria
for large enrollment.⁸



165 Figure 1. Five-year Course and Final Exam Formats for Summer Organic Chemistry I and Organic Chemistry II

In the data analysis, Year 3 was chosen as the baseline for final exam consistency, as the final exam administered in OCII was identical in Years 3–5 and differed slightly from the final exam administered in OCII in Years 1 and 2. Midterm exam questions in OCII were isomorphic in nature, measuring the same set of concepts with cosmetic changes in detail. To maintain study integrity, students had access to graded midterm exams, but never graded final exams. Additionally, Year 3 was the third consecutive summer that Instructor 1 had taught the OCI course in traditional format, theoretically

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providing a stable comparison between the traditional and flipped results, as the instructor would be familiar with teaching this course in the accelerated context.

175 Students made enrollment decisions prior to the first summer session, making it highly unlikely for students to make enrollment decisions for the second session based on their learning experience in the first session. Because the courses were offered in accelerated summer terms, two distinct student populations were present: a) “Non-Repeaters,” those seeking to accelerate their progress towards degree completion, having not completed any prior organic chemistry courses; and b) “Repeaters,”
180 those students who had previously taken OCI and earned grades of C- or below. During the study, 979 students enrolled in OCI and 845 students enrolled in OCII; 378 students took both courses consecutively, of whom 44% (168 students) were Repeaters taking OCI after an unsuccessful attempt in the previous academic year. Of the 168 Repeater students enrolled in OCI, 11 were enrolled after multiple failed attempts in the prior academic year (Table 4). Data from Years 1 and 2 is included for
185 reference purposes and to demonstrate any differences year over year of student enrollment in the accelerated summer courses. This also allowed a larger sample size in our first analysis of student demographics.

Table 4. Accelerated OCII Enrollment by OCI Status

	Organic Chemistry I Summer Status			Total
	Non-Repeater	Repeater	Did not take consecutively	
Year 1	36 (26%)	22 (16%)	78 (57%)	136
Year 2	40 (29%)	11 (8%)	88 (63%)	139
Year 3	61 (38%)	35 (22%)	66 (40%)	162
Year 4	41 (24%)	53 (31%)	76 (45%)	170
Year 5	32 (13%)	43 (18%)	163 (68%)	238
Total	210 (25%)	168 (20%)	471 (55%)	845

190 **Final Study Population**

To be included in this study, students agreed to the study conditions about data collection, enrolled in OCI and OCII in Summer, and were fully matriculated students at the university. Students enrolled in OCII in Summer but not exposed to the treatment during OCI (traditional vs flipped classroom) were removed from the analysis. After meeting all study requirements, 250 students with complete data, representing multiple forms of diversity, were included in the final modeling. The sample consisted of 54% repeaters, 62% female, and 41% first-generation college students (Table 5). Additionally, students who self-identified as Black, African American, Latino, Spanish American, Chicano, Mexican American, American Indian, and Alaskan Native were classified as PEERs. The sample average SAT Total score was 1770. Two policy changes enacted in Year 4 created a cost savings for summer school, encouraging more low income students to enroll in summer courses. A policy to allow the use of financial aid to pay for summer school and a “Pay for 8” policy where students could take unlimited units for the same cost as eight units were introduced.

Table 5. Demographic Summary Statistics for OCII Students Who Took OCI in the Traditional Format (Year 3) and the Flipped Format (Years 4 and 5).

	Traditional (Year 3)			Flipped (Years 4-5)		
	Non-Repeater	Repeater	Full Class	Non-Repeater	Repeater	Full Classes Weighted Average ^a
Female	46%	69%	54%	61%	73%	63%
PEER	30%	20%	26%	32%	15%	22%
First Generation	26%	31%	28%	32%	43%	38%
Low Income	13%	23%	17%	26%	29%	28%
SAT Math Mean (SD)	648 (74)	605 (85)	632 (80)	631 (79)	606 (100)	616 (93)
SAT Writing Mean (SD)	596 (88)	575 (81)	588 (86)	581 (99)	565 (86)	571 (92)
Sample Size	61	35	96	73	96	169

^aWeighted average accounts for the differing enrollments in Years 4 and 5.

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Flipped Course Description: Organic Chemistry I

Students were assigned material to review prior to class in a manner of their choosing — textbook reading sections or short lecture videos. Copies of slides with blanks facilitated note-taking of the material. Pre-class quizzes consisting of 3–5 multiple choice content questions and one open-ended question regarding what the student found most difficult were used as an accountability mechanism only to verify that students had completed the assigned reading or video segments rather than to probe specific knowledge.

During class, students worked on problems designed to guide their progression through the concepts presented in the pre-class materials. In-class activities included working problems on paper, using model kits to investigate three-dimensional structures, and acting out chemical processes. For example, during a class period focusing on conformational analysis, pairs of students built models representing two similarly substituted cyclohexane structural drawings and worked together to determine whether their models represented conformers or stereoisomers. When working on nucleophilicity trends, a group of students volunteered to act out roles as solvent molecules and nucleophiles of varying sizes, with the solvent molecule students attempting to “trap” the nucleophile students. For all in-class activities, students were strongly encouraged to work with peers, but could work alone if they preferred. Most students chose to work with classmates despite the difficulties for facilitating group work presented by the fixed seating format of the classroom. Student work for in-class activities was not collected and did not count for any credit toward final grades. Students were incentivized to attend class because only solutions to in-class activities not completed during class meetings were posted. Based on headcounts during randomly selected class meetings, approximately 70-85% of enrolled students attended.

After class, students completed homework through an online homework system for additional practice. To keep the OCI workload hours comparable between the traditional and flipped courses, the homework assignments for the flipped course were pared down versions of the assignments used in the traditional lecture format. Any questions removed in the lighter homework assignments were

moved to optional assignments that students could complete for practice but not for credit. In both formats the course structure included a one-hour discussion section each week in which the graduate student teaching assistant provided additional practice worksheets.

Measurements

Student exam performance, final course grades (GPA), and pass rate in OCI and OCII in Year 4 and Year 5 were compared with Year 3 to identify any reduction in the achievement gap for students who had previously failed OCI (Figure 1). Surveys were administered to complement the quantitative analysis. Finding no appropriate pre-validated survey addressing perceptions of instructional strategies and skill development, we developed a survey specifically for this study (Supporting Information). In Year 4, we administered one survey at the end of the course. In Year 5 a modified survey was administered at the beginning and end of the course. In developing the survey items, we consulted with a colleague in Sociology involved in SoTL (Scholarship of Teaching and Learning) and a colleague conducting similar qualitative research on flipped instruction.^{39–42} The open-ended questions provided the richest data to identify any long-term benefits for students who have previously failed a traditional organic chemistry course when retaking the course delivered in an accelerated, flipped format.

Data Analysis

Statistical analyses were performed to determine the effect of flipping a classroom during OCI on college students' performance in OCII. Performance in OCII was analyzed using linear mixed models in three parts: score on the final exam; second midterm score; and first midterm score. Linear mixed-effects models were fit to the data to account for the correlation of students nested within a class using the open-source programming environment R as well as the lme4 and r2glmm packages.^{43–50} The model was chosen to be parsimonious and included variables that have shown to be related to performance in previous studies; covariates included student demographics (gender,^{9,51} first-generation college status,⁵² PEER status⁹), previous academic performance (OCI Repeater status, standardized SAT Math scores, standardized SAT Writing scores^{53–55}), and the type of OCI class (traditional or flipped classroom). SAT Reading scores were not included in the model because of the high collinearity with SAT Writing scores. To check for the collinearity of the remaining variables we

calculated the correlation and the variance inflation factor (VIF) for the covariates in the model. The correlation between the covariates were weak to moderate ($r < |0.51|$) and the VIF values were all acceptable ($VIF < 1.52$). Both measures indicate that there are no issues with collinearity of our covariates. A detailed description of the linear mixed effects models and the model results for performance on the midterm exams are included in the Supporting Information.

To test the difference in the final exam score earned in OCII for students who took the OCI in the flipped format versus those who took OCI in the traditional format, we used an independent samples t-test. We also tested the difference in the pass rate for the two groups by testing the difference of the two proportions. We hypothesized that the students who took the flipped format for OCI would score higher in OCII and that they would have a higher pass rate in OCII compared to the students who took OCI in the traditional format.

Survey items with Likert rankings were analyzed using a Wilcoxon rank sum test with continuity correction (two-tailed) to identify any survey items that had statistically significant differences between Non-Repeaters and Repeaters. Likert ratings were employed with a 5-point scale either “disagree-agree” or “ineffective-effective,” as appropriate. We controlled the overall Type I error rate to be 0.05 using a Bonferroni correction ($\alpha^* = \alpha/m = 0.05/12 = 0.004$).

RESULTS

Analysis of the quantitative and qualitative data show that students who previously attempted OCI and took a flipped, accelerated format when repeating the course scored higher on exams during OCII, earned higher grades in OCI and OCII, passed OCII on par with Non-Repeaters, and preferred the flipped format.⁵⁶ Table 6 shows summary statistics for Repeater and Non-repeater students and provides evidence of the significant achievement gap in OCII between students who had unsuccessfully attempted OCI previously and those who had not when taking an accelerated summer course. The average final exam scores from summary statistics for Non-repeaters in OCII after OCI in traditional format was 60 out of 100 points as compared to the Repeater’s average of 33 points. This difference indicates a performance gap of 27 points between the two groups.

Final exam averages of Non-repeaters and Repeaters in OCII after OCI was taught in the flipped format show a smaller performance gap of 14 points (Figure 2). Exam scores for Non-Repeaters

appeared to decrease by four points, but this effect was not statistically significant (see below).

Repeaters scores, however, increased by 11 points. Midterm exams showed consistent trends

290 compared to the final exam. Although exam scores for all groups may appear low, an average exam score of 60% is typical for organic chemistry courses at this university and does not represent a failing grade. Final course letter grades are highly curved.

Table 6. Exam scores, Grades and Pass Rate Summary Statistics for OCII Students Who Took OCI in the Traditional Format (Year 3) and the Flipped Format (Years 4 and 5). Grades and exam scores are given as Mean (SD).

	Traditional (Year 3)			Flipped (Years 4-5)		
	Non-Repeater	Repeater	Full Classes Weighted Average	Non-Repeater	Repeater	Full Classes Weighted Average
OCII Midterm 1	62 (17)	41 (15)	54 (19)	56 (19)	49 (18)	52 (19)
OCII Midterm 2	57 (19)	39 (15)	50 (20)	53 (22)	45 (15)	49 (18)
OCII Final Exam	60 (20)	33 (14)	51 (22)	56 (20)	42 (18)	48 (20)
OCI Course GPA	2.80 (0.75)	2.01 (0.38)	2.51 (0.75)	2.93 (0.70)	2.83 (0.65)	2.87 (0.67)
OCII Course GPA	3.04 (0.97)	1.43 (1.10)	2.44 (1.28)	2.60 (1.23)	2.03 (1.00)	2.28 (1.14)
OCII Pass Rate	93%	60%	81%	82%	80%	81%
Sample Size	61	35	96	73	96	169

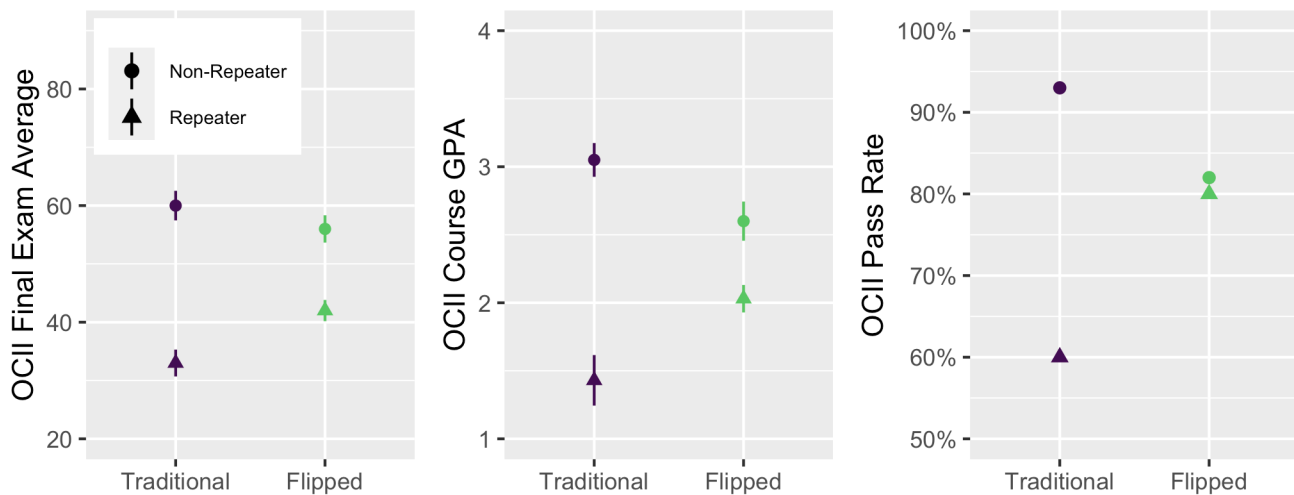


Figure 2. Average exam scores on OCII final exams with standard errors, OCII course GPA with standard errors, and OCII pass rates indicate that Non-repeaters on average score better than Repeaters, and the gap between the two groups closes in OCII when OCI had flipped instruction.

The OCI course GPA, OCII course GPA, and the passing rate (final grade of C- or higher) for OCII show a similar closing of the gap between Non-Repeater and Repeater students (Table 6). Students repeating OCI in the traditional format earned lower final course grades than their Non-Repeater counterparts in both OCI (0.79 GPA difference) and OCII (1.61 GPA difference). While 93% of Non-Repeaters passed OCII with a grade of C- or higher after taking OCI in traditional format, only 60% of Repeaters passed OCII.

After OCI was converted to the flipped format, these gaps were decreased. Repeater students who took flipped OCI had a final course GPA only 0.1 points below their Non-Repeater counterparts in OCI and 0.57 points in OCII. The gap in the passing rate for OCII was eliminated as Repeaters passed OCII at the same rate as Non-repeaters (Table 6, Figure 2). Although the final course GPA and the passing rate for Non-Repeater students in OCII after flipped OCI did decrease, this change can be explained by the class being graded on a competitive curve. The likelihood of a student earning a passing grade or higher in OCII after the flipped OCI course was not dependent on whether or not they had repeated OCI. A larger number of Repeater students scored above the passing threshold in the curved OCII class after taking OCI in flipped format while some Non-Repeaters did not, again emphasizing that the gap between these two groups was eliminated. The linear mixed effects model for OCII final exam

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scores is given in Table 7. The standardized effect size (R^2) for the model was found to be 0.28, indicating the 28% of the variation in OCII final exam scores can be explained by the combination of the course format, student demographics, and whether or not the student was repeating the course.

Table 7. OCII Final Exam Linear Mixed Effects Model for Years 3-5

	Coefficient	Standard Error	Degrees of Freedom	Test Statistic	p-value
(Intercept)	64.31	5.39	223	11.93	<0.001
Flipped	-11.67	6.47	1	-1.80	0.323
Repeater	-27.32	4.08	223	-6.70	<0.001
First Generation	-7.51	4.41	223	-1.70	0.090
PEER	3.82	2.81	223	1.35	0.177
Female	-3.19	2.55	223	-1.25	0.212
Standardized SAT Math	0.26	1.41	223	0.18	0.855
Standardized SAT Writing	0.77	1.35	223	0.57	0.569
Flipped and Repeater	14.52	4.95	223	2.94	0.004
Flipped and First Generation	13.82	5.28	223	2.62	0.010
$R^2 = 0.28$					

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Taking OCI in flipped format for Non-Repeaters did not have a statistically significant effect on OCII final exam performance (coefficient = - 11.67, $p = 0.323$). Similarly, effects of demographic variables and SAT scores were not significant. The achievement gap for Repeaters and Non-Repeaters was smaller in the flipped format compared to the traditional format. While being a Repeater in OCI resulted in a lower OCII estimated final exam score (coefficient = -27.32, $p < 0.001$), Repeaters who took OCI in the flipped format experienced an estimated OCII final exam score boost (coefficient = 14.52, $p = 0.004$). Non-Repeater students and Repeater students with similar demographics and SAT

330 scores who took OCI in traditional format would have an estimated final exam score gap of 27.32 points, whereas equivalent Non-Repeater and Repeater students who took OCI in the flipped format would have an estimated final exam score gap of only 12.80 points (see Supporting Information for calculation).

In tests for two-way interactions between the course format and demographic characteristics, a
335 significant interaction was found only for first-generation status and course design (Table 7). First-generation students who took OCI in the flipped format experienced an estimated OCII final exam score boost (coefficient = 13.82, $p = 0.010$). Tests for the three-way interaction between course design, repeater status and first-generation status showed no significant interaction, indicating that first-generation students benefited from the OCI flipped course format regardless of repeater status. While
340 Repeater first-generation students experienced the same closing of the exam performance gap with their Non-Repeater counterparts (27.32 points in OCII after OCI in traditional format versus 12.80 points in OCII after OCI in flipped format), Non-Repeater first-generation students outperformed Non-repeater students who did not self-identify as first generation. These Non-Repeater students and Non-Repeater first-generation students with similar demographics and SAT scores who took OCI in
345 traditional format would have an estimated final exam score gap of 7.52 points. The model indicated that the predicted exam score gap between equivalent Non-Repeater students (who do not identify as first generation) and Non-Repeater first-generation students who took OCI in the traditional format (7.52 points) was completely closed when the students took OCI in the flipped format. In fact, predicted exam scores for Non-Repeater first generation students were 6.31 points higher than their
350 counterparts who did not identify as first generation.

Results from the surveys support the quantitative findings.⁵⁷⁻⁶¹ The open-ended questions provide qualitative evidence that the flipped instruction in OCI was helpful and changed students' study habits. Table 8 includes representative student quotes. Students' own wording was used to identify themes based on identified relations, similarities and differences that were grouped conceptually.⁶²
355 Common themes described the learning experience as: demanding, engaging, lots of problem solving (with peers), interactive, helpful demonstrations, hands-on (molecular model kits) and gaining a

deeper understanding. Common caveats included: more work (for students and instructors), more responsibility, and no room to procrastinate.

Table 8. Flipped Organic Chemistry I Student Post-Survey Representative Examples of Common Responses (Year 4 and Year 5)

What did you think of the “inverted” method of teaching the course?	What in-class methods did you find especially helpful?	What out-of-class methods did you find especially helpful?	How did your study habits change in the “inverted” class?
Demanding; Deeper understanding; Engaging; Interactive;	Solving problems; Building with model kits; iClickers; Demonstrations; Peer discussions	Podcasts; Quizzes before class; Self-study strategies; Online homework; Discussion section	Study daily; No room to procrastinate; More ownership
<i>I failed my first OChem course...this method has helped me learn and succeed...allowed me to fully understand the fundamentals...who would have thought I would have a strong interest in organic chemistry</i>	<i>Working on problems in which you are given time to work with peers and listen to their thoughts and opinions on the subject, seeing how they personally work on problems...may see another approach towards a problem.</i>	<i>Encouraging the podcasts and readings BEFORE class...Requiring Sapling homework after each podcast...forced students not to procrastinate... actually helped learn the material instead of cram before exams.</i>	<i>I am more active in studying and less hesitant to attempt problems...because I've learned the common mistakes in class and have my professor...for questions or struggles I may be facing.</i>
<i>It was a little harder since we, as the students, definitely had a lot more responsibility since we had to take the time to review the subjects we would be talking about in lecture...hard to follow along when I skipped a podcast or two because of lack of time management on my part...</i>	<i>I thought working on problems during class slowly was helpful in the chapters that were particularly difficult... Using the 3D model kit was VERY helpful for me and I appreciated how the TA and [Instructor] would walk around to check if students had the right structure.</i>	<i>I felt the podcasts were the most helpful...gave me the ability to listen to the lecture at my own speed...pause...when I didn't fully understand... allowed me to be more productive in class by actually applying the concepts...</i>	<i>With this method, there is no room nor any reason to procrastinate so I just did it, I just studied easily and smoothly...never felt rushed to move onto the next topic...knew there would be time to ask questions and practice with my peers and instructor...I have a strong foundation in O-chem...feels awesome...</i>
<i>I thought it was useful and more efficient since we were able to do hands on problems during lecture. However for the students that didn't watch the podcasts, lecture was pretty much useless since they didn't know what is going on. It makes you better prepared and avoids procrastination.</i>	<i>I especially liked doing practice problems with the class as a whole...awesome when [Instructor] and TA were going around the huge lecture hall answering questions...made me feel like it was a small, interactive class...liked that we could actually keep up with the pace and learn every step.</i>	<i>Podcasts, since I could review them if needed, and the online pre-class quizzes, so I could see how well I really understood the material and decide what I need to focus my attention on when studying.</i>	<i>It made me realize how much better it is to be prepared... online quizzes...forced me to watch the podcasts and learn the material before class...I always knew what was going on and was never confused... study habits have slowly involved much less procrastinating... grew to appreciate a bit of studying each day</i>

Finally, the Likert scale items support the qualitative, open-ended results (Table 9). The majority of students felt that the flipped format was effective and would prefer to take more flipped courses. The findings are even more compelling when Non-Repeaters and Repeaters are separated. We used Wilcoxon rank sum tests with continuity corrections (two-tailed) to identify any items that had statistically significant differences between Non-Repeaters and Repeaters, and we controlled the overall Type I error rate to be 0.05 using a Bonferroni correction ($\alpha^* = \alpha/m = 0.05/12 = 0.004$). Repeaters' preferences for the flipped format were statistically higher than Non-Repeaters (Table 9). Because many changes were made to the survey in Year 5, we include it in the Supporting Information for reference.

Table 9. Comparison of Non-Repeaters and Repeaters on Year 4 Survey Items

Survey Question ^a	Non-Repeaters mean (sd)	Repeaters mean (sd)	p-value
I would recommend an inverted class to my friends who need to take organic chemistry.	3.72 (1.19)	4.26 (0.91)	0.001
I think listening to lecture outside of class and working on problem solving in class is an effective way to learn.	3.77 (1.19)	4.42 (0.84)	<0.001
I would prefer to take more science classes that use this type of class format.	3.69 (1.23)	4.21 (0.91)	0.004

^aLikert rankings were either “disagree-agree” or “ineffective-effective,” as appropriate to the survey statements and employed a 5-point scale

DISCUSSION

The change in OCI course structure reduced the achievement gap between Non-Repeaters taking an accelerated course to “get ahead” and Repeaters taking the course to “get back on track”. The difference in final exam performance was nearly halved, the GPA gap was reduced, and the gap in passing rate was eliminated. The decrease in Non-Repeaters' outcomes between the flipped and traditional course formats is not statistically different (Table 7). Additionally, first-generation students experienced a benefit in OCII from the flipped OCI course format regardless of repeater status; Non-Repeater first-generation students outperformed those Non-Repeaters that did not self-identify as first-generation. Because the courses were offered in the accelerated summer term, one would expect a

significant achievement gap between the “Non-Repeaters,” those seeking to accelerate their progress towards degree completion, and the at-risk “Repeaters,” who had previously failed OCI one or more times. However, converting OCI to a flipped format eliminated the gap in passing rate for Repeaters in OCII, potentially increasing Repeaters’ chances of graduating in STEM and pursuing their career goals. The increased performance for first-generation students, regardless of repeater status, is consistent with previous studies on cultural mismatch.¹⁰ When the learning environment matches first-generation students’ interdependent learning norms, they perform academically on par with students accustomed to an independent learning norm, more typical of American Universities.¹⁰ Studies that show a gain within the flipped course may be promising, but to show that the gain persists throughout the second course is compelling.

The qualitative data further supports that there is a difference between Non-Repeaters and Repeaters in the accelerated summer course. For certain survey items (Table 9) there was a statistically positive difference for Repeaters in preference for a flipped format that guides how they study for the course outside of class (i.e., watching lectures) to prepare for working on problems in class, potentially increasing their performance in other STEM courses. Repeaters reported they would like to take more STEM courses in a flipped format.³⁴ These findings are consistent with previous studies on flipped organic chemistry courses.^{24,25,41,63–65}

Comparison of final exam scores, course grades and passing rate in OCII affirm that flipping the accelerated OCI course — culturally responsive teaching — promotes equity beyond access to include persistence for undergraduate STEM majors. The course format provided opportunities for Repeaters to develop a stronger sense of social and academic integration as they learned problem solving skills alongside their peers. Research shows this leads to improved academic performance.³⁵ The flipped format provided many avenues by which students’ academic potential could be reached. Random headcounts revealed that approximately 70-85% of enrolled students attended class, where they were strongly encouraged (but not required) to work with peers. Such a strong attendance rate affirms students’ positive feedback regarding course structure. Students found the format to be engaging, active, more personal, and hands-on; they valued peer discussions, demonstrations, building molecular models with physical kits, covering the “tricky” practice problems, and clicker questions as

410 a means to foster discussion. Students participated in activities intentionally designed to foster social integration, guide their academic progression and increase their academic integration. For example, pairs of students worked together to build models of structural drawings while solving problems. On other occasions, students volunteered to act out roles, such as solvent molecules and nucleophiles of varying sizes. These activities created an environment of interdependent learning whereby students
415 were able to work with one another and learn from one another towards a common goal.¹⁰ This flipped course modeled culturally responsive teaching by matching the students' diverse learning needs. In culturally responsive teaching, we refer to these as multiple modalities. In the classroom, these include: hands-on activities (inclusive of molecular model kits), peer problem solving, and embodied learning. Outside of the classroom, these include: podcasts, reading, note taking, online homework
420 and online quizzes. Another aspect of culturally responsive teaching includes reteaching where content is presented in new and different ways that attend to students' needs.⁶⁶ Providing multiple instructional modalities in person and online increased the learning opportunities for all students. The flipped course also taught and modeled study strategies explicitly, rather than assuming the students were enculturated in the norms of higher education. Students specifically described how their study
425 habits changed. It is likely these new skills transferred to the next, traditionally taught course. The flipped format not only provided a deeper understanding of the fundamental concepts of Organic Chemistry I, it provided skill development, applicable to future courses, enhancing academic integration.

LIMITATIONS

430 While this study is potentially generalizable to other public research institutions, there are noteworthy limitations. Although surveys were used to support quantitative results, further studies are needed to establish the surveys' validity. The institution's selectivity may also have blunted the statistical significance of findings. To enroll in organic chemistry, students must have successfully completed the first-year chemistry series. Furthermore, in order to enroll in the first course of first-
435 year chemistry, students must have scored above 600 on SAT Math or completed an additional chemistry preparatory course. Therefore, those students taking organic chemistry have had initial success in their STEM major, but are at risk of dropping out of STEM during their second year.^{2,9}

FUTURE RESEARCH

Additional studies of accelerated summer STEM courses employing culturally responsive teaching
440 are needed, including studies on effective reteaching for students who are retaking courses and
include a disproportionate number of students who self-report as first-generation, low-income, PEERs,
and women. This is especially true for developmental courses that are often taught using pre-packaged
online programs with fewer instructional modalities and taken independently by students to get
“caught up.” This course structure results in minimal opportunity for social or academic integration.
445 Further qualitative research is needed to follow-up on student perceptions in subsequent courses after
they have taken flipped courses, especially those flipped courses that are culturally responsive and
engender social and academic integration. This qualitative research needs to focus on large enrollment
courses to complement the current research on smaller classes.

CONCLUSION

450 Organic chemistry has been described as one of the most difficult STEM gateway courses, forcing
students out of their STEM major more than any other course and contributing to the *persistence*
achievement gap.^{5,6,9} Increased performance between an intervention and control group in the current
course is encouraging but anticipated. Improved outcomes — higher final exam scores, higher course
grades, and consistent passing rates between Repeaters and Non-Repeaters, and the increase in exam
455 scores for first-generation students regardless of repeater status — in the next course have
implications for STEM graduation rates and careers for all students. The flipped format of instruction
in this study models culturally responsive teaching in ways rarely seen at the undergraduate level, as
compared with K–12 classes.^{67,68} Reteaching material to students (Repeaters) is most successful when
it is engaging and interactive (group work), information is in digestible chunks (video podcasts), and it
460 includes frequent formative assessment (clicker questions) and opportunities for practice.^{69,70}
Furthermore, effective reteaching has not been studied as well at the undergraduate level because
students typically retake failed courses in the same traditional format as the original course. The
findings here affirm that while flipped instruction may be generally preferred and helpful to all
students, its significance lies in its commitment to culturally responsive teaching, and appropriately

465 reteaching previously unsuccessful students, rather than weeding these students out of STEM
courses, majors and careers.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available:

470 Survey Instruments (PDF)

Statistical Models (PDF)

Survey Data Analysis (PDF)

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