Chemistry Education Research and Practice

Accepted Manuscript

Flipped Classroom Modules for Large Enrollment General Chemistry Courses: A Low Barrier Approach to Increase Active Learning and Improve Student Grades

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Abstract

In the face of mounting evidence revealing active learning approaches result in improved student learning outcomes compared to traditional passive lecturing, there is a growing need to change the way instructors teach large introductory science courses. However, a large proportion of STEM faculty continues to use traditional instructor-centered lectures in their classrooms. In an effort to create a low barrier approach for the implementation of active learning pedagogies in introductory science courses, flipped classroom modules for large enrollment general chemistry course sequence have been created. Herein is described how student response systems (clickers) and problem-based case studies have been used to increase student engagement, and how flipped classroom modules have integrated these case studies as collaborative group problem solving activities in 250-500 seat lecture halls. Preliminary evaluation efforts found the flipped classroom modules provided convenient access to learning materials that increased the use of

active learning in lecture and resulted in a significant improvement in the course grade point average (GPA) compared to a non-flipped class. These results suggest this approach to implementing a flipped classroom can act as a model for integrating active learning into large enrollment introductory chemistry courses that yields successful outcomes.

Introduction

Active Learning in STEM Instruction

The notion that engaging students in cognitive processing activities such as answering or discussing questions leads to more effective learning compared to instructor-led lectures is likely not disputed by most university instructors (Mayer *et al*., 2009). For the remaining skeptics this paradigm should be confirmed by a recent meta-analysis of 158 active learning studies, in which it was found active learning interventions led to significant increases in student learning gains compared to traditional lectures, and that students in passive lecture courses are 1.5 times more likely to fail compared to students in active learning environments (Freeman *et al.*, 2014). However, a large proportion of Science-Technology-Engineering-Mathematics (STEM) faculty continues to rely on traditional lecture approaches. The 2013-2014 Higher Education Research Institute (HERI) national faculty survey found 50.6% of faculty respondents across all disciplines use extensive lecturing in all or most of their courses (Eagen *et al*., 2014).[1] Though this most recent survey does not compare the use of lecture between different academic disciplines, the previous 2010-2011 HERI survey respondents reported 43.7% of non-STEM men and 27.8% of non-STEM women use extensive lecturing, whereas 69.7% of STEM men and 50.4% of STEM women faculty used lecturing in all or most of their courses (Hurtado *et al*., 2011). In short, the adaption of more engaging methods of teaching is still lagging in STEM courses.

Despite the slow transition away from the exclusive use of traditional lecture, progress is being made in regards to increasing the use of active learning in undergraduate chemical education, and instructional initiatives such as Process Oriented Guided Inquiry Learning (POGIL) and ChemConnections have made available a wide variety of resources dedicated to fostering active learning environments (Anthony *et al*., 1998; Yezierski *et al*., 2008;). In addition, the curricular redesign project Chemical Thinking is an example of a broader initiative aimed at both rethinking the content coverage in traditional general chemistry courses and integrating active learning environments into large lectures (Telanquar and Pollard, 2010). Unfortunately, the data collected by the HERI faculty surveys indicate the broader implementation of these types of active learning approaches in chemistry and the broader STEM education community has yet to take place.

Flipped Classes

An area of instructional innovation that is leading to the increased use of active learning in STEM disciplines is the flipped classroom approach. In short, a flipped classroom moves the content learning to a student centered out-of-class setting, usually using online learning technologies, and integrates problem solving activities into the lecture component (Christiansen, 2014; Seery, 2015). Conversely, introducing students to new content is traditionally done in the lecture, with the practice and application of the course content subsequently being done by the students as homework. This reversal of roles for the in-person lecture has led to the flipped classroom moniker.

Flipped classes can be implemented in a hybrid learning format, in which the content learning is exclusively done in an out-of-class setting and the actual number of in-person contact hours are reduced. The in-person lecture is then used solely for problem solving activities and the online learning counts as part of the course credit hour requirement (Ealy, 2013). A more common flipped classroom approach involves carrying out the content learning in both a traditional lecture setting and an online learning environment. This type of flipped classroom is also known as blended learning since the student learning is "blended" between the online and in-person lecture environments. Flipped classrooms using the blended learning approach usually maintain the same number of in-person contact hours, and the amount of online learning and associated in-class problem solving can vary widely depending on the specific implementation (Shibley *et al*., 2011; Seery, 2015).

Flipped classroom pedagogies are well established in the physics community, and the evidence clearly indicates these instructional approaches lead to improved performance and student learning gains in large introductory classes (Crouch and Mazur, 2001; Deslauriers *et al.*, 2011). The flipped classroom approach also has a growing cadre of devotees among the chemical education community, however publications reporting the implementation and effectiveness of these instructional innovations are relatively sparse and generally report flipped classes in chemistry courses enrolling fewer than 100 students (Shibley *et al.*, 2011; Christiansen, 2014; Smith, 2013; Fautch, 2015). It is noted reports of implementations in larger classes are slowly coming online (Yestrebsky, 2015; Flynn, 2015; Rein and Brookes, 2014), and we expect the use of flipped classroom modules in large enrollment chemistry courses to increase in the coming years. A review of the state of the art of flipped classes in undergraduate chemistry has recently been published in this journal, and interested readers can find therein a summary of how flipped classroom approaches have been implemented and an overview of the general impact of this teaching strategy on student learning and engagement (Seery, 2015).

Given the dearth of flipped classroom implementations in large enrollment general chemistry courses, attention was given to a first quarter general chemistry course in which concepts well suited for online instruction were targeted. The course design focused on creating a series of flipped classroom modules that can be classified as blended learning, and for the sake of clarity, any reference to flipped classrooms or flipped classroom modules for the remainder of the manuscript imply the use of the blended learning approach. This modular flipped classroom approach has an advantage over a fully flipped hybrid classroom since no changes to the course schedule and lecture meeting times are needed, enabling new adopters the ability to integrate any number of the flipped classroom modules as they see fit. The implementation of the flipped classroom modules, and a comparison of course performance between students in the flipped class and a non-flipped class are described herein.

Implementation

Flipped Classroom Modules vs. Non-flipped Classroom

In order to gain insight about the efficacy of the flipped classroom approach, student performance was compared to a non-flipped course incorporating a significant amount of active learning previously implemented by J.F. Eichler (this course will be referred to as the "non-flipped classroom" or "non-flipped class"). Active learning can take place in many forms, but for the purposes of this study active learning refers to instances in lecture in which students work in small informal groups as they work on problems/questions posed by the instructor. Though students may be "actively" engaged when the instructor is explaining concepts or doing example problems, we generally assume this more passive learning mode does not engage students in the cognitive process of actively answering or discussing questions/problems. The non-flipped classroom used personal response systems (clickers) to foster collaborative active learning as defined above and incorporated two problem-based case studies and six collaborative group problem solving activities in mandatory recitation sections. These students also used the Assessment and Learning in Knowledge Spaces (ALEKS)[2] online learning system to complete outside-of-class homework (see Table 1).

The implementation of the flipped classroom course was designed in an effort to minimize changes to the course structure and provide flexibility to potential new faculty adopters. Thus, four flipped classroom modules were introduced throughout the ten-week quarter, and the remaining lectures that incorporated the use of traditional lecture and periodic clicker questions were structured in a similar fashion to the non-flipped classroom. In an effort to more effectively link the dependent variable of student performance with the flipped class intervention, the collaborative group problem solving was removed from the mandatory recitation sections and the ALEKS learning objectives associated with the flipped classroom module topics were not included in the online homework. Modifying the online homework was particularly important since it was previously shown the ALEKS online learning system has a significant impact on student performance (Eichler and Peeples, 2014). In order to eliminate exam bias on student course grade performance, the flipped and non-flipped classroom courses were given common midterm and final exams. Aside from the format of the discussion group recitations, the topics covered in the ALEKS online homework, and the group learning activities implemented in the flipped classroom course, the topics covered were the same and the non-flipped classroom sessions were carried out analogously in both courses. Table 1 provides the structure of the flipped and non-flipped classroom courses studied in fall 2014, and Appendix 1 summarizes the schedule of topics for the flipped and non-flipped classes. The reader will note the non-flipped course had more class meetings overall because the class was scheduled on a Monday/Wednesday/Friday format, whereas the flipped classroom lecture was scheduled on a Tuesday/Thursday format.

Table 1: Structure and format of the flipped and non-flipped classroom courses.

Fall 2014	**Flipped Classroom Course**	**Non-flipped Classroom Course**
Instructor	J.F. Eichler	J.F. Eichler
Course schedule	10 week quarter; T/Th lectures	10 week quarter; M/W/F lectures
Enrollment	452	294
Lecture activities	4 flipped classroom sessions (80 minutes each) 13 instructor led lectures with significant use of clickers (80 minutes each)	28 instructor led lecture lectures with significant use of clickers (50 minutes each)
Recitation activities	Graduate TA led review sessions (non-graded practice problems, student Q&A)	Graduate TA led group problem solving; 2 problem based case studies and 6 collaborative group quizzes[a]
Homework	138 ALEKS topics	213 ALEKS topics
Grading[b]	Clickers – 200 points ALEKS HW – 100 points Online pre-lecture quizzes – 100 points Two midterms – 200 points Final exam – 400 points A/A- = 900-1000; B+/B/B- = 800-899; C+/C/C- = 600-799; D = 500-599; W = student withdrawal	Clickers – 100 points ALEKS HW – 100 points Recitation activities – 200 points Two midterms – 200 points Final exam – 400 points A/A- = 900-1000; B+/B/B- = 800-899; C+/C/C- = 600-799; D = 500-599; W = student withdrawal
Active Learning in Lecture (as measured by time spent responding to clicker questions)	28% of lecture time	13% of lecture time

[a]Traditional Active Lecture problem-based case studies can be accessed through the UCR Chemistry Case Studies website.[2]
[b]Final course grade point averages (GPAs) are assigned as follows: A = 4.0, A- = 3.7, B+ = 3.3, B = 3.0, B- = 2.7, C+ = 2.3, C = 2.0, C- = 1.7, D = 1.0, F = 0; W = withdrawal (withdrawals do not get calculated into student GPAs).

One potential drawback of flipped classroom environments is the fact students are trusted to independently complete the pre-lecture online learning assignments. If students do not successfully complete these activities and make significant learning gains, not only will the completion of the in-class activities be difficult, the students will likely not gain mastery of the associated learning objective. In an effort to mitigate this possible outcome, learning objectives in the first quarter general chemistry course associated with more algorithmic approaches to solving problems or answering questions were chosen (see Table 2). As an example, providing learning activities to help students learn the rules and procedure for writing electron configurations is more appropriate for an online learning space than the more complex concepts required to understand the quantum mechanical model of the atom and how atomic orbitals are used to describe probable positions/energies of electrons. Just as important as helping ensure successful student learning in the online learning space, it is predicted targeting these types of learning objectives will reduce the hesitation of faculty in adopting these modules.

Flipped Classroom Pre-lecture Activities

One common misconception about flipped classes is the idea instructors simply provide a video of the normal lecture and require the students to view this prior to participating in the in-class problem solving activity. Though this is certainly an approach one might take, the goal for this implementation was to create a more engaging pre-lecture learning environment. After all, if the aim is to increase the amount of active learning in lecture, instructors should strive to provide more than passive videos in the online learning space. Since many faculty might hesitate to implement flipped classroom activities due to the effort required to create supplemental videos, freely available Khan Academy general chemistry videos were used.[3] However, since these are passive activities that do not prompt the students to answer questions or practice the specific problems, Wolfram Computable Document Format (CDF) interactive tutorials[4] or freely available Norton Chemtours tutorials were also included as pre-lecture learning assignments.[5] These activities allow the students to interact with the tutorial interface, and provide opportunities to answer concept building questions and practice problems associated with the learning objective. Once the students completed the videos and interactive tutorials, they were required to complete an online quiz in which they completed practice problems associated with the flipped class topic (see Table 2). Requiring a graded activity in the pre-lecture learning is highly recommended, as this incentivizes the students to complete the tutorials and ultimately ensures students are making the necessary learning gains prior to lecture. Finally, since the in-class collaborative group work activities were adapted from problem-based case studies, students were given a short reading assignment related to the case issue. For example, the reaction stoichiometry activity, students were assigned to read a literature article that described how coal can be converted to liquid hydrocarbon fuel. Links to the Khan Academy chemistry videos, Norton ChemTours tutorials, and the Wolfram CDF chemistry demonstrations site are provided in the footnotes, and the Wolfram CDF file for the stoichiometry tutorial is available in the supplemental materials.

Flipped Classroom In-class Activities

Even though the pre-lecture online quiz provided formative assessment for class-wide learning gains, a short clicker quiz was implemented at the beginning of the lecture to help ensure students had the requisite mastery of the pre-lecture learning objective. The clicker responses provided data that allowed the instructor to decide if a "just-in-time" mini-lecture was needed prior to beginning the collaborative group activity. After the short clicker quiz and associated discussion, a short introduction to the problem solving activity was completed. This generally included providing some background in regards to the context of the overall activity (e.g., for the stoichiometry module this included a short discussion about why policy makers might be interested in funding processes aimed at converting coal to liquid hydrocarbon fuel), as well as hints or guidance for specific problems.

The students were then instructed to work in collaborative groups of 3-4 people, and worked on completing the free response problems. Prior to the lecture, the graduate student teaching assistants (TAs) and undergraduate supplemental instructors (SIs) were given the worksheet and answer key to prepare them in answering student questions. For the flipped classroom course in the fall of 2014, there were three TAs and four SIs who helped the faculty instructor moderate the collaborative group work. Even though these activities were done in an auditorium lecture hall with 454 students, the students were able to work effectively in groups, and the instructor, TAs, and SIs were able to answer all student questions and address points of clarification.

Finally, after the students had completed the worksheets, the students were given clicker questions in which the free response problems had been converted to multiple choice questions. This was done to provide a quick method for "collecting" the student work, and since the clicker system generates an automated grade report the need to hand grade the student responses was eliminated. Table 2 summarizes the flipped classroom topics, and the structure of the pre-lecture learning and in-class lecture activities for the flipped classroom modules. The in-class activity worksheet and a power point file containing the clicker questions for the stoichiometry flipped classroom module are provided in the online supplemental materials.

Table 2: Flipped classroom topics and module activities.

Flipped Classroom Topics	**Pre-lecture Learning**	**In-class Collaborative Group Learning**

1. Electron Configurations 2. Ionic Bonding 3. Lewis Structures 4. Reaction Stoichiometry	1. Khan Academy Videos (40-60 minutes total). 2. Wolfram CDF Interactive Tutorials (electron configurations and stoichiometry). 3. Norton ChemTours Interactive Tutorials (ionic bonding and Lewis Structures). 4. Online quiz (Blackboard Course Management System). 5. Pre-lecture reading (short literature article or article excerpt).	1. Clicker question learning check (5-10 minutes). 2. Just-in-time teaching mini-lecture (10-15 minutes). 3. Collaborative group worksheet/case introduction (10-15 minutes). 4. Collaborative group work on free response worksheets (35-45 minutes). 5. Clicker answer input with instructor feedback (25-30 minutes).

Experimental Methods

Data Collection

In conjunction with the University of California, Riverside (UCR) Office of Undergraduate Education, UCR course evaluation/survey results, student data (e.g. gender, race/ethnicity, socio-economic status, etc.), and final course grades were obtained for the flipped and non-flipped classroom courses from the fall 2014 quarter. The UCR Office of Undergraduate Education also provided the W/D/F rates for two traditional lecture classes from the fall 2012 quarter. A common final exam was written by J.F. Eichler and administered to the flipped class and non-flipped class populations, and the exam scores were tabulated and analyzed by J.F. Eichler and J. Peeples. Active learning was measured by tracking the time used to complete the in-class clicker questions, which was collected by the course instructor. The Hyper-Interactive Teaching Technology (H-ITT) clicker system provides metrics of time usage, and given the fact the collaborative group learning conducted in both courses was carried out exclusively with student clickers using the time spent in the clicker system was chosen to measure active learning. All data collection and analysis was carried out under the Human Subjects Protocol No. HS-10-

135, which was approved by the UCR Human Research Review Board, and included obtaining informed consent from all students.

Statistical Analysis

To determine whether participating in the flipped classroom modules resulted in a statistically significant impact on final course grade and/or final exam performance in comparison to the non-flipped classroom course, this analysis imposed a linear regression model. Appendix 2 provides the variable definitions for the dependent variables and each of the independent variables used in this analysis. Appendices 3 and 4 display the descriptive statistics for the student populations in the flipped and non-flipped classrooms. The Statistical Package for the Social Sciences (SPSS) predictive analytics package was used to run the descriptive statistics, an Analysis of Variance (ANOVA) test, and the multiple regression analyses. Appendix 5 summarizes the results of the ANOVA test that was carried out to determine if the D/F/W rates for the flipped and non-flipped classroom courses were significantly different. Additionally, as previously described, the regression model allows one to test the nature of the relationship between the independent variable of classroom instructional intervention and the dependent variables of student performance, while holding constant the other various independent variables related to the students' background characteristics (Kachigan, 1991). Appendices 6 and 7 summarize the regression analyses in which the final exam scores and final course letter grades were compared for the flipped and non-flipped classes.

Results

Student Attitudes

The reluctance of faculty to change their teaching methods is often linked to the potential negative effects on student course evaluations (Ryan, 1980). Since responses to student end-of-course evaluations are often included in merit and tenure evaluations such concerns are well warranted. Therefore, it was of interest to compare the general student satisfaction between the flipped classroom and non-flipped classroom courses. Table 3 summarizes the average student response to five questions from the UCR institutional end-of-course evaluation survey. Generally speaking, the student satisfaction with how the instructor used the course time and the impact of the course activities and assignments are nearly indistinguishable. More importantly, both the flipped classroom and non-flipped classroom courses displayed a trend of increased student satisfaction compared to the average response of all undergraduate courses taught at UCR in the fall 2014 quarter. In short, these results indicate instructional innovations that increase the amount of student work can be implemented without resulting in more negative student evaluations. Though it has been shown engaging students in a drastically new type of learning environment can lead to decreased satisfaction (Gutwill-Wise, 2001), a recent report of a flipped classroom implementation in large enrollment organic chemistry also found that student satisfaction was not negatively impacted (Flynn, 2015). Furthermore, the recent review of flipped classroom implementations in undergraduate chemistry courses also reports a general trend of positive student feedback to flipped classroom approaches (Seery, 2015).

Table 3: Fall 2014 UCR course evaluation results (average response +/- standard deviation).

Questions *(1-5 Likert scale responses; 5 = strongly agree, 1 = strongly disagree)*	**Flipped Classroom Course** *(response rate = 87%)*	**Non-flipped Classroom Course** *(response rate =*	**Average of all UCR Undergraduate Courses** *(response rate =76%)*

		81%)	
The instructor used class time effectively.	4.7 +/- 0.6	4.8 +/- 0.4	4.3 +/- 0.9
The syllabus clearly explained the structure of the course.	4.6 +/- 0.6	4.7 +/- 0.5	4.4 +/- 0.8
The assignments contributed to my learning.	4.5 +/- 0.7	4.5 +/- 0.7	4.2 +/- 0.9
The supplemental materials were informative.	4.5 +/- 0.7	4.5 +/- 0.7	4.2 +/- 0.9
The course overall as a learning experience was excellent.	4.5 +/- 0.7	4.6 +/- 0.6	4.2 +/- 0.9

Student Performance – Descriptive Statistics

In addition to demonstrating the flipped classroom modules could be implemented without significantly affecting student satisfaction with the course, it was important to this analysis to assess the impact of this instructional approach on the student's course performance. The average course grades for the flipped classroom and non-flipped classroom, measured by the course letter grade after conversion to a grade point average (GPA), were 2.92 and 2.80, respectively (refer to Table 1 for a description of how course letter grades/GPAs were assigned; see Table 4 and Appendix 5 for the course GPAs). Figure 1 shows the course grade distributions in the flipped and non-flipped classroom courses taught by J.F. Eichler in the fall 2014 quarter. Comparatively, the flipped course showed a decrease in the percentage of students earning C grades and a concomitant increase of grades in the A and B grade range. The flipped classroom course had slightly more students with W/D/F grade assignments, but this change was less than one percent and smaller than the increase in A/B grades. Because the W/D/F rates for the flipped and non-flipped classroom populations were not drastically different, these were compared to two courses previously taught by other instructors in which traditional lecture was the predominant form of content delivery. Notably, both the flipped and non-flipped classroom courses had lower W/D/F rates compared to these traditional general chemistry lecture courses (see Table 4).

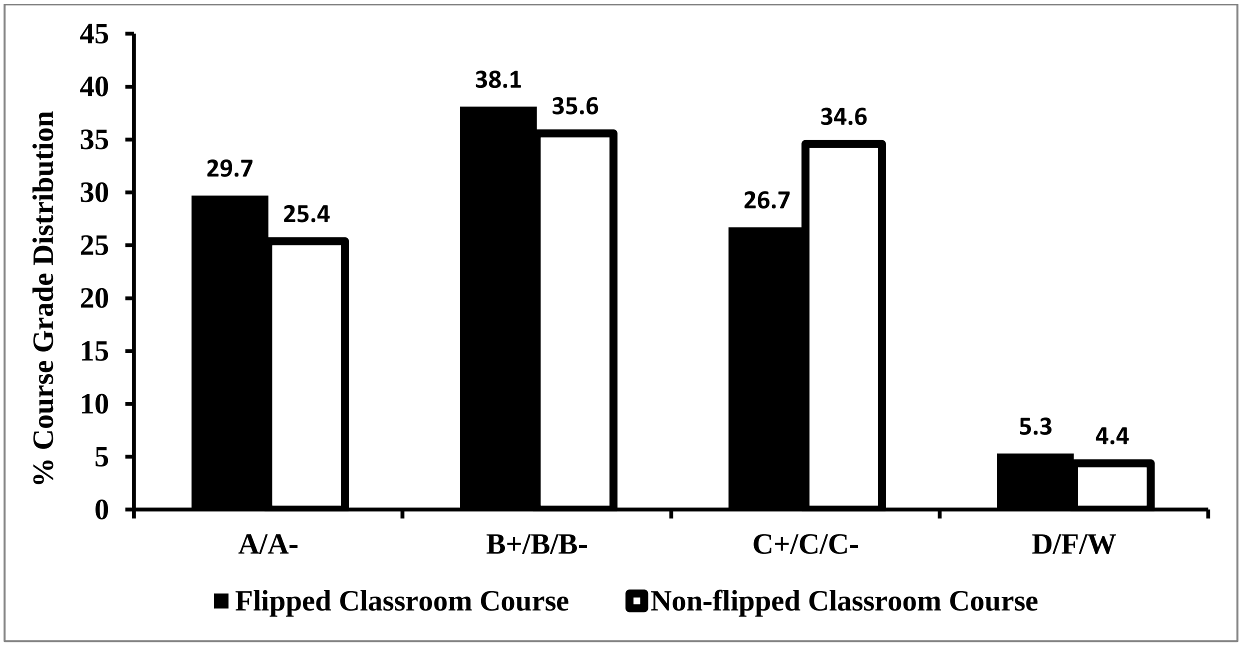

Figure 1: Course Grade Distributions in the flipped classroom and non-flipped classroom courses taught by J.F. Eichler in the fall 2014 quarter.

Table 4: Course W/D/F rates, exam scores, and clicker averages.

Lecture Type	Total W/D/F	Percent W/D/F	Course GPA	Exam 1 Avg.	Exam 2 Avg.	Final Exam Avg.	Clicker Avg.
Flipped Classroom Course J.F. Eichler (one section) Fall 2014	24/454	5.3%	2.923	83.4% +/- 12.1%	75.0% +/- 16.5%	73.6% +/- 12.1%	85.9% +/- 18.6%
Non-flipped Classroom Course J.F. Eichler (one section) Fall 2014	13/295	4.4%	2.807	83.7% +/- 12.5%	73.5% +/- 14.8%	73.9% +/- 13.0%	74.4% +/- 18.8%
Traditional Lectures Other instructors (two sections) Fall 2012[a]	107/724	14.8%	N/A	N/A	N/A	N/A	N/A

[a]The traditional lectures taught by other instructors had similar exam formats as the flipped classroom and non-flipped classroom courses (two midterms and a final exam), and had TA led practice problem sessions and quizzes in the discussion group recitations.

Student Performance - Statistical Analysis

As previously mentioned, Table 4 provides a comparison of the W/D/F course grades for the flipped classroom and non-flipped classroom courses. The descriptive results indicate the flipped classroom had a slight increase in W/D/F rates compared to the non-flipped classroom. An ANOVA test was carried out to determine if the percentage differences of W/D/F rates between the flipped classroom and non-flipped classroom courses were in fact statistically significantly different (see Appendix 5 for complete ANOVA results). Findings show there was no statistically significant difference in W/D/F course grade rates between the groups who participated in the flipped and non-flipped classroom (significance = 0.655; $p > 0.05$).

In order to determine if there might be a distinguishable impact on the final exam performance, a multiple regression analysis was conducted. The final exam scores were compared between the students in the flipped and non-flipped classrooms, while holding constant the student background variables. Table 5 summarizes the correlation between the classroom interventions and the student final exam scores (the complete statistical summary of the correlation coefficients for all the independent variables can be found in Appendix 6). Results reveal there was not a statistically significant difference in the final exam grades between the flipped and non-flipped courses (unstandardized B = -6.292; significance > 0.05). Even though the flipped classroom led to an in increase in course grade/GPA compared to the non-flipped classroom (see Table 4), the fact no significant difference was observed in the final exam is not completely unexpected. The recent review of flipped classroom interventions in undergraduate chemistry courses observed that approximately half of the published studies report no improvement in exam scores for flipped classrooms (Seery, 2015).

Table 5: Flipped classroom vs. con-flipped classroom; impact on final exam score*

Independent Variable	Unstandardized Coefficients		Standardized Coefficients	t*	Significance
	B	**Standard Error**	**Beta**		
(Constant)	289.493	21.375		13.544	0.000
Flipped Classroom Course	**-6.292**	4.196	-0.065	**-1.499**	**0.134**

*Dependent variable = final exam score; t = t statistic (regression coefficient/standard error)

In addition to comparing performance on the final exam, it was desired to determine whether participating in a flipped classroom environment had a statistically significant impact on overall course grade/GPA. A multiple regression model was also used to measure whether course grades between the flipped and non-flipped courses differed significantly, while holding constant the various student background variables. Table 6 summarizes the correlation between the flipped classroom intervention and the non-flipped classroom by student course grade/GPA performance (the complete statistical summary of the correlation coefficients for all the independent variables can be found in Appendix 7). Students who participated in the flipped classroom course could expect to positively and significantly increase their overall course GPA by nearly 18 percentage points (unstandardized B coefficient = 0.179, significance < 0.05). In conjunction with these findings, the linear correlation coefficient quantifying the strength and direction between the dependent and independent variables was calculated. Although there is a significant and positive relationship between participating in the flipped classroom environment and the impact on a student's course grade GPA, the correlation is considered weak (R = 0.396; R < 0.50 considered weak correlation; see Appendix 8).

Table 6: Flipped classroom vs. non-flipped classroom; impact on course grade/GPA*

Independent Variable	**Unstandardized Coefficients**		**Standardized Coefficients**	**t***	**Significance**
	B	**Standard Error**	**Beta**		
(Constant)	1.163	0.412		2.822	0.005
Flipped Classroom Course	**0.179**	0.064	0.098	**2.795**	**0.005**

*Dependent variable = course grade (as quantified by course GPA);
t = t statistic (regression coefficient/standard error)

In short, the flipped classroom implementation resulted in an increased amount of active learning in the classroom and a significant improvement in overall course grade/GPA. The flipped classroom modules also achieved the same course completion rate as the non-flipped course taught by the same instructor, and both the flipped class and non-flipped class reduced the W/D/F failure rate compared to traditional lecture courses taught by other instructors. The results presented here corroborate previous findings about the efficacy of the flipped classroom approach. In particular, it was observed that a flipped classroom approach in large enrollment organic chemistry significantly improved student course grade/GPA performance, and reduced withdrawal and failure rates compared to non-flipped courses (Flynn, 2015). Improved student performance, as measured by course grade/GPA, has also been observed in flipped classroom implementations in small lecture courses (Fautch, 2015).

Analysis and Conclusion

One might predict the impact of the flipped classroom approach is generally attributed to the fact it allows for a significant increase in active learning, and given the recent findings of Freeman, *et al*. (Freeman, 2014) it is expected designing a course that increases the amount of active learning would improve student learning gains. From the perspective of creating a more engaging lecture environment, the flipped classroom approach described above was a success because it more than doubled the amount of class time devoted to active learning exercises compared to the non-flipped class (see Table 1). However, the fact the flipped classroom modules positively impacted the overall course grade (see Table 6), but led to final exam scores indistinguishable from the non-flipped class (see Table 5) suggests the active learning intervention in lecture may not have been the most impactful independent variable in regards to longer term learning. Even though this study was not able to implement experimental controls in which the impact of the pre-lecture learning activities could be isolated from in-class active learning, it is hypothesized the pre-lecture learning activities had greater impact on the student grade performance.

The flipped classroom approach incentivizes the students to complete their "homework" since the pre-lecture learning activities conclude with an online quiz. Additionally, the students are able to view the videos and work with the interactive tutorials at their own pace and if necessary multiple times, allowing the students to tailor the learning experience to their own needs. The advantage of this type of flipped pre-lecture learning environment might be explained by cognitive load theory, recently summarized by M.K. Seery. In essence, learning new material in a traditional lecture environment is restricted because the delivery of the content (the intrinsic load) and extraction of information by the student (the extraneous load) limit the capacity for learning new information (Seery, 2015).

It is proposed the pre-lecture learning environment carried out in the flipped classroom course reduced the cognitive load by allowing the students to access the content and extract the new information when it was most convenient for them to do so and at their own desired pace. This likely led to gains in the short/intermediate term learning for the students in the flipped classroom course. However, after the entire 10-week quarter the final exam performance in the flipped lecture course and non-flipped course equalized. A comparison of the descriptive clicker grades suggests the pre-lecture learning activities positively impacted the short/intermediate term learning, as the clicker average for the course implementing the flipped learning modules was over ten percentage points higher compared to the students in the non-flipped classroom course (see Table 4). Conversely, these gains did not translate to the final exam performance, which were found to be statistically equivalent for the flipped and non-flipped classes (see Tables 4 and 5). The improvement in overall course grade/GPA for the flipped class compared to the non-flipped class (see Tables 4 and 6) can thus be attributed to the marked improvement in student clicker performance, which most likely reflects the impact of the pre-lecture learning activities. The active learning clicker questions and more comprehensive ALEKS homework in the non-flipped classroom course also likely contributed to the fact students in the control group had comparable longer term learning gains, as measured by the final exam scores. Future studies will focus on isolating the impact of the in-class and pre-lecture activities on student learning, and efforts will be made to determine if changing the flipped classroom implementation might increase long term learning gains (e.g., will increasing the number of flipped classroom modules increase student final exam performance compared to a non-flipped course that incorporates active learning and ALEKS).

In addition to comparing the overall course grades and final exam scores for the flipped and non-flipped classes, insight was gained by comparing the W/D/F rates of the flipped and non-flipped classes to previous classes in which active learning approaches were not adopted. The results presented in this work indicate both the flipped classroom and non-flipped classroom courses significantly reduced the W/D/F rates compared to general chemistry courses in which traditional passive lecture was the predominant method of instruction. In fact, the percentage of students who did not earn a grade of C- or higher in the flipped classroom or non-flipped classroom courses was approximately three times lower than traditional lecture courses taught by other instructors (see Table 4). This marked improvement in student success was accompanied by high levels of student satisfaction with the courses described here, providing compelling evidence for practitioners of traditional passive lecture who are hesitant to adopt new approaches to teaching. These results, in conjunction with previous studies finding flipped classroom implementations improved student success rates and/or grade performance (Flynn, 2015; Fautch, 2015), also suggest the flipped classroom approach might help address the broader problem of student retention in STEM majors.

In summary, the flipped classroom implementation described here only requires the replacement of four traditional lectures in a ten-week Tuesday/Thursday course with active learning group problem solving exercises, which are coupled to pre-lecture learning activities that are readily available to new adopters (the Khan Academy videos and Norton Publishing ChemTours are freely available online resources). The most daunting challenge for faculty using traditional lecture approaches may be the use of in-class clickers, however this technology is becoming more widespread and a number of web-based student polling systems are now available.[6] Of course, instructors could choose to not use clickers and grade the student in-class work in more traditional methods, especially if graduate teaching assistants are available for grading or if the flipped classroom modules are adopted in small enrollment courses. Hence, using student response systems to foster active learning should not be a large barrier for implementing flipped classroom approaches. The flipped classroom approach is an instructional intervention that requires a manageable amount of course material development, does not impact course content coverage, and improves student grades in large enrollment lectures without negatively impacting end-of-course instructor evaluations. With these considerations in mind, the flipped classroom implementation outlined herein can act as a model for instructors teaching large enrollment general chemistry courses and stimulate broader adoption of active learning approaches, ultimately improving student success in a large introductory course required by students pursuing STEM degrees.

Notes

1. The HERI survey is a national survey of higher education faculty across the United States. More information about the survey can be found at: http://www.heri.ucla.edu/facoverview.php

2. ALEKS (www.aleks.com).

3. Khan Academy general chemistry video tutorials (https://www.khanacademy.org/science/chemistry)

4. Wolfram CDF: (https://www.wolfram.com/cdf/)
The primary advantage of the CDF tutorial is the students are able to manipulate graphs and schematics, view dynamic molecular models, etc. Our tutorials are designed to have students make predictions and determine resulting outcomes based on the changes to specific variables. The CDF player software can be downloaded for free by students. Though a number of chemistry tutorials are available online

(http://demonstrations.wolfram.com/search.html?query=chemistry), we chose to create our own tutorial specifically designed to address the learning objectives in our stoichiometry blended learning unit. The stoichiometry CDF tutorial is available in the supplemental materials associated with this article.

5. Norton ChemTours:
http://www.wwnorton.com/college/chemistry/chemistry3/ch/01/chemtours.aspx

6. Examples of commonly used web-based student response/polling systems:
   a) https://www.polleverywhere.com/
   b) https://tophat.com/

Acknowledgements

We would like to acknowledge support of this project by the NSF Division of Undergraduate Education (Transforming Undergraduate Education in STEM Grant No. 1140522). We also gratefully acknowledge the anonymous referees who reviewed this article, whose suggestions for revision led to a greatly improved final manuscript.

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Appendices

Appendix 1: Flipped classroom schedule of course topics.

	Flipped Classroom Course Schedule **(Suggested sections of textbook reading shown in parentheses)**
Week 0	Course Logistics & Goals/Student Learning Goals Review of Measurement Conversions (1.8-1.9)
Week 1	Atomic Structure (Democritus Reading, 2.1-2.4)
	Electronic Structure (de Broglie Reading, 3.1-3.5)
Week 2	Electronic Structure (3.6-3.8)
	Electronic Structure (3.9) – **Blended Learning Module**
Week 3	Electronic Structure (3.9) - Review
	Exam 1 (Chapters 1-3)
Week 4	Ionic Bonding (4.1-4.2) – **Blended Learning Module**
	Periodic Trends (3.10-3.12)
Week 5	Covalent Bonding (4.1, 4.3)
	Lewis Structures (4.3, 4.8) - **Blended Learning Module**
Week 6	**No Class - Holiday**
	Molecular Geometry (5.1-5.2)
Week 7	Intermolecular Forces (6.1-6.2)
	Advanced Bonding (5.4, 5.7)
Week 8	**Exam 2 (Chapters 4-6)**
	No Class - Holiday
Week 9	Reactions/Stoichiometry (7.1-7.2, 7.4)
	Reactions/Stoichiometry (7.5-7.7)
Week 10	Reactions/Stoichiometry (7.8, 8.1-8.2) – **Blended Learning Module**
	Finish Chapter 7/Review
	Final Exam (Chapters 1-7) (11:30-2:30; Location TBD)

	Non-flipped Classroom Course Schedule **(Suggested sections of textbook reading shown in parentheses)**
Week 0	Course Logistics & Goals/Student Learning Goals Review of Measurement Conversions (1.8-1.9)
	Finish Measurement Conversions (1.8-1.9)
Week 1	Atomic Structure (Democritus Reading, 2.1-2.4)
	Electronic Structure (de Broglie Reading, 3.1-3.5)
	Electronic Structure (3.6-3.7)
Week 2	Electronic Structure (3.8)
	Electronic Structure (3.9)
	Electronic Structure (3.9) - Review
Week 3	**Exam 1 (Chapters 1-3)**
	Ionic Bonding (4.1-4.2)

	Ionic Bonding (4.1-4.2)
Week 4	Periodic Trends (3.10-3.12)
	Periodic Trends (3.10-3.12)
	Covalent Bonding (4.1, 4.3)
Week 5	Covalent Bonding (4.1, 4.3)
	Lewis Structures (4.8)
	Lewis Structures (4.8)
Week 6	Molecular Geometry (5.1-5.2)
	Molecular Geometry (5.1-5.2)
	Intermolecular Forces (6.1-6.2)
Week 7	Intermolecular Forces (6.1-6.2)
	Advanced Bonding (5.4, 5.7)
	Advanced Bonding (5.4, 5.7)
Week 8	**Exam 2 (Chapters 4-6)**
	No Class - Holiday
Week 9	Reactions/Stoichiometry (7.1-7.2, 7.4)
	Reactions/Stoichiometry (7.5-7.7)
	Reactions/Stoichiometry (7.8)
Week 10	Reactions/Stoichiometry (7.8)
	Reactions/Stoichiometry (8.1-8.2)
	Finish Chapter 7/Review
	Final Exam (Chapters 1-7) (11:30-2:30; Location TBD)

Appendix 2: Variable definitions for the multiple regression analysis.

Variable Model Name	**Variable Full Name**	**Variable Meaning**
R_GRADE	Failure Rates/Final Exam Grade/Course Grade GPA (Dependent Variable)	Course GPA (0.0-4.0)
GROUPS	Type of Classroom Structure (Flipped Classroom vs. Non-flipped Classroom)	1 if Flipped Classroom; 0 if Non-Flipped Classroom
WOMEN	Gender	1 if female; 0 if male
MEN	Gender	1 if male; 0 if female
AFRAM	African American Race/Ethnicity	1 if African American; 0 else
NATVAMER	Native American Race/Ethnicity	1 if Native American; 0 else
HISP	Hispanic Race/Ethnicity	1 if Hispanic; 0 else
ASIAN	Asian/Pacific Islander Race/Ethnicity	1 if Asian/P.I.; 0 else
CAUCASIAN	Caucasian Race/Ethnicity	1 if Caucasian; 0 else
OTHER	Other/Unknown Race/Ethnicity	1 if Other/Unknown; 0 else
R_FIRSTGEN	First Generation Status	1 if either Parent Education < no 4-yr degree received; 0 if > 4-yr degree or higher
R_LOWINC	Low Income Status	1 if Parental Income < 30K; 0 otherwise
cuhsgpa	High School GPA	GPA score (0.0-4.0)
sat1verb	SAT Verbal	SAT Verbal score
sat1math	SAT Math	SAT Math score
sat1writ	SAT Writing	SAT Writing score
FROSH	Freshman Class Status	1 if freshmen; 0 else
SOPH	Sophomore Class Status	1 if sophomore; 0 else
JR	Junior Class Status	1 if junior; 0 else
SR	Senior Class Status	1 if senior; 0 else
ONCAMPUS	On Campus Living	1 if living in residence halls or university owned apartments; 0 if otherwise
CHASS	College of Humanities Arts and Social Sciences (includes School of Business)	1 if CHASS/SOB; 0 else
CNAS	College of Natural and Agricultural Sciences	1 if CNAS; 0 else
BCOE	Bourns College of Engineering	1 if BCOE; 0 else
LC	Learning Community	1 if participated in a living learning community; 0 otherwise

Appendix 3: Flipped classroom descriptive statistics.

Flipped Classroom Population	N*	Mean		Standard Deviation
	Statistic	Statistic	Standard Error	Statistic
R_GRADE (Course Grade GPA)	452	2.9231	.04308	.91792
WOMEN[a]	452	.5531	.02341	.49772
MEN[a]	452	.4469	.02341	.49772
AFRAM[a]	452	.0509	.01035	.22001
NATVAMER[a]	452	.0133	.00539	.11457
HISP[a]	452	.3031	.02164	.46011
ASIAN[a]	452	.4978	.02354	.50055
CAUCASIAN[a]	452	.1128	.01490	.31674
OTHER[a]	452	.0000	.00000	.00000
R_FIRSTGEN[a]	452	.4978	.02354	.50055
R_LOWINC[a]	452	.3960	.02303	.48961
cuhsgpa	452	3.706173	.0201362	.4281023
sat1verb	452	505.09	7.339	156.021
sat1math	452	554.40	7.951	169.040
sat1writ	452	512.74	7.409	157.515
FROSH[a]	452	.7588	.02014	.42826
SOPH[a]	452	.2146	.01933	.41100
JR[a]	452	.0133	.00539	.11457
SR[a]	452	.0133	.00539	.11457
ONCAMPUS[a]	452	.5973	.02309	.49098
CHASS	452	.0951	.01382	.29372
SOBA[a]	452	.0000	.00000	.00000
CNAS[a]	452	.8319	.01761	.37441
BCOE[a]	452	.0730	.01225	.26044
LC[a]	452	.3673	.02270	.48259
Valid N (listwise)	452			

*N = number of students in the flipped class
[a]The statistic for these variables is given as a fraction of the total student population (e.g., women comprised 55.31% of the population in the flipped classroom course).

Appendix 4: Non-flipped classroom descriptive statistics.

Traditional Lecture Population	N*	Mean		Standard Deviation
	Statistic	Statistic	Standard Error	Statistic
R_GRADE (Course Grade GPA)	294	2.8017	.05199	.89296
WOMEN[a]	294	.4830	.02919	.50056
MEN[a]	294	.5170	.02919	.50056
AFRAM[a]	294	.0442	.01201	.20593
NATVAMER[a]	294	.0000	.00000	.00000
HISP[a]	294	.2585	.02558	.43856
ASIAN[a]	294	.5476	.02908	.49858
CAUCASIAN[a]	294	.1327	.01982	.33978
OTHER[a]	294	.0000	.00000	.00000
R_FIRSTGEN[a]	294	.4830	.02919	.50056
R_LOWINC[a]	294	.3571	.02799	.47997
cuhsgpa	294	3.630510	.0354519	.6078739
sat1verb	294	522.72	8.215	140.851
sat1math	294	576.50	9.011	154.512
sat1writ	294	534.18	8.413	144.257
FROSH[a]	294	.7415	.02558	.43856
SOPH[a]	294	.2109	.02383	.40863
JR[a]	294	.0340	.01059	.18157
SR[a]	294	.0136	.00677	.11604
ONCAMPUS[a]	294	.6361	.02811	.48195
CHASS	294	.0680	.01471	.25222
SOBA[a]	294	.0000	.00000	.00000
CNAS[a]	294	.8333	.02177	.37331
BCOE[a]	294	.0986	.01742	.29869
LC[a]	294	.4694	.02916	.49991
Valid N (listwise)	294			

*N = number of students in the non-flipped class

[a]The statistic for these variables is given as a fraction of the total student population (e.g., women comprised 48.30% of the population in the non-flipped classroom course)

Appendix 5: Flipped classroom vs. non-flipped classroom; W/D/F course grade rates and Analysis of Variance (ANOVA).

Course Grade Distribution		
	Flipped Classroom Population	**Non-flipped Classroom Population**
A-C Course Grades	94.7% (N=430)	95.6% (N=282)
W/D/F Course Grades	5.3% (N=24)	4.4% (N=13)

Descriptives

Failure Course Grades (D/F)

	N*	**Mean**	**Standard Deviation**	**Standard Error**	**95% Confidence Interval for Mean**		**Minimum**	**Maximum**
					Lower Bound	**Upper Bound**		
Flipped Classroom	24	.5750	.59728	.12192	.3228	.8272	.00	1.30
Non-flipped Classroom	13	.4846	.55052	.15269	.1519	.8173	.00	1.30
Total	37	.5432	.57520	.09456	.3515	.7350	.00	1.30

ANOVA

Failure Course Grades (D/F)

	Sum of Squares	**df***	**Mean Square**	**F***	**Significance**
Between Groups	.069	1	.069	.204	.655
Within Groups	11.842	35	.338		
Total	11.911	36			

*N = number of students in each category; df = degrees of freedom; F = test statistic (ratio of two mean square values)

Appendix 6: Flipped classroom vs. non-flipped classroom; impact on final exam scores.*

Model	Unstandardized Coefficients		Standardized Coefficients	t*	Significance	Correlations			Collinearity Statistics	
	B*	**Standard Error**	**Beta***			**Zero-order**	**Partial**	**Part**	**Tolerance**	**VIF***
(Constant)	289.493	21.375		13.544	.000					
Flipped Classroom	**-6.292**	**4.196**	**-.065**	**-1.499**	**.134**	-.039	-.067	-.064	.957	1.045
MEN	8.683	4.285	.091	2.027	.043	.104	.090	.086	.899	1.112
AFRAM	-33.899	17.372	-.143	-1.951	.052	-.110	-.087	-.083	.337	2.965
NATVAMER	-23.430	25.324	-.048	-.925	.355	-.036	-.041	-.039	.675	1.480
HISP	-19.625	14.942	-.172	-1.313	.190	-.104	-.058	-.056	.106	9.400
ASIAN	-8.244	14.687	-.085	-.561	.575	.123	-.025	-.024	.078	12.748
CAUCASIAN	-10.432	15.550	-.071	-.671	.503	.012	-.030	-.029	.165	6.075
ALIEN	20.766	13.701	.068	1.516	.130	.053	.067	.065	.901	1.109
R_FIRSTGEN	-12.662	4.746	-.133	-2.668	.008	-.151	-.118	-.114	.732	1.366
R_LOWINC	3.900	4.859	.039	.803	.422	-.026	.036	.034	.761	1.314
sat1verb	-.026	.036	-.087	-.726	.468	.044	-.032	-.031	.125	7.982
sat1math	.028	.030	.102	.946	.345	.077	.042	.040	.155	6.450
sat1writ	.012	.037	.042	.332	.740	.060	.015	.014	.111	8.980
SOPH	18.838	9.106	.091	2.069	.039	.081	.092	.088	.944	1.059
JR	6.274	23.618	.013	.266	.791	.010	.012	.011	.777	1.288
ONCAMPUS	-5.289	4.833	-.050	-1.094	.274	-.012	-.049	-.047	.876	1.142
CHASS	1.782	10.778	.007	.165	.869	-.007	.007	.007	.916	1.092
BCOE	-10.661	15.984	-.029	-.667	.505	-.029	-.030	-.028	.949	1.053
LC	10.032	4.305	.105	2.330	.020	.086	.103	.099	.894	1.119

* Dependent Variable: R_GRADE = Final Exam Scores; B and Beta = regression coefficients; t = test statistic (regression coefficient/standard error); VIF = variance inflation factor

Appendix 7: Flipped classroom vs. non-flipped classroom; impact on course grade/GPA*

Model	Unstandardized Coefficients		Standardized Coefficients	t*	Significance	Correlations			Collinearity Statistics	
	B*	**Standard Error**	**Beta***			**Zero-order**	**Partial**	**Part**	**Tolerance**	**VIF***
(Constant)	1.163	.412		2.822	.005					
Flipped Classroom	**.179**	**.064**	**.098**	**2.795**	**.005**	.073	.103	.095	.954	1.048
MEN	.038	.066	.021	.580	.562	.039	.022	.020	.876	1.142
AFRAM	-.085	.262	-.020	-.325	.745	-.034	-.012	-.011	.299	3.345
NATVAMER	-.188	.409	-.019	-.460	.646	-.012	-.017	-.016	.705	1.419
HISP	-.210	.229	-.105	-.918	.359	-.206	-.034	-.031	.088	11.336
ASIAN	.152	.225	.085	.677	.499	.214	.025	.023	.074	13.428
CAUCASIAN	-.014	.238	-.005	-.058	.954	-.016	-.002	-.002	.157	6.376
ALIEN	.053	.186	.010	.287	.774	-.014	.011	.010	.951	1.052
R_FIRSTGEN	-.172	.073	-.096	-2.370	.018	-.172	-.088	-.081	.715	1.399
R_LOWINC	-.057	.073	-.031	-.782	.435	-.114	-.029	-.027	.750	1.334
Cuhsgpa	.421	.074	.238	5.719	.000	.147	.208	.195	.675	1.482
sat1verb	.000	.001	-.027	-.292	.770	.020	-.011	-.010	.138	7.262
sat1math	.001	.000	.143	1.735	.083	.066	.064	.059	.172	5.799
sat1writ	-.001	.001	-.159	-1.648	.100	.018	-.061	-.056	.124	8.043
SOPH	.090	.090	.041	.995	.320	-.098	.037	.034	.686	1.458
JR	1.080	.244	.174	4.434	.000	.057	.163	.151	.755	1.324
SR	.720	.306	.092	2.357	.019	-.011	.087	.080	.760	1.315
ONCAMPUS	.058	.070	.031	.824	.410	.119	.031	.028	.813	1.230
CHASS	.030	.127	.009	.235	.814	-.038	.009	.008	.758	1.319
BCOE	-.186	.131	-.057	-1.423	.155	-.037	-.053	-.049	.720	1.390
LC	.350	.071	.192	4.901	.000	.194	.179	.167	.762	1.312

* Dependent Variable: R_GRADE = Overall course grade/GPA; B and Beta = regression coefficients; t = test statistic (regression coefficient/standard error); VIF = variance inflation factor

Appendix 8: Model summary for the multiple regression of overall course grade/GPA (flipped classroom vs. non-flipped classroom course).[a,b]

Model	R*	R Square	Adjusted R Square	Standard Error of the Estimate	R Square Change	F* Change	df1*	df2*	Significance F Change
1	0.396[a]	0.157	0.133	0.83734	0.157	6.421	21	724	0.000

a. Predictors: (Constant), LC, NATVAMER, ALIEN, R_FIRSTGEN, AFRAM, SR, GROUPS, MEN, JR, CAUCASIAN, sat1verb, ONCAMPUS, CHASS, BCOE, HISP, R_LOWINC, SOPH, cuhsgpa, sat1math, sat1writ, ASIAN

b. Dependent Variable: R_GRADE = overall course grade/GPA

*R = correlation factor; R Square = goodness of fit; F = test statistic (ratio of two mean square values); df = degrees of freedom