Implementation of a Flipped Active-Learning Approach in a Community College General Biology Course Improves Student Performance in Subsequent Biology Courses and Increases Graduation Rate

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ABSTRACT

Active learning has been shown to improve student learning and engagement in many 4-year institutions; however, large-scale studies on the efficacy of active learning in community colleges are lacking. In this study, we investigate the effects of active learning in a first semester majors' general biology course at a large, suburban community college by designing and implementing a flipped active-learning model in the course. Our study included 33 sections of general biology class, 16 instructors, and ~800 students. Students in active-learning sections performed significantly higher on common exam questions than their peers in traditional sections with primarily didactic pedagogy. Although students from the active-learning sections had similar pass rates and grade distributions, they passed subsequent biology courses with significantly higher grades. The 3-year graduation rate for students from active-learning sections was also significantly higher. These findings suggest that a flipped active-learning pedagogy is more effective than traditional didactic methods for teaching general biology concepts and that the improvement in student learning may lead to higher graduation rates.

INTRODUCTION

As a student-centered, inductive instructional method, active learning requires students to construct their own knowledge by engaging them through higher-order thinking activities, cooperative learning, or problem-solving exercises. This pedagogical approach of placing students at the center of their learning process has resulted in many positive education outcomes across multiple disciplines (Bonwell and Eison, 1991; Towns and Grant, 1997; Peckham *et al.*, 2007; Cherney, 2008; Minhas *et al.*, 2012; Graham *et al.*, 2013). Indeed, a recent review of 28 articles about active learning found improvements in academic performance, critical thinking as well as problem-solving skills, mastery of course content, student satisfaction, college persistence, and degree completion (O'Flaherty and Phillips, 2015).

Previous research has also shown that these observed impacts are particularly prominent for students in science, technology, engineering, and mathematics (STEM) fields (McClanahan and McClanahan, 2002; Freeman *et al.*, 2014a; Linton, 2020). For example, introducing active learning into science courses not only increases student performance and engagement, but also leads to deeper knowledge and understanding of the material (Knight and Wood, 2005; Romero, 2009; Jensen and Lawson, 2011; Connell *et al.*, 2016; Styers *et al.*, 2018; Wilton *et al.*, 2019). In addition, active learning increases student interest in the subject matter (Brickner and Etter, 2008) and gives students a greater sense of confidence in learning science (Graham *et al.*, 2013).

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In an extensive meta-analysis that compared active learning with traditional lecture methods, the average failure rate decreased from 34% with traditional lecture to 22% with active learning, while performance on comparable tests and on concept inventories increased significantly (Freeman *et al.*, 2014a). As a matter of fact, it has been generally accepted for decades that science courses must include a hands-on laboratory component to effectively teach students how to learn science. However, the lecture portion of most science courses continues to rely heavily on passive didactic instruction (Bauerle, 2011), which has been shown to be ineffective in fostering long-term learning (Hake, 1998; Wood, 2009).

According to a report published by the American Association of Community Colleges, ~41% of the nation's undergraduate students were enrolled in community colleges in Fall of 2018. Among those students, 29% were first-generation students, 20% were students with disabilities, and 49% were races other than white (AACC, 2020). Although almost half of all undergraduates are attending community colleges, the great majority of studies on the effects of active learning in postsecondary education have been done at 4-year institutions. In fact, a recent analysis of biology education research showed that only 3% of articles were associated with community college students or faculty (Schinske *et al.*, 2017). Therefore, it is unclear how active learning impacts the academic outcomes and performance of community college students. Findings from several studies suggest that active-learning methods may have an even greater benefit for students with disadvantaged educational backgrounds (Haak *et al.*, 2011; Eddy and Hogan, 2014; Gavassa *et al.*, 2019), which are common in community college students (AACC, 2020). It is reasonable to hypothesize that there may exist a positive correlation between engagement in active learning and academic performance among community college students, particularly those beginning in STEM fields of study. Indeed, a recent study done by Wang and colleagues showed that active learning in 2-year colleges has a direct and positive effect on student transfer intent into STEM fields in 4-year institutions. This effect is largely due to increased transfer self-efficacy (Wang *et al.*, 2017).

Front Range Community College (FRCC) is a large community college that has traditionally had low pass rates (~66%) in our majors' general biology course (BIO111). We therefore set out to improve student learning by designing and implementing an active-learning model in the course. The model of active learning used in this study is often referred to as the flipped-classroom model. In a flipped classroom, students have their first interaction with the content before class in a way designed to replace traditional lecture. Classroom time is then used to give students more in-depth, individualized exposure to the material (Abeysekera and Dawson, 2014).

This study is the first large-scale study at a community college that describes the impact of implementing active learning in a first-year science course on academic achievement, performance in future courses, and subsequent graduation rate. The research was conducted over two semesters and included nearly 800 community college students and 16 community college instructors. Student success was measured using a variety of parameters, including performance on common exam questions, course pass rates, grades in subsequent biology courses, and 3-year graduation rate.

METHODS

Background and Participants

This research was approved by the FRCC Institutional Review Board.

FRCC serves ~30,000 students annually, of which 74% are part-time. The course studied is a 5 credit-hour General Biology I with Lab for science majors (BIO111). This is a high-enrollment required course for biology and health profession majors. Because there is no prerequisite for this course, most students take it during the first semester in college. The pass rate for this course is ~66%. Students in 33 sections of BIO111 participated in this study. Each section contained approximately 24 (mean ± SD = 23 ± 2) students, for a total of 794 students. Two students from the flipped sections who received an incomplete grade were excluded from the data analysis. Four students, two from flipped sections and two from non-flipped sections, were excluded because of administrative withdrawals. This left 378 students in the flipped sections and 410 students in the non-flipped sections. To mitigate self-selection bias, each student enrolled into a section without knowing which teaching methodology would be used. The study took place over two 15-week semesters (Fall 2013 and Spring 2014). Classes met for 6 hours each week, with approximately two of the hours dedicated to lab.

A single instructor taught each section (i.e., there was no teaching assistant or coteaching), with a total of 16 participating instructors. Six instructors taught exclusively flipped sections, nine taught exclusively non-flipped sections, and one instructor taught one of each. Two of the authors (A.R., T.B.) taught in the flipped format, while one (F.Y.) taught in the non-flipped format. Sixteen of the sections were taught in the flipped active-learning format, and 17 of the sections served as a control.

Recruitment of Instructors

Instructors with various backgrounds were recruited for the study. Most often two sections were offered at the same time; where scheduling allowed, one was taught in the flipped format and one in the non-flipped format. After instructors were assigned to sections based on their availability, one instructor from each time slot was asked to teach in the flipped format. All seven of the instructors who were asked agreed to teach in the flipped format. The rest of the instructors were then assigned to the non-flipped control group. The non-flipped instructors were aware that they were in the control group, but they were asked to teach their courses as normal, except for adding five common exam questions per chapter to their unit exams and incorporating 50 common questions onto their comprehensive final exams. Pass rates of both groups of instructors before the study were very similar, and they also had similar average years of teaching experience at FRCC (Supplemental Table S1). The similar prior experience and pass rates between flipped and non-flipped instructors should have minimized teaching qualification differences between the two groups.

Research Design

Data from the first semester (16 sections, Fall 2013) were combined with data from the second semester (17 sections, Spring 2014). Student performance in the flipped experimental sections ($n = 378$) was compared with student performance in the non-flipped sections ($n = 410$).

A quasi-experimental nonequivalent groups design was used. We compared outcomes from 33 small (24 student) sections of the same course, 16 of which were taught using active-learning methods, while the other 17 were taught using more traditional didactic instruction. The two groups were treated as similarly as possible.

The same textbook, curriculum, classrooms, and laboratory materials were used in all sections.

To control for time-of-day effects, most flipped and non-flipped sections ran concurrently.

Format of Flipped Sections. The seven instructors who taught the flipped active-learning sections worked closely together to design the course and shared materials so that the flipped sections could be taught in a highly standardized format. Funds from a small internal grant were used to pay instructors for development of course materials. A typical flipped classroom involved three components: pre work, a daily quiz, and in-class activities. Examples of each component are included in the Supplemental Material (Supplemental Figure S2 and Appendix A).

One important component of our design was that students were required to complete a significant amount of work on their own before attending class. Increased preclass preparation has been postulated to be responsible for at least some of the student outcome improvement in flipped classrooms (Gross *et al.*, 2015). We therefore required students to complete an interactive-learning module and an online homework assignment before attending each class. We designed online interactive modules using SoftChalk software (SoftChalk LLC, Richmond, VA), because many students struggle with reading and understanding science textbooks (Berry *et al.*, 2010). Each SoftChalk module covers the equivalent of one-half to one chapter in the textbook and includes short readings, brief videos, interactive quiz questions, and embedded learning activities. Vocabulary words are hyperlinked to definitions so students can read with less interruption. We chose to design SoftChalk modules rather than record lectures, because their interactive nature allows students to actively apply newly learned material in various engaging activities, which is more difficult with video lectures. Students were encouraged (but not required) to fill out a study guide consisting of vocabulary words and a series of short-answer questions as they completed each module. SoftChalk modules were collectively worth 10% of the course grade. Out of 28 modules, the lowest three scores were dropped.

Homework assignments were created using the textbook publisher website MasteringBiology, which is a Pearson Education product packaged with the prescribed textbook (Freeman *et al.*, 2014b). In the Fall semester, students earned points only for the online homework assignments, while in the Spring, they also earned points for the SoftChalk modules. In both semesters, the preparatory work accounted for 10% of the final grade to motivate students to complete work before class.

In class, students sat at tables in groups of four. Each week, students were randomly rearranged into different groups. At the beginning of each class, students were given two multiple-choice quizzes with material from the preclass preparation assignments. The first five questions were answered individually. The second five questions were discussed and answered as a group. Only one answer was accepted from each group. The group quiz was only worth 1 extra-credit point if all answers were correct. In total, the reading quizzes were worth 10% of the final grade, plus up to 2% of extra credit. Out of 28 quizzes, the lowest three scores were dropped.

After the quiz, the instructor went over the answers and answered questions about the pre work. The quiz plus going over the answers took an average of 20 minutes. Class time was then devoted to giving students opportunities to interact with the material at a deeper level and to practice difficult concepts. Class activities included worksheets with practice problems and case studies, model building, card sorts, games, group discussions, and acting out concepts. Whenever possible, students were asked to draw, describe, or construct models to build their own representation of a concept. Activities were done in groups of two to four students, while the instructors circulated among the groups, assisting them, challenging them, and answering questions. An example of a typical 110-minute class period, along with examples of activities, is provided in the Supplemental Material (Supplemental Figure S1 and Appendix A). The in-class activities were not worth points toward student grades.

The pre work, in-class activities, and quiz questions in the flipped sections were not specifically designed to mirror the common exam questions used to compare learning between flipped and non-flipped classes. Examples of reading quizzes and common exam questions from a typical chapter are provided in Supplemental Figure S2 for comparison.

The course was divided into five units, each consisting of 2½ weeks of material, covering two to three chapters in the textbook. At the end of each unit, an exam was given. Each exam included five common multiple-choice questions per chapter (10 to 15 questions per exam), which were worth an average of 25% of the total exam score. The rest of the exam consisted of a variety of question types, including but not limited to short-answer questions and process- or pathway-based essay questions.

Format of Non-flipped Sections. No attempt was made to standardize instruction in the 17 non-flipped (control) sections. The 10 instructors teaching these sections were aware that they were teaching control sections for the study, but they were not told exactly what the study was measuring. They were simply told to teach as they normally would. Some of the instructors from the non-flipped sections used a lecture-only format, most used an interactive lecture format, and a few used lectures interspersed with an occasional activity. However, in all cases, the predominant method of instruction was lecture using PowerPoint slides. Before the study, the teaching style of all instructors from flipped and non-flipped sections was very similar to that described for the non-flipped (control). Instructors from the non-flipped sections asked students to read the textbook before coming to class and assigned Mastering Biology homework after class. The lead author of the paper (A.R.) observed several classes during the study and informally interviewed the instructors. There is no evidence that any of the non-flipped instructors changed their teaching style during the study.

Assessment. Students from all flipped and non-flipped sections were assessed by common multiple-choice exam questions. Five questions per chapter were included on unit exams given during the semester. Fifty common multiple-choice questions, composed of three to four questions per chapter, were included on a comprehensive final exam. Scores of common unit exam and final exam questions were calculated as percent correct. All common unit exam and final exam questions were designed to assess low- to midlevel cognitive skills (Bloom's levels 1–3) such as recall, interpretation, and application (Bloom, 1956). Common exam questions were written by the lead author of the study (A.R.). However, all instructors, from flipped and non-flipped sections, received the common exam questions before test days and were given the opportunity for comments and revisions. For example, if any instructor did not cover a particular topic in his or her class, an exam question on that topic was replaced with another question. Examples of the common exam questions and the common comprehensive final exam questions are included in the Supplemental Material (Supplemental Figure S2 and Appendix B).

Because many instructors in the non-flipped sections divided the chapters differently onto their exams, we wrote only five common multiple-choice questions per chapter, for a total of 75 common multiple-choice questions across the semester. These were given to the instructors so they could put them onto their appropriate exams and report the scores by chapter. Thus, a typical unit exam would contain only 15 to 20 of these questions, which amounted to an average of 25% of the points on each unit exam. The remainder of the exam questions on any given instructor's exam were not included in the study. Similarly, the 50 common final exam questions were integrated into the final exams by each instructor. The common final exam questions were worth 100% of the final exam grade in most sections. However, a few non-flipped instructors chose to make them worth slightly less than 100% by adding a few of their own questions to the final exam. In these cases, the additional questions were not scored for this study. Examples of the common exam questions are included in Supplemental Figure S2.

The same exam questions were used for the Fall and Spring semesters. The exams were administered in a proctored classroom and the questions were not returned to students, so the likelihood of the questions being shared was minimal.

Data Analysis

Test performance data were analyzed with a factorial analysis of variance, with the factors of type of instruction, exam, and semester using Statistica (v. 6.0, Statsoft, Tulsa, OK).

Final grades of students who completed the course were obtained from the college registrar and final grade distribution was compared between flipped and non-flipped courses. Grades were defined as "A", "B", "C", "D", "F", or "W" (student withdrawal). Students with a grade of "C" or better were defined as "passing," as a "C" or better is required for students to go on to higher-level biology courses. Students with grades of "D", "F", or "W" were combined and defined as non-passing.

Students from the study who were defined as passing and who took a subsequent biology course at FRCC in the following three semesters were assessed. The subsequent courses offered at our college that had General Biology I (BIO111) as a prerequisite include General Biology II (BIO112), Microbiology (BIO204), and Anatomy and Physiology I (BIO201). Subsequent biology courses were primarily taught in a traditional format, similar to the control group. Pass rates and grade distribution in these subsequent courses were obtained from the college registrar.

Graduation rate for students who participated in flipped and non-flipped sections were also examined for the 5 years following the academic year of the study. Graduation rates were provided by the college registrar.

Statistical significance for percent pass rates, grade distribution, graduation rate, prior instructor experience, and demographic distribution was determined using a p value calculator to calculate the z-score and p value to determine whether the difference between two proportions is statistically significant using absolute differences (Georgiev, 2017). All p values less than 0.05 were considered significant.

RESULTS

Demographic Data

This study took place at a suburban community college serving ~30,000 students annually. Table 1 shows the self-reported demographics of students from flipped and non-flipped sections. The majority of students in the study, 63%, were first-generation students. The percent of first-generation students was not significantly different between the two groups ($p = 0.1912$; Supplemental Table S4). Thirty-nine percent of students in the study belong to a minority race, including 23% Hispanic. The distribution of students by race in flipped and non-flipped sections was not significantly different (Supplemental Table S3).

Pass Rates and Exam Performance

Nearly 800 students from 33 sections of General Biology I (BIO111) over two semesters were taught using either active-learning methods (flipped) or more traditional didactic instruction (non-flipped). Students did not know which teaching methodology would be used before enrolling in a section. Student performance was assessed by percent correct on common multiple-choice exam questions on unit exams and on common final exam questions. Data from the two semesters were combined.

The overall pass rates for flipped and non-flipped sections were not significantly different: 63.5% of students from flipped sections passed the course with an "A", "B", or "C" grade, compared with 60.2% of students from non-flipped sections ($p = 0.170$; Supplemental Table S2). Pass rates for first-generation students were also similar: 59% of students from flipped sections passed the course, compared with 57% of students from non-flipped sections ($p = 0.2846$; Supplemental Table S4). Pass

TABLE 1. Self-reported student demographics[a]

	Flipped (percent of total) $n = 379$	Non-flipped (percent of total) $n = 412$
First-generation students	245 (65%)	256 (62%)
Race		
Hispanic	84 (22%)	98 (24%)
White	219 (58%)	242 (59%)
Asian	22 (6%)	22 (5%)
Black	10 (3%)	9 (2%)
Other/unknown	54 (14%)	50 (12%)

[a]There is not a significant difference in the percent of first-generation students between the two groups ($p = 0.1912$). There is also no significant difference in distribution by race between the two groups. For more detailed distributions and the p values for each race, please refer to Supplemental Table S3.

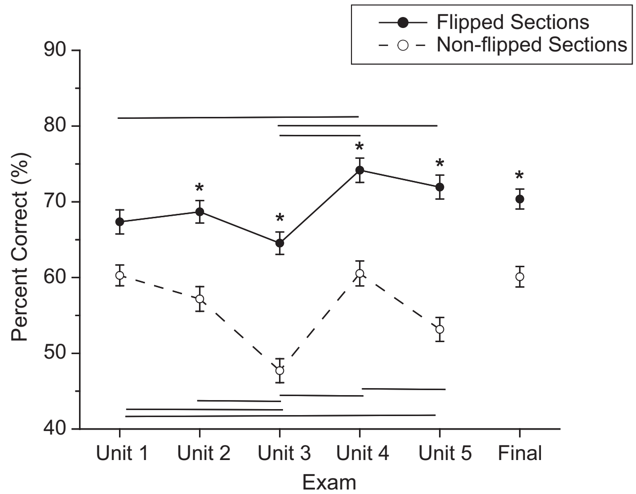

FIGURE 1. **Percent correct on common exam questions. Data are presented as combined semester student performance. Plotted area mean ± SEM scores. An asterisk (*) indicates significant effects between flipped and non-flipped sections ($p < 0.05$). The comprehensive final exam scores have been added to this graph to emphasize the trend in student performance. Thicker lines above the plot represent significant effects between unit scores for the flipped sections at either end of the line ($p < 0.05$). Thicker lines below the plot represent significant effects between unit scores for the non-flipped sections at either end of the line (P < 0.05). Flipped $n = 378$; non-flipped $n = 410$.**

rates for Hispanic students—our largest non-white demographic—were also not significantly different: 52% of Hispanic students from flipped sections passed the course, compared with 47% of Hispanic students from non-flipped sections ($p = 0.0804$; Supplemental Table S5).

Instructors from flipped and non-flipped groups had taught for a similar number of semesters at FRCC before the study. Instructors from non-flipped sections had taught an average of 10.8 sections of BIO111 before the study, while instructors from flipped sections had taught an average of 9.5 sections (Supplemental Table S1). In addition, pass rates for flipped and non-flipped instructors were not significantly different from each other before the study. Non-flipped instructors had a 65% pass rate, while flipped instructors had a 68% pass rate ($p = 0.2421$; Supplemental Table S1). This suggests that instructor ability or previous experience may not be influential factors in the outcomes of our study.

Although the pass rates were similar, students from flipped sections scored significantly higher on the five common exam questions per chapter for units 2 through 5 and on the 50 common comprehensive final exam questions (Figure 1). The performance gap widened as the semester progressed from a non-significant 6.1 percentage point differential on unit 1 to a nearly 20 percentage point differential on unit 4 and a 17 percentage-point differential on unit 5. The performance of non-flipped students decreased by 12% between unit 1 and unit 5. Conversely, the performance of flipped students increased by 5% between unit 1 and unit 5. Both groups showed a decrease in performance on unit 3. This unit introduced cellular respiration and photosynthesis, which are typically judged by students to be the hardest topics. Interestingly, the decrease in performance on unit 3 was relatively smaller for the flipped active-learning group (4%) versus the non-flipped group (21%). Significant main effects for teaching method, $F(1, 468) = 176.39$, $p = 0.0000$, and for unit, $F(4, 468) = 13.55$, $p = 0.00000$, were observed for performance on unit exam common questions. Significant interaction effects between section and unit were also observed, $F(4, 468) = 5.53$, $p = 0.00023$.

Furthermore, performance on the common comprehensive final exam questions was significantly higher for the flipped sections compared with non-flipped sections, $F(1, 31) = 23.748$, $p = 0.00003$. On the common final exam questions, students from flipped sections averaged 35.2 correct out of 50 (70.4%), while students from non-flipped sections averaged 30.1 correct out of 50 (60.2%).

Together, these results demonstrate that the flipped active-learning format significantly improved student performance on common exam questions in BIO111.

Grade distribution between flipped and non-flipped sections was also very similar (Figure 2). Even though students from flipped sections performed better on common unit exam questions and on the common comprehensive final exam questions, pass rates were not significantly higher for these students, as described earlier. This is probably because there were only five common unit exam questions per chapter, while the rest of each exam was written by the instructor for that section.

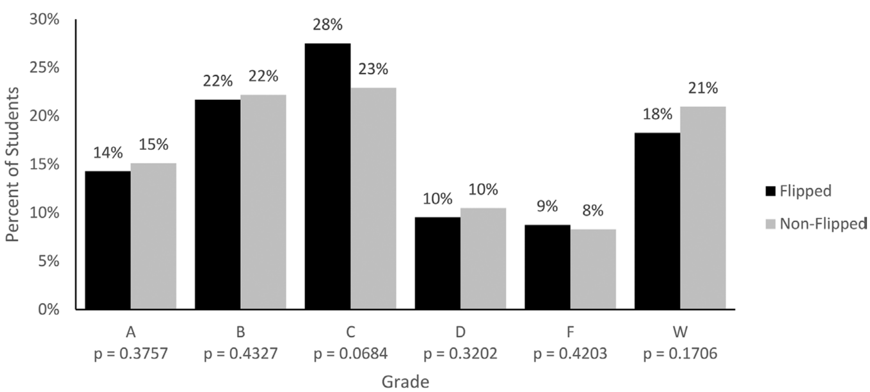

FIGURE 2. **Grade distribution in BIO111. Data are presented as combined semester student performance. No significance difference was observed for any grade. Flipped $n = 378$; non-flipped $n = 410$.**

Performance in Subsequent Biology Classes

To assess whether the improvements observed in the flipped active-learning classrooms are transferable to other biology classes, the pass rates and grades earned in three subsequent biology courses: BIO112–General College Biology II, BIO201–Human Anatomy and Physiology I, and BIO204–Microbiology, were tracked over the next three semesters. Table 2 shows that the percent of students from each group who went on

TABLE 2. Percent of students who advanced to higher-level biology courses[a]

Subsequent course	Number of students from flipped sections ($n = 379$)	Number of students from non-flipped sections ($n = 412$)	p value
BIO112–General Biology II	44 (12%)	36 (9%)	0.0840
BIO20–Anatomy and Physiology I	105 (28%)	107 (26%)	0.263
BIO204–Microbiology	37 (10%)	51 (12%)	0.185
Total students who advanced	186 (49%)	194 (47%)	0.287

[a]Data are presented as combined semester student performance. No significance difference was observed in the percent of students going into each of the higher-level biology courses. Flipped $n = 378$; non-flipped $n = 410$.

to higher-level biology courses was not significantly different, and the percent of students who went on to each specific course from each group was also not significantly different. In addition, pass rates in these three courses were not significantly different (Figure 3).

However, students who had taken a flipped section had significantly higher rates of earning an "A" in BIO112 and BIO201 when compared with students from non-flipped sections (Figure 4). Because approximately the same percent of students went into each subsequent course and their grade distributions are similar, it is unlikely that the higher "A" rate is a result of different populations of students advancing from each group. Indeed, 136 students out of 378 (36%) from flipped sections achieved "A" or "B" grades in BIO111, while 186 students advanced. Similarly, 153 students out of 410 (37%) from non-flipped sections achieved "A" or "B" grades in BIO111, while 194 students advanced. Therefore, some "C" students from each group must have proceeded on to the subsequent courses. The similarity of grade distribution in BIO111, along with the similar number of students going on to subsequent courses, is strongly suggestive that the higher percentage of students earning an "A" is not attributable to different student populations in the subsequent courses.

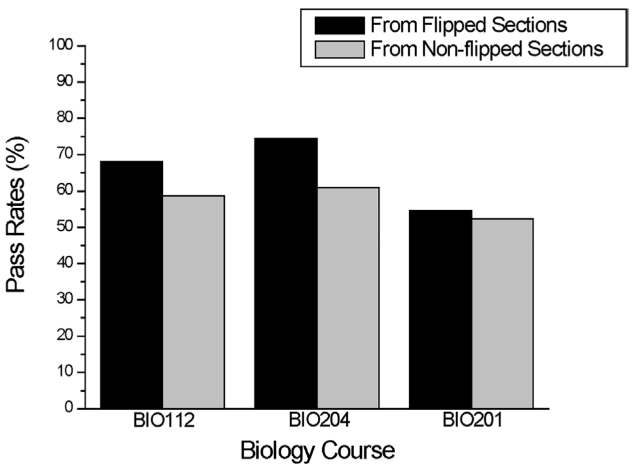

FIGURE 3. Percentage pass rates in subsequent biology courses for students. Pass rates are defined as students earning a letter grade of "C" or better. There was no significant difference between flipped and non-flipped sections, although BIO112 approaches significance. Data are presented as combined semester student performance. BIO112: flipped $n = 74$, non-flipped $n = 54$, $p = 0.0511$; BIO204: flipped $n = 66$, non-flipped $n = 84$, $p = 0.0822$; BIO201: flipped $n = 164$, non-flipped $n = 161$, $p = 0.2028$.

Graduation Rate

To measure whether participating in one semester of active learning early in one's college career has longer-term effects on academic success, 3-year graduation rates were determined for study participants. Figure 5 shows that the 31% three-year graduation rate for students who participated in flipped sections was significantly higher than the 21% three-year graduation rate for students who participated in non-flipped sections ($p = 0.00067$). This difference persists with 4-year and 5-year graduation rates (Supplemental Table S6). The 21% three-year graduation rate for students from non-flipped sections was identical to the overall graduation rate at FRCC for the same academic year (Institutional Research, personal communication).

Interestingly, the 3-year graduation rate for students from flipped sections was significantly greater for every grade category except "F" and "W" (Supplemental Figure S3). For example, "A" students from flipped sections graduated at a 46% rate, while "A" students from non-flipped sections graduated at a 32% rate ($p = 0.000027$).

DISCUSSION

Changing General Biology I at a community college to a flipped format is correlated with improved student performance. Our results agree with previous studies from 4-year institutions that demonstrated active learning supports college student success (Freeman *et al.*, 2014a). Although research experience has been

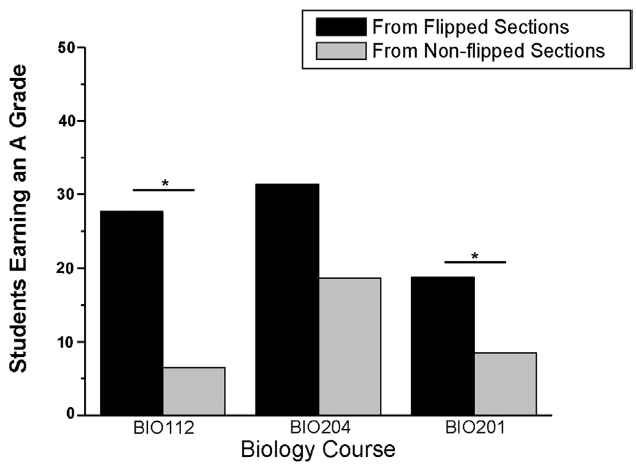

FIGURE 4. Percentage of students who earned an "A" in subsequent biology courses. An "A" letter grade is defined as a 90%. Data are presented as combined semester student performance. An asterisk (*) indicates significant effects between flipped and non-flipped sections ($p < 0.05$). n values are the same as in Figure 3.

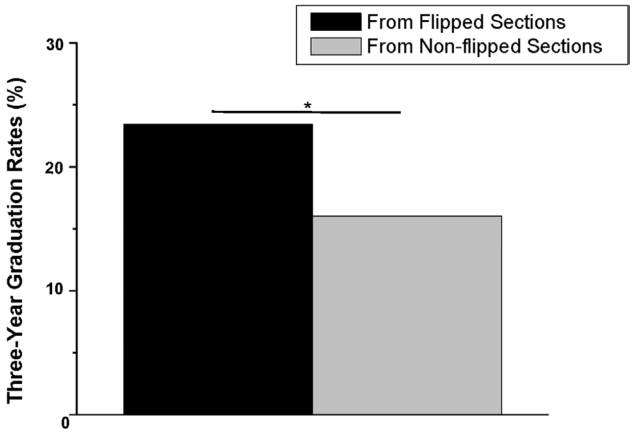

FIGURE 5. Three-year graduation rate. A higher percentage of students from flipped sections earned an associate's degree within 3 years of completing BIO111. Data are presented as combined semester student performance. An asterisk (*) indicates significant effects between flipped and non-flipped sections ($p < 0.05$). Flipped $n = 378$; non-flipped $n = 410$

shown to increase graduation rates (Rodenbusch *et al.*, 2016), a large increase in graduation rates associated with changing the format of a single course, as observed here (Figure 5), has not previously been reported. Indeed, this is the first study that has investigated the effect of active learning on performance in subsequent courses and on graduation rates at a community college.

Active Learning Improves Community College Student Success

Comparison of performance on common multiple-choice questions on each unit exam indicates that students from flipped sections made greater improvements than their peers in non-flipped sections (Figure 1). The widening gap between the two groups across the semester suggests that the active-learning format used in this study improved student mastery of the material. This is supported by the fact that students from flipped sections also did better on the common comprehensive final exam questions (Figure 1). This effect may result from the more interactive nature of the flipped format, which kept students engaged and provided them with regular formative feedback during class activities. Despite doing better on common exam questions, students from flipped sections did not pass BIO111 at a higher rate or get higher grades in BIO111. One possible reason is that the common unit exam questions accounted for only an average of 25% of each unit exam grade. It is also possible that the nonstandardized portion of each exam, which contained many short-answer and essay questions, was more difficult in the flipped sections.

Because most students take General Biology I in their first or second semesters at our institution, our results suggest that participating in one semester of active learning early in students' college careers is correlated with a persistent positive effect on student learning. Students from our flipped sections earned significantly more "A's" in higher-level biology courses when compared with students from non-flipped sections, even though these courses were predominantly taught in a traditional format (Figure 4). Studies have shown that separate learning strategy courses can increase graduation rates of students who take them (Tuckman and Kennedy, 2011). Indeed, we observed a significant increase in the 3-year graduation rate of students who took the course with the flipped format (Figure 5). The increased success in future courses and the increased graduation rate with the flipped format suggests that one of the most important functions of introductory college science classes may be to teach students transferable study skills. Active learning could be a good instrument for integrating learning strategies into a curriculum.

The observed effects from this study may be associated with multiple factors specific to the flipped classrooms. It is possible that the specific format of the flipped sections helped students understand the role they play in their learning. In the flipped format, students are expected to do a substantial amount of work before each class. Expectations were clear, and points were associated with each of the preclass assignments. All instructors from the flipped sections reported very high compliance rates. Another contributing factor may be student perception of responsibility, as the active-learning format encourages students to take responsibility for their own learning. It is also possible that the in-class activities offered students a chance to practice concepts, discover where they had problems, and ask for help as needed. These are important skills in any learning environment and may have been transferable to other courses. Finally, psychosocial outcomes such as an increased sense of belonging may contribute to persistence in college (Ballen *et al.*, 2017). Because our flipped-classroom model included a large amount of group work, it is possible that students from these sections forged stronger relationships with the instructors and/or with one another that helped them feel connected to the college. Furthermore, it is possible that the higher passing grades in subsequent courses could be due to the flipped classroom generating cohorts of students who study together.

Departmental Impact of the Study

Recruiting part-time adjunct faculty (instructors) to the study was much easier than might be expected. All the instructors who were asked to participate in teaching flipped classrooms accepted. Our institution has a history of providing professional development to instructors, and most of the instructors in the study were actively involved in various professional development activities, which may have made them more open to the opportunity. Most of our instructors hold doctoral degrees in biology, which may have made the chance to be part of a research study more appealing. Finally, our instructors are very invested in seeing their students succeed, so they were eager to improve the relatively low pass rates in BIO111. Instructors were not additionally compensated for participating in the study. However, the study was supported by a small internal grant, and two of the instructors who taught flipped sections received funds the summer before the study for developing SoftChalk modules and other materials for the flipped sections.

The faculty in our science department at the time of the study taught very traditionally, using predominantly lecture with at most a small amount of active learning. In fact, no full-time faculty participated in this study. However, in the years since the study, all 13 of the department's full-time science faculty, along with many instructors from various science disciplines, have incorporated more active learning, and some have completely flipped their classes. The vast amount of teaching resources created during the study have made it more feasible for other instructors and faculty to implement components of active learning in their classrooms. It has also become a department priority to hire new faculty who use active-learning strategies. The results observed in our study may have had a positive impact on this departmental change.

More research is needed to find ways to improve student outcomes for community college students. Graduation rates for community college students remain very low, ~25%, across the nation (AACC, 2020). Studies such as this one show that outcomes can be affected by changing the teaching method in even a single science course. It may be beneficial for other researchers to examine the impact of changing their teaching paradigms on performance in future courses and on graduation rates.

Limitations and Future Directions

Instructor Effects. Some recent studies have questioned whether confounding variables such as teacher experience and student self-selection could explain some or all of the increase in learning and positive attitude in active-learning sections. For example, Andrews *et al.* (2011) postulate that many teachers who use active-learning methods are science education researchers who have a better than average understanding of teaching and learning. They did not see learning gains in active-learning sections taught by "typical college biology instructors" (Andrews *et al.*, 2011). However, the meta-analysis published by Freeman *et al.* (2014a) did not find evidence that the differences were instructor dependent.

One limitation of this study is that we could not control completely for instructor effects. However, it is not likely that the differences in student performance on common exam questions are due entirely to instructor effects, because instructors from both groups had a similar range of teaching experience and pass rates before the study (Supplemental Table S1). Additionally, none of the instructors in our study had taught in the flipped format before the study began.

Student Effects. Similarly, we could not control for student effects, because more motivated students may have selected specific instructors (Chan and Bauer, 2015), or a cohort of students may have taken a class together. However, it is unlikely that self-selection bias was the primary basis for our results, because our students did not know which format would be used when they registered for the class. The fact that we offered a flipped and a non-flipped section at most time slots mitigates selection bias based on time of day. It is very uncommon for students at our community college to take classes as a cohort, as we are a commuter campus with mostly part-time students and our students have many time constraints on their schedules, such as jobs and family responsibilities. Anecdotally, we can report that it is very rare for students in BIO111 to know each other before taking the course. Additionally, we could not get prior college data for our students, because most of them are taking this course in their first semester and there is no prerequisite for this course. High school grade point averages were not available and would not be particularly relevant, as many of our students have been out of high school for 5 years or longer.

Multiple factors contribute to flipped-classroom effects. Because none of the instructors in the flipped sections had taught a flipped class before this study, we changed many aspects of how we taught the flipped sections. We are therefore unable to tease out the specific components of our format that are responsible for the improvements in performance, subsequent course success, and graduation rates for the students in the flipped active-learning sections. Previous studies have suggested that increased preclass preparation accounts for at least some improvement in flipped classrooms (Gross *et al.*, 2015). Additional studies have suggested that collaborative learning in the classroom accounts for improvements (Romero, 2009; Jensen *et al.*, 2015). It is possible that testing effect played a role in improving performance on common exam questions, as we gave daily reading quizzes in the flipped sections. At this point, we can only postulate that, taken as a whole, the flipped format that we used correlates with the observed improvements.

Future Directions. Further studies are needed to determine the degree to which different components of our format contribute to the observed improvements. For example, we might explore whether testing effect influenced our results by administering the same reading quiz questions to flipped and non-flipped groups.

We will also examine whether various student demographics, such as race, gender, socioeconomic status, and first-generation status, are differentially impacted by active learning. Based on self-reported demographic data from students in this study, 63% are first-generation college students and 39% belong to a minority race, including 23% Hispanic (Supplemental Tables S4 and S5). In this study, we did not see a significant difference in pass rate for these different populations between the flipped and non-flipped groups (Supplemental Tables S3–S5). However, future studies are necessary to correlate different demographic groups with various measures of student success. In addition, student input could be collected by conducting surveys about which components of the flipped section they perceive as most beneficial and whether being in flipped sections increases self-efficacy, engagement, or study skills.

One of the most useful products of this study is the large quantity of teaching resources that were generated to support active learning in introductory biology. We are willing to share these materials with any interested instructors.

As a result of this study, the lead author (A.R.) has continued to teach in the flipped format and has mentored many faculty and instructors in our department as they have incorporated active learning into their classrooms. As we seek to continue to improve student outcomes, we are currently investigating the effects of competency-based learning, peer instruction, the use of an open resource textbook, and team teaching on student success in BIO111.

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