Combined effect of different teaching strategies on student performance in a large-enrollment undergraduate health sciences course

Aditi Marwaha,1 Marjan Zakeri,2 Sujit S. Sansgiry,2 and Samina Salim1

1Department of Pharmacological and Pharmaceutical Sciences, College of Pharmacy, University of Houston, Houston, Texas and 2Department of Pharmaceutical Health Outcomes and Policy, College of Pharmacy, University of Houston, Houston, Texas

Abstract

Students’ course performance is fundamental for any institution to carry out its academic mission. Often, in-class disengagement and lack of after-class course support in large-enrollment classes trigger academic problems for students. This leads to poor exam performance and an increased rate of final letter grade of a D or F or student withdrawal (DFW), an indicator of students’ poor academic success. Changing teaching strategies by using interventions that incorporate student-student interaction and student-faculty interaction may offer the opportunity to improve course performance. In this retrospective study, we examined the effect of changing teaching strategies on student course performance of 5,553 students enrolled in an undergraduate health sciences course over a span of 20 semesters. Three different interventions namely 1) daily low-stake in-class quizzes, 2) team-based learning, and 3) after-class review sessions were incorporated as teaching strategies. To assess the combined effect of these strategies’ students’ performance in the intervention period (12 semesters) was compared with control period (8 semesters). Student performance in the course was measured by exam grades; overall score; percentage of students receiving letter grades and A, B, C; and DFW rates. The data indicated that in the intervention period, exam scores increased by 6.6%, overall course score increased by 6.2%, percentage of students receiving letter grade A/B increased by 21.3%, percentage of students receiving letter grade C decreased by 6.9%, and the DFW rates decreased by 14.5%. Overall, changing teaching strategies through incorporation of these interventions improved students’ performance in the course.

active learning; DFW rates; large enrollment; student performance; teaching strategies

INTRODUCTION

Factors that impact academic achievement, retention, and success among undergraduate students have been a topic of research and discussion for several decades. Student academic success, defined as strong course retention and degree completion rate, is fundamental to the mission of an educational institution, and high attrition is commonly considered a failure in accomplishing institutional purpose (1). An emerging approach to advancing academic success is to carefully examine student course performance and academic progression by measuring patterns by which students reach and move through intermediate stages of degree completion (2). This is critical considering the analysis conducted by Vincent Tinto (3) who suggested that, “If students do not succeed in the classroom, often one class at a time, they do not succeed in college.” Thus improving classroom practices by conducting periodic assessments, providing feedback, providing after-class course support, and promoting student-centered learning may be predictive of positive outcomes (3). Teaching strategies that incorporate these classroom practices by including active learning and providing after-class course support could improve students’ performance and lower attrition rates.

A key factor that contributes to lower academic success is poor student performance in “gateway courses,” which are described as foundational, credit-bearing, typically large-enrollment classes. They are associated with high D or F or withdrawal (DFW) rates, that is the total percentage of students who obtained a grade of D or F or who “withdrew” (W) from the course. Poor performance in such courses can adversely affect a student’s grade point average (GPA), motivation, and academic success (4). Like other foundational courses, health sciences courses are often offered in a large-enrollment class setting and are integral to students from diverse disciplines. Health sciences courses have been associated with high DFW, high attrition rates, and therefore poor academic success. (5, 6)

A large and growing body of research indicates that undergraduate students succeed in classrooms that incorporate classroom practices with emphasis on student-centered learning using active learning instructional approaches (7, 8). Active learning engages students in the process of learning through activities and/or discussion in class, as opposed to passively listening to an expert. It emphasizes higher order thinking and often involves group work (9). A variety of active learning interventions are typically used in large
classroom settings including group problem-solving activities, worksheet tasks, and live quizzes using polling devices with or without peer-aided learning. Studies show that classes that incorporate active learning exhibit significantly improved examination scores as opposed to traditional lecture-based classes (9). Furthermore, students in traditional lecture-based classes were reportedly 1.5 times more likely to fail the course compared with students enrolled in classes that incorporated active learning (9). Use of a polling system with multiple-choice clicker devices is one way to incorporate active learning in a large classroom setting (10). This technology allows student-student interaction and encourages student responsiveness and student engagement. Use of clickers and the immediate question-answer feedback followed by in-class discussion enable productive student-instructor interaction and improves student performance (11, 12).

Another technique that has been used to incorporate active learning is team-based learning (TB50), which shifts instruction from a traditional lecture to a student-centered active learning that allows students to explore concepts in greater depth and promotes critical thinking and problem-solving abilities. TB50 has been reported to improve student learning and performance in various disciplines including physiology courses, medical, and health sciences (13–15).

In addition to providing in-class student-centered learning, providing after-class course support is also important in improving student performance and needs to be aligned with student learning for the specific classes in which they are enrolled. One of the most effective models of course support is supplemental instruction (SI) (16). SI is a nontraditional form of tutoring, where some courses may provide extra-credit for attending these sessions. SI targets courses with a relatively high number (30%) of students that get a letter grade of D or F or may withdraw (17). The U.S. Department of Education has identified that students participating in SI programs earn a higher final grade, higher retention rates, and lower attrition rates compared with those students who do not attend SI sessions (18).

Several studies have demonstrated a positive impact of active learning techniques such as clickers and team-based learning (11, 15), and others have reported a positive impact of the use of SI as a form of course support on student course performance in health science courses (19). To our knowledge, there are no studies that have examined the effect of a combined approach on student course performance, including incorporating all three strategies in a large-enrollment undergraduate health sciences class.

The health science course considered in this study is a large-enrollment undergraduate course offered by the College of Pharmacy, University of Houston and fulfills the life and physical sciences core requirement for undergraduate students at the University. This course is a stand-alone course and is not a prerequisite for courses at either College of Pharmacy or any other college at the university. The course introduces students to topics in pathophysiology of common disease states and discusses the pharmacology of over-the-counter (OTC) medications used for these common disease states.

In this study, we examined the effect of incorporating three teaching strategies, as interventions: 1) daily in-class clicker quizzes, 2) team-based learning, and 3) optional supplemental instruction in the form of after-class review sessions on student performance in a large-enrollment undergraduate health sciences course. The objective of the study was to evaluate the combined effect of these three strategies on student performance as measured by exam scores, overall course scores, and percentage of students receiving letter grades A, B, C, and DFW rates.

### METHODS AND MATERIALS

This study was conducted in accordance with the protocol submitted to and approved by the Institutional Review Board at the university. In this retrospective longitudinal study, data from 20 semesters, starting from fall 2007 to fall 2018 were included. During some academic years, the course was offered in fall as well as in spring semesters (2008–2015), while in other academic years it was offered only during the fall semester (2007, 2016, 2017, and 2018). The first 4 yr beginning fall 2007 to spring 2011 served as the control period, and the next 7 yr beginning fall 2011 to fall 2018 were considered as the intervention period.

### Course Content

The large-enrollment health sciences class is called the Principles of Drug Action (PHAR 2362) course and serves as an introduction to pharmacological and health sciences. The course is divided into three sections, based on the topics covered. The first section covers processes of drug discovery and development, drug-receptor interaction, pathophysiology of pain, fever, inflammation, common cold, cough, and pharmacology of OTC medications available for these conditions. Around 13 lecture hours are spent on this section. The second section covers pathophysiology of disease states such as sleep disorders, skin disorders, pharmacology of OTC medications for treating these conditions and physiological effects of drugs of abuse such as alcohol, nicotine, amphetamines, cocaine, and marijuana. Around 13 lecture hours are spent on this section. The third and the final section covers pathophysiology of oral cavity, constipation, diarrhea, peptic ulcer disease, gastroesophageal reflux disorder, pharmacology of OTC medications for treating these conditions, basics of nutrition, and pathophysiology of nutritional deficiencies. Around 12 lecture hours are spent on this section. The course has practical content that can be used by students in their everyday life as well.

### Course Details and Assessment

This course is 3 credit hours and serves as a science core requirement at the University. It has no university-level prerequisite and can be taken by students of any major. The course is offered on Mondays, Wednesdays, and Fridays from 12:00 to 12:50 PM, as a 50-min session in a large auditorium. The course has three exams that are the primary assessment for student course performance. The number of exams and number of questions per exam remained the same in both control and intervention period. The overall course score during the control period was based on three exams (85%) and online homework assignment (15%). The overall course score during the intervention period was
based on three exams (82%), team-based learning (3%), online homework assignment (6%), daily in-class clicker quizzes (9%), and optional after-class review sessions (0–5%). This is a team-taught course, with more than two-thirds of the course taught by one instructor and a varied portion of the remaining one-third taught by two or more instructors.

**Lecture Presentation**

Lectures were presented using a PowerPoint with a computer that supported writing/chalkboard features. The lecture handouts were posted on Blackboard 48 h before the class, and students were expected to download and/or print the handouts before coming to class. In the intervention period, two or more clicker quizzes were inserted daily in the lecture to actively engage students in the learning process. Students were required to purchase their own Turning Technologies response system clicker and mobile application subscription for $40.

**Teaching Interventions**

Three specific interventions namely, 1) daily low-stake in-class quizzes, 2) team-based learning, and 3) after-class review sessions were launched in this course simultaneously as targeted approaches to improve student course performance. Daily low-stake in-class quizzes and team-based learning were mandatory for all students while after-class review sessions were optional.

**Daily low-stake in-class quizzes.**

Daily low-stake in-class quizzes were conducted using Turning Technologies response system. Students were required to bring a clicker or a mobile device with Turning Technologies response system application every day to class to record quiz responses. A daily in-class quiz consisted of a minimum of two questions, and each class began with a clicker question related to the previous lecture and ended with a clicker question related to the current lecture. Each question was displayed on screen for 45–90 s, and during this time students could think-pair-share with another student before answering the question. After the quiz ended, a bar-chart displaying percentage of students choosing various answers was displayed, followed by presentation of the rationale behind the correct answer and discussion of the relevant material by the instructor. Students were graded based on their quiz performance, with correctly answered questions worth half a point and an incorrectly answered question worth zero.

**Team-based learning.**

Team-based active learning (TB50) hour was added in a class right before exam 2. Teams of six to eight students were created, and the teams were created based on exam one scores, with equal representation of all grade levels. On the day of the activity, students had assigned seating, and they sat next to their teammates. TB50 was divided into three parts. In the first part, students took quiz individually using Turning Technologies response system. In the second part, the students retook the same quiz as a team and answered using Turning Technologies response system. After the team quiz ended, a bar-chart displayed percentage of students with various selection of answers options, and the correct answer was discussed with students by the instructor. In the third part, students solved application-based case as a team and provided answers to the question related to the clinical case on an answer sheet provided in class. The correct answer was discussed once students turned in the answer sheet.

**After-class review sessions.**

Review sessions were offered as a form of supplemental instruction to provide after-class course support. These were weekly 1-h sessions that were offered at multiple times for the students to accommodate varying schedules. These sessions were in addition to the scheduled class lectures and served as a review to what was covered in class during that week. The weekly after-class review sessions were conducted by teaching assistants. Each review session was comprised of 30–40 students. The small group session enabled a more personalized and interactive discussion platform.

**Course Evaluations**

At the end of every semester, students were asked to complete an online anonymous evaluation survey that included the question: “Overall, I was satisfied with the quality of the course.” Their answers were provided on a scale between 1 and 5 (i.e., strongly disagree, disagree, neutral, agree, and strongly agree).

**Data**

The study had a retrospective longitudinal design. Data from student course records were obtained from instructor’s Blackboard gradebook and deidentified for analysis. Student’s course evaluations were obtained from the office of assessment, College of Pharmacy, University of Houston. The information about each course included the year and the semester the course was offered; student enrollment characteristics (freshmen, sophomore, junior, senior, or postbaccalaureate, science or nonscience major); number of instructors, combined effect group (control vs. intervention); all exam 1, 2, and 3 scores; overall course scores; and final letter grades. The outcomes for student’s course performance in this study were individual exam 1, 2, and 3 scores as well as the average exam scores; the overall course scores; percentage of students receiving letter grades A, B, and C; and DFW rates. The DFW rate was the percentage of students who received a grade of D, F, or W and remained enrolled in the course at the end of the “add/drop” period. Students who were granted a grade of “incomplete,” i.e., those students given an extra semester to finish coursework that is nearly completed due to measures outside of their control, were excluded from the study.

**Statistical Analysis**

Description analysis followed by comparatives tests were conducted using SAS statistical package 9.4. Since the data were normally distributed, t-test was performed for comparing exam scores, average exam scores, overall course scores, final grade percentages, and A, B, C, and DFW rates. Repeated measures ANOVA with a Tukey post hoc test was conducted to evaluate differences in exam 1, 2, and 3 scores within intervention period and control period. $P < 0.05$ was considered significant.
RESULTS

Overall, in this study data from 5,553 students was evaluated with 1,958 students in the control period and 3,595 students in the intervention period. Control period had 8 semesters and intervention period had 12 semesters. The average number of students in the control period and the intervention period was not significantly different (Table 1).

A summary of the student enrollment characteristics and the average number of instructors teaching in the course is provided in Table 1. No significant difference was observed in percentage of students in freshmen/sophomore, percentage of students in junior/senior/postbaccalaureate, percentage of science and nonscience majors, and number of instructors teaching the course, between the control and the intervention period.

Exam 1, 2, and 3 scores as well as the average exam score of all three exams were compared between the control and the intervention periods (Table 2). The t test results indicated that during the intervention period, exam scores for each of the three exams were significantly higher than the same exam during the control period (P < 0.05). Average exam score in the intervention period was significantly higher than the control period (73.9% vs. 67.3%, P < 0.0001). Repeated measures ANOVA test followed by a Tukey test indicated that within the intervention period, exam 2 scores were significantly higher than exam 1 and exam 3 scores, while there was no significant difference in the exam 1 and exam 3 scores. Repeated measures ANOVA test within in the control period did not show any significant difference among exam 1, 2, and 3 scores. Within the intervention period, students who attended five or more optional after-class review session had a significantly higher exam score than students who attended zero to four after-class review sessions (76.0% vs. 71.5%, P < 0.0001). This information can be viewed in Fig. 1 and indicates that 43% students attended 5 or more sessions.

Table 1. Course characteristics during control and intervention period

|                          | Control (n ± SD) (8 Semesters) | Intervention (n ± SD) (12 Semesters) | P Valuea |
|--------------------------|-------------------------------|--------------------------------------|----------|
| Average number of students in each semester | 245 ± 56.97                  | 300 ± 57.41                          | 0.0501   |
| Freshman/sophomore student percentage | 73.78 ± 4.84                  | 69.68 ± 5.34                         | 0.098    |
| Junior/senior/postbaccalaureate student percentage | 26.22 ± 4.84                  | 30.32 ± 5.34                         | 0.098    |
| Science major percentage | 13.43 ± 4.69                  | 12.27 ± 4.45                         | 0.5827   |
| Nonscience/undecided percentage | 86.53 ± 4.67                  | 87.73 ± 4.45                         | 0.5691   |
| Average number of instructors | 3.15 ± 0.46                   | 2.5 ± 1.31                           | 0.141    |

*p < 0.05, significant by Student’s t test.

The overall course score was also significantly higher in the intervention period compared with the control period (76.0% vs. 69.8%, P < 0.05). However, when overall course score and average exam score were compared within each period, there was no significant difference (Table 2). It should be noted that due to missing data on individual exam scores for three semesters, the n varied from the other analysis.

Information on the percentage of students receiving a particular letter grade can be viewed in Table 3. The percentage of students who received grades A or B was significantly higher in the intervention period (59.4% vs. 38.1%; P < 0.0001). On the other hand, the percentage of students who received C was significantly lower in the intervention period (21.8% vs. 28.7%; P < 0.0001). The t test results indicated that in the intervention period there was a significant decrease in DFW rates compared with the control period (18.8% vs. 33.3%; P < 0.0001).

We wanted to see if these interventions made any impact on course evaluations. Students in the intervention period gave significantly higher course evaluation (4.22 ± 0.17, P < 0.0001) for the question: “Overall, I was satisfied with the quality of course,” in comparison with the students in control period (3.33 ± 0.09) (Fig. 2). In addition, written students’ comments indicated that they found the interventions helpful. Selected comments from the course evaluation are presented in Table 4.

DISCUSSION

The purpose of this study was to examine the combined effect of three different teaching strategies on student course
Table 3. Comparison of A, B, and C grade distribution and DFW rates between control and intervention period

| A/B/C grade distribution | Control (n = 1,958) | Control (% ± SD) (8 semesters) | Intervention (n = 3,595) | Intervention (% ± SD) (12 Semesters) | P Value* |
|--------------------------|--------------------|-------------------------------|--------------------------|--------------------------------------|---------|
| A grade                  | 272                | 13.75 ± 3.12                 | 946                      | 26.23 ± 3.96                        | <0.0001 |
| B grade                  | 472                | 24.31 ± 5.25                 | 1207                     | 33.22 ± 4.16                        | 0.0005  |
| C grade                  | 557                | 28.7 ± 2.78                  | 778                      | 21.77 ± 1.8                         | <0.0001 |
| DFW rate                 | 306                | 15.38 ± 2.54                 | 312                      | 8.77 ± 1.43                         | <0.0001 |
| D grade                  | 181                | 8.98 ± 3.38                  | 207                      | 6.06 ± 2.54                         | 0.0406  |
| F grade                  | 170                | 8.87 ± 1.86                  | 145                      | 3.96 ± 1.39                         | <0.0001 |
| W grade                  | 657                | 33.3 ± 4.78                  | 664                      | 18.79 ± 3.27                        | <0.0001 |

DFW, grade of D or F or withdrawal. *P < 0.05, significantly different from control period by Student’s t test.

In our study, several factors could have contributed to the success of the combined interventions. First, all these interventions facilitated peer-aided learning. The students responded to quizzes and TB50 after a think-pair-share that facilitated peer-aided learning. In addition, the smaller group setting after-class review sessions also facilitated peer-aided learning. Think-pair-share and smaller group setting engages students in an active learning process leading to significant student learning (12, 20). Second, in addition to promoting peer-aided learning, these interventions promoted student-instructor interaction in the form of a discussion following the question and an instantaneous feedback provided to the students. Others have noted that dialog associated with instant feedback turns a lecture into a conversation and enhances student engagement and learning (21–23). Third, testing students every day during class increases the overall learning, retention, and retrieval. Two of the three interventions incorporated in this study used repeated testing in the form of low-stake quizzes and TB50. Compared with repeated studying, retrieving information during test (in this case a low-stake quiz or a TB50) may have enhanced learning process and metacognition (21, 24).

When the individual exam scores were compared between intervention and control period, intervention period had significantly higher scores in all three exams. Student-student interaction and student-faculty interaction as promoted by our interventions could have contributed to this effect. This has been noted by others as well, pharmacy students learning chemistry performed better and increased their grade by 3.5% when working as a group rather than working individually (25). Within the intervention period, exam 2 score was significantly higher than exam 1 and exam 3 score. Higher exam 2 scores relative to exam 1 and exam 3 scores in the intervention period could be due TB50 intervention which was right before exam 2 and reinforced major concepts to be tested on exam 2. However, the effect of TB50 did not last for the third exam and was static. Hence, performing TB50 before each exam may help in the future. Other studies in large enrollment classes have shown that introducing TB50 leads to an increase in exam scores by 4 to 7%. (26, 27). Within the intervention period, students who attended five or more optional after-class review session had a 4.45% (P < 0.05) higher exam score than students who attended zero to four after-class review sessions (Fig. 1). Student participation in these sessions ranged from some students not attending any session to some students attending all 10 sessions. Others researchers have noted that offering supplemental instructions such as after-class review sessions facilitate learning and performance (28). However,

Figure 2. Effect of interventions on course evaluation. Students unpaired t test: P < 0.0001; control, n = 6 semesters; intervention, n = 10 semesters. Scale of 1–5 (i.e., strongly disagree, disagree, neutral, agree, strongly agree) for the question “Overall, I was satisfied with the quality of the course.” Data are presented as means (SD).

Table 4. Selected comments from course evaluations

| Selected Comments |
|-------------------|
| Classes like this one remind me what education is all about. The innovative setup of this course is a treasure. |
| Attendance isn’t required but beneficial as you have daily poppers. The class is very interesting. I like the after-class review sessions because when I miss a lecture or don’t understand some part of the lecture, it gives me a chance to go back to the lecture and the TA explains to me the things I don’t understand. |
| Professors were well prepared. Visual aids in lecture material were very helpful. After-class review sessions and team-based learning, also a plus. Great course overall. |
| Engaging and very informational. There should be more team-based learning activities throughout the semester. |
| Instructor made lectures seem engaging rather than having lectures that feel like I’m just copying notes from a PowerPoint. Instructor made challenging topics understandable by explaining it to the class and was a professor who encouraged participation and helped students make a good grade in the course. |

TA, teacher’s assistant.
many students do not tend to avail this opportunity (29). In our study the more successful students utilized after-class review sessions more than the less successful students (Fig. 1). Overall course score was higher than the average exam scores in both control and the intervention period. In the intervention period, exam scores contributed to 82% of the overall score, and the remaining contribution was due to grades associated with intervention and homework assignments. In the control period, exam scores contributed to 85% of the overall score, and the remaining contribution was due to homework assignments. However, in the intervention period, both average exam scores and overall course grade increased by ~6% compared with control period. A similar increase in exam score and overall score in the intervention period indicates that the interventions primarily helped improve the exam performance and by themselves did not make a major contribution in the overall course score as exam percentage was relatively a higher percentage of the total overall course score.

We observed a significant increase in percentage of students receiving letter grades A and B and a drop in percentage of students receiving a letter grade of C in the intervention period. Others that have redesigned their courses by incorporating different teaching strategies have reported different trends in the letter grade distribution after similar individual interventions. In a physiology course, when students worked as a group to answer clicker questions at the end of a class, it resulted in a better academic performance with an increase in percentage of students earning a letter grade B and a decrease in letter grade C but not a significant increase in percentage of students receiving a letter grade A (30). Another study reports, significant increase in students passing with a C average with no significant changes in percentage of students receiving an A or a B grade (31). The increase in percentage of As and Bs along with a decrease in Cs, Ds, and Fs in our study could indicate that the combined effect of the interventions not only benefited the low-performers in the class but also mid-performers. Although there was a significant drop in Ds, Fs, and Ws in the intervention period, drop in Ds and Ws was higher compared with a drop in Fs. Many students who received a letter grade F, both in control and intervention period enrolled for the course but never attended the class or just stopped coming to class after the first exam. This may have contributed to a lower drop in F grades compared with drop in Ds and Ws.

Grades earned as D, F, or W, negatively impact semester grade point average and progression toward degree completion. Gateway courses including foundation health sciences courses such as physiology have been associated with DFW rates of 30% or more (5). In our study, the control period was associated with high DFW rates, with an average DFW rate in the 30s. In the intervention period, the DFW rates dropped in the teens. Others have reported incorporation of active learning strategies including team-based learning decreased DFW rates by 11–12% (27). In our study, we observe a greater drop in DWF rates as compared with what has been reported previously; this could be due to the combined approach that we used in contrast to the earlier study that incorporated TB50 (or individual interventions) alone.

Student evaluations of teaching, also known as course evaluations, have been used to measure teaching quality in higher education. While some studies have indicated that course evaluations are often not correlated with student learning (32, 33), others have suggested a positive correlation between course evaluations, expected grades, and overall satisfaction with the quality of course (34, 35). Of the various questions posed in the course evaluations, the one that has received the most attention and the most weight is the question, “Overall, I was satisfied with the quality of this course.” (34). In this study, we found a significant increase in response to this question in course evaluations, following incorporation of interventions. Student evaluation comments (Table 4) reflected that the interventions helped them with class attendance, allowed them to be engaged and reinforced or clarified lecture concepts.

Limitations

There are several limitations to this study. Some of the limitations are because this study spans over a period of 20 semesters, equating to 11 yr. First, while we had data for student and course characteristics and students’ final letter grades for all 20 semesters, exam scores and student course evaluations were missing for two to three semesters. Second, it was not possible to have identical exam questions and quiz questions across all semesters. However, the process of all assessments was the same across each individual period and between exams across all periods. Third, lecture notes were updated every semester and growth in faculty member’s teaching ability was not factored in when considering the student course performance. Fourth, we did not have access to students’ SAT scores, or their comprehensive GPA and it is possible that students’ general academic ability could have differed over 11 yr. In addition, this course was offered in the fall and spring semesters, we did not analyze the effect of semester on student course performance. Finally, in the intervention period the student enrollment was higher than the control period; this was only marginally significant (P = 0.0501). We believe that this higher student enrollment in the intervention period made our findings even more robust considering that higher class size has been associated with lower academic performance (36).

Conclusions

Our study spanning 20 semesters in a large-enrollment undergraduate health sciences course indicated that using a multipronged approach, with three different interventions, led to a significant increase in student exam scores and overall course scores, improved letter grades, and therefore led to an increased student course performance. It would be interesting to see the additive effect of each intervention in the overall contribution to students’ performance and to see, overall, which among the three interventions was most impactful in improving exam scores and overall grades. This study adds to the growing body of work that incorporating teaching strategies that engage students in active learning and providing after-class course support can have a positive impact on students’ performance in a course.

**GRANTS**

This work was partly supported by a University of Houston, Student Success Grant (2011–2014).

**DISCLOSURES**

No conflicts of interest, financial or otherwise, are declared by the authors.
AUTHOR CONTRIBUTIONS

A.M. conceived and designed research; A.M., M.Z., and S.S.S. analyzed data; A.M., M.Z. and S.S.S. interpreted results of experiments; A.M. prepared figures; A.M. and S.S. drafted manuscript; A.M., M.Z., S.S.S., and S.S. edited and revised manuscript; A.M. and S.S.S. approved final version of manuscript.

REFERENCES

1. Voigt L, Hundrieser J. Noel-Leviton Retention Codifications. Student Success, Retention, and Graduation: Definitions, Theories, Practices, Patterns, and Trends. https://www.stetson.edu/law/conferences/highered/archives/media/Student%20Success,%20Retention,%20Graduation-%20Definitions,%20Theories,%20Practices,%20Patterns.pdf.

2. Bloemer W, Day S, Swan K. Gap analysis: an innovative look at gateway courses and student retention. Online Learning 21: 5–14, 2017.

3. Tinto V. Promoting Student Completion One Class at a Time Pell Institute for the Student of Opportunity in Higher Education. https://www.acenet.edu/Documents/Promoting-Student-Completion-One-Class-at-a-Time–Tinto.pdf.

4. Koch D, Pistilli M. Analytics and Gateway Courses: Understanding and Overcoming Roadblocks to College Completion. https://www.insidehighered.com/sites/default/server_files/Analytics%20and%20Gateway%20Courses%20PP.pdf.

5. Gultice A, Witham A, Kallmeyer R. Are your students ready for anatomy and physiology? Developing tools to identify students at risk for failure. Adv Physiol Educ 39: 108–115, 2015. doi:10.1152/advan.00012.2014.

6. Harris D, Hannum L, Gupta S. Contributing factors to student success in anatomy and physiology: lower outside workload and better preparation. Am Biol Teach 66: 168–175, 2004. doi:10.2307/4451650.

7. Knight JK, Wood WB. Teaching more by lecturing less. Cell Biol Educ 4: 298–310, 2005. doi:10.1187/05-06-0082.

8. Michael J. Where’s the evidence that active learning works? Adv Physiol Educ 30: 157–167, 2006. doi:10.1152/advan.00053.2006.

9. Freeman S, Eddy SL, McDonough M, Smith MK, Okoroafo N, Jordt H, Wenderoth MP. Active learning increases student performance in science, engineering, and mathematics. Proc Natl Acad Sci U S A 111: 8410–8415, 2014. doi:10.1073/pnas.1319030111.

10. Bruff D. Teaching with Classroom Response Systems: Creating Active Learning Environments. San Francisco, CA: Jossey-Bass, 2009. p. xix, 220 p.

11. FitzPatrick KA, Finn KE, Campisi J. Effect of personal response systems on student perception and academic performance in courses in a health sciences curriculum. Adv Physiol Educ 35: 280–289, 2011. doi:10.1152/advan.00036.2011.

12. Gauci SA, Dantas AM, Williams DA, Kemm RE. Promoting student-centered active learning in lectures with a personal response system. Adv Physiol Ed 33: 60–71, 2009. doi:10.1152/advan.00019.2007.

13. Parmelee D, Michaelsen LK, Cook S, Hudes PD. Team-based learning: a practical guide: AMEE guide no. 65. Med Teach 34: e275–e doi:10.1080/0142159X.2012.651797. 287, 2012.

14. Andersen EA, Strampel C, Fensom I, Andrews W. Implementing team based learning in large classes: nurse educators’ experiences. Int J Nurs Educ Scholar 8: iijnes.2011.issue-11/548-923X.2197/1548-923X.2197.xml, 2011. doi:10.2202/1548-923X.2197.

15. Kibble JD, Bellew C, Asmar A, Barkley L. Team-based learning in large enrollment classes. Adv Physiol Educ 40: 435–442, 2016. doi:10.1152/advan.00095.2016.

16. Moore R, LeDee O, Learning JC. Supplemental instruction and the performance of developmental education students in an introductory biology course. J Coll Read Learn 36: 9–20, 2006. doi:10.1080/10790195.2006.10850184.

17. Kennelly KR, Salvonah M. Synergizing education: supplemental instruction in a blended learning context. Working Paper Series 15-03, 2015.

18. Dawson P, Meer JVD, Skalicky J, Cowley K. On the effectiveness of supplemental instruction: a systematic review of supplemental instruction and peer-assisted study sessions literature between 2001 and 2010. Rev Educ Res 84: 609–639, 2014. doi:10.3102/003465431450007.

19. Lunsford E, Diviney M. Changing Perspectives on anatomy & physiology: from killer class to gateway course. Bioscene: J Coll Biol Teach 46: 3–9, 2020.

20. Powell JM, Murray IV, Johal J, Elks ML. Effect of a small-group, active learning, tutorial-based, in-course enrollment program on student performance in medical physiology. Adv Physiol Educ 43: 339–344, 2019. doi:10.1152/advan.00075.2017.

21. Hennick M. Test-enhanced learning in an immunology and infectious disease medicinal chemistry/pharmacology course. Am J Pharm Educ 79: 97, 2015. doi:10.5688/ajpe79797.

22. Liu C, Chen S, Chi C, Chien K, Liu Y, Chou T. The effects of clickers with different teaching strategies. J Educ Comp Res 55: 603–628, 2017. doi:10.1177/073563311674213.

23. Blasco-Arcas L, Buil I, Hernandez-Ortega B, Sese FJ. Using clickers in class. The role of interactivity, active collaborative learning and engagement in learning performance. Comp Educ 62: 102–110, 2013. doi:10.1016/j.compedu.2012.10.019.

24. Breame CJ, Biel R. Test-enhanced learning: the potential for testing to promote greater learning in undergraduate science courses. CBE Life Sci Educ 14: es4–12, 2015. doi:10.1177/cbe.14-11-0208.

25. Pearson RJ. Tailoring clicker technology to problem-based learning: What’s the best approach? J Chem Educ 94: 1866–1872, 2017. doi:10.1021/acs.jchemed.7b00270.

26. Peters T, Johnston E, Bolles H, Ogilvie C, Knaub A, Holme T. Benefits to students of team-based learning in large enrollment calculus. PRIMUS 30: 211–229, 2020. doi:10.1080/10511970.2018.1575417.

27. Comerford L. Team-based learning reduces attrition in a first-semester general chemistry course. J Coll Sci Teach 46: 42–46, 2016. doi:10.2505/4/jcst16_046_02_42.

28. Channing J, Okada N. Supplemental instruction and embedded tutoring program assessment problems and opportunities. Commun Coll J Res Pract 44: 241–247, 2020. doi:10.1080/10668926.2019.1575777.

29. Moore R. Who does extra-credit work in introductory science courses? J Coll Sci Teach 34: 12, 2005.

30. Priego-Quesada JI, Jimenez-Perez I, Cibrian Ortiz de Anda RM, Gonzalez-Pena R, Salvador Palmer R. Effect of in-class group clicker-quiz competition on student final exam performance. Adv Physiol Educ 43: 430–434, 2019. doi:10.1152/advan.00032.2019.

31. Long M, Cottrell-Yongye A, Huynh T. Backward redesign of a non-majors’ biology course at a two-year technical college. J Coll Sci Teach 49: 7–16, 2020.

32. Spooren P, Brock B, Mortelmans D. On the validity of student evaluation of teaching: the state of the art. Rev Educ Res 83: 598–642, 2013. doi:10.3102/003465431496870.

33. Utti B, White CA, Gonzalez DW. Meta-analysis of faculty’s teaching effectiveness: Student evaluation of teaching ratings and student rating are not related. Studies Educ Eval 54: 22–42, 2017. doi:10.1016/j.stueduc.2016.08.007.

34. Denson N, Loveday T, Dalton H. Student evaluation of courses: what predicts satisfaction? High Educ Res Dev 29: 339–356, 2010. doi:10.1080/0729813100394466.

35. Weidman-Evans E, Hayes S, Bigler T. Relationship between course evaluations and course grades in six allied health programs. Health Profess Educ 6: 612–616, 2020. doi:10.1016/j.hpe.2020.07.006.

36. Milhea M, Wills R, Elder A, Molina D. What matters in college student success? Determinants of college of college retention and grade rates. Education 138: 309–322, 2018.