Adv Physiol Educ 37: 316–320, 2013;
doi:10.1152/advan.00091.2013.

Flipped classroom model improves graduate student performance in cardiovascular, respiratory, and renal physiology

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Submitted 6 August 2013; accepted in final form 27 September 2013

Tune JD, Sturek M, Basile DP. Flipped classroom model improves graduate student performance in cardiovascular, respiratory, and renal physiology. *Adv Physiol Educ* 37: 316–320, 2013; doi:10.1152/advan.00091.2013.—The purpose of this study was to assess the effectiveness of a traditional lecture-based curriculum versus a modified "flipped classroom" curriculum of cardiovascular, respiratory, and renal physiology delivered to first-year graduate students. Students in both courses were provided the same notes and recorded lectures. Students in the modified flipped classroom were required to watch the prerecorded lectures before class and then attend class, where they received a quiz or homework covering material in each lecture (valued at 25% of the final grade) followed by a question and answer/problem-solving period. In the traditional curriculum, attending lectures was optional and there were no quizzes. Evaluation of effectiveness and student performance was achieved by having students in both courses take the same multiple-choice exams. Within a comparable group of graduate students, participants in the flipped course scored significantly higher ($P \leq 0.05$) on the cardiovascular, respiratory, and weighted cumulative sections by an average of >12 percentage points. Exam averages for students in the flipped course also tended to be higher on the renal section by ~11 percentage points ($P = 0.06$). Based on our experience and responses obtained in blinded student surveys, we propose that the use of homework and in-class quizzes were critical motivating factors that likely contributed to the increase in student exam performance. Taken together, our findings support that the flipped classroom model is a highly effective means in which to disseminate key physiological concepts to graduate students.

flipped classroom; didactic lectures; student performance

AS ADVANCEMENTS in our understanding of key physiological mechanisms continue to expand, the challenge for educators to effectively disseminate increasing volumes of complex material to students is readily apparent. Along with the expansion of course content are studies that indicate that comprehension is enhanced when students are actively engaged in the learning process (1, 3, 8). This active engagement of students typically involves problem-based learning (PBL) modules with or without traditional didactic lectures to promote critical thinking and self-directed learning skills (2, 3, 7, 10). Although previous investigations have suggested that students' perceived understanding and performance can be improved by promoting active learning (3, 4, 9), the overall effectiveness of these approaches continues to be debated. In fact, a systematic review of PBL learning in preclinical medical education by Hartling et al. (5) in 2010 concluded that 22 yr of research does not unequivocally support that PBL enhances learning or impacts knowledge acquisition, although there are notable exceptions showing benefit (6). Therefore, research to elucidate the most effective methods to facilitate student learning and performance is greatly needed to guide the future teaching of graduate medical physiology.

Teaching based on a "flipped classroom" approach occurs when students conduct significant preclass preparation, including watching prerecorded lectures, while traditional class time is reserved for discussion and/or problem solving of the relevant topics (9). In reality, this modality has long been used in nonscience courses, but the recent expansion of video and internet capabilities has led to a renewed interest in this flipped format in science, technology, engineering, and mathematics (STEM) courses. Instructors of biology and physiology are enthusiastically embracing this approach by creating web-based bulletin boards to share ideas on the topic, but there are few published studies demonstrating its effectiveness. As the technological infrastructure becomes increasingly efficient at providing course materials (including videos), it is critical to determine if the incorporation of these approaches actually increases student learning as assessed by objective examinations.

Accordingly, the purpose of this study was to assess the effectiveness of a traditional lecture-based (passive) curriculum versus a modified flipped classroom (active) curriculum of cardiovascular, respiratory, and renal physiology delivered to first-year graduate students at the Indiana University School of Medicine (Indianapolis, IN) in the spring of 2013. Students in both courses were provided the same notes and objectives and attended or watched the same recorded lectures. Students in the modified flipped classroom were required to watch the prerecorded lectures before class and then attend class, where they received a quiz over the material covered in each lecture followed by a question and answer/problem-solving period. In the traditional curriculum, attending lectures was optional and there were no quizzes. Evaluation of the efficacy of these approaches was assessed by having students in both courses take the same multiple-choice exams. Perspectives and comments from students in the modified flipped course were also obtained.

METHODS

Graduate students ($n = 27$) were enrolled in either Mammalian Physiology course (traditional course, $n = 14$) or the Cardiovascular, Renal, and Respiratory Function in Health and Disease course (modified flipped course, $n = 13$). Neither group was aware of the differences in course format before enrollment. The Mammalian Physiology course is a larger course encompassing a full semester and also contains other content (e.g., endocrine and gastrointestinal physiology), which was not part of the present study. The course in cardiovascular, renal, and respiratory function is part of a series of modular courses and is shorter, albeit with the same content in these subject areas. The courses are geared toward different programs, and

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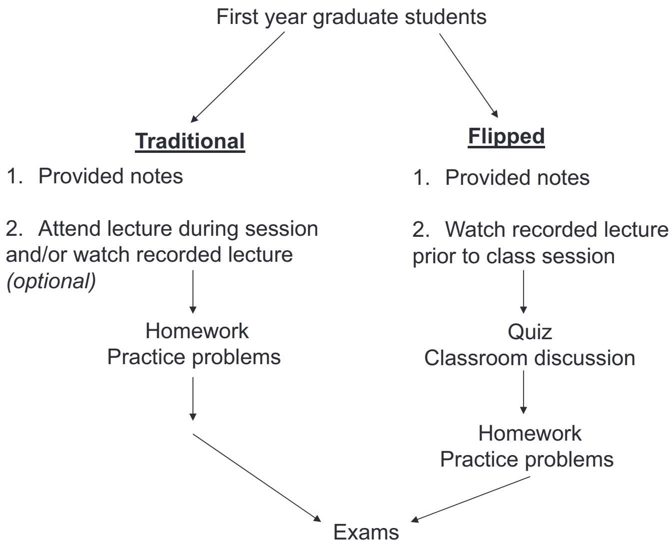

Fig. 1. Chronology of educational modalities provided to students in traditional (passive) versus modified flipped (active) physiology courses.

students may choose one or the other for different reasons. The chronology of educational modalities provided to the students is shown in Fig. 1. Students in both courses were provided with essentially identical objectives and lecture handouts before class. In the traditional course, faculty members presented "live" lectures to the students, but attendance was optional and not recorded. These 1-h lectures were recorded and posted on the internet so they could be viewed by the students at any time. The cardiovascular portion consisted of 11 lectures; the respiratory and renal portions each included 8 lectures for a total of 26 h of didactic lecture material. Students in the traditional course had no quizzes and took two (5-five part) multiple-choice examinations (one cardiovascular exam and one combined respiratory + renal exam).

Students enrolled in the modified flipped course were not presented "live" lectures but were required to watch the recorded lectures from the traditional course before class. Lectures were reinforced with either homework problems that were discussed in class or a four- to five-question quiz that was administered at the beginning of class. Problems were not worked on as a group in class, but each class referred to homework and/or quizzes as part of the discussion in lieu of a traditional lecture. Quizzes and homework scores were graded and assigned a weight of 25% to the final course grade (15 quizzes and 5 homework assignments, ~1% per exercise). If time permitted, additional questions/problem sets were provided to the students to work and discuss in class. Students in the modified flipped course took three (5-five part) multiple-choice examinations (one exam over each system).

The faculty instructors who delivered the lectures and participated in problem-solving sessions were the same for each course. Students in both courses were provided identical sample exam questions that were discussed in an hour-long review session before each examination. Care was taken to ensure that homework, quiz, and sample exam questions were not repeated on the formal examinations. The overall effectiveness of these different learning strategies was primarily assessed by having students in both courses answer the exact same (5-part) multiple-choice exam questions for each organ system. A survey of student perspectives regarding the flipped classroom model was also obtained at the end of the course.

Data are reported as means ± SE. Statistical comparisons were performed by an unpaired *t*-test and Pearson correlation analysis (Sigma Plot 11.0 software).

RESULTS

The demographic distribution of first-year graduate students is shown in Table 1. All 14 students who enrolled in the traditional Mammalian Physiology course were in the MS program, whereas 8 of 13 students enrolled in the modified flipped course were in the MS program with the remaining 5 students enrolled in the PhD program. All students had similar course loads and schedules. When students enrolled in each course were compared, more women were enrolled in the flipped course, whereas more men were enrolled in the traditional course, but there were no obvious differences in undergraduate grade point average (GPA) or average standardized test scores (Table 1). Among the students enrolled in the flipped course, no differences in standardized test scores were observed in MS versus PhD students ($P = 0.40$).

The breakdown of scores on identical exams for students in the traditional versus modified flipped courses is shown in Fig. 2. Taken together, students in the flipped course scored significantly higher ($P \leq 0.05$) on the cardiovascular, respiratory, and weighted cumulative sections by an average of >12 percentage points (Fig. 3). Exam averages for students in the flipped course also tended to be higher on the renal section by ~11 percentage points ($P = 0.06$). Importantly, the inclusion of PhD students ($n = 5$) in the flipped modified course did not significantly influence overall exam performance (final class average with PhD students: 79.8 ± 12.7 vs. average without PhD students: 79.3 ± 5.2, $P = 0.94$). Similarly, grades on each of the organ system-based exams were also not significantly influenced by the inclusion of PhD students ($P > 0.8$ for cardiovascular, respiratory, and renal sections).

To determine if performance could be predicted from data obtained from student applications, mean cumulative exam averages in the traditional and flipped courses were plotted relative to their respective undergraduate GPA (Fig. 4*A*) or their average percentile rank on standardized tests (Fig. 4*B*). Correlation analysis between these variables did not support these demographic data as strong predictors of student performance in either the traditional or modified flipped formats. However, a strong correlation ($r = 0.77$) between student performance on in-class quizzes and final cumulative exam averages was noted for students in the modified flipped course (Fig. 5).

Table 2 shows summaries of student opinion surveys on the modified flipped format. Most students agreed that they consistently watched the lecture videos before coming to class. Although many students commented that they liked being able to review videos (Table 3), rewatching videos was not a common practice. Regarding other course materials, most students were aware that textbooks were recommended, but their

Table 1. *Demographic data of students in traditional versus flipped physiology courses*

	Traditional Course	Flipped Course	*P* Value
Number of students	14	13	
Men/women	12/2	3/10	
Undergraduate grade point average	3.47 ± 0.10	3.67 ± 0.10	0.17
Percentile standardized exam	64 ± 3	68 ± 4	0.38

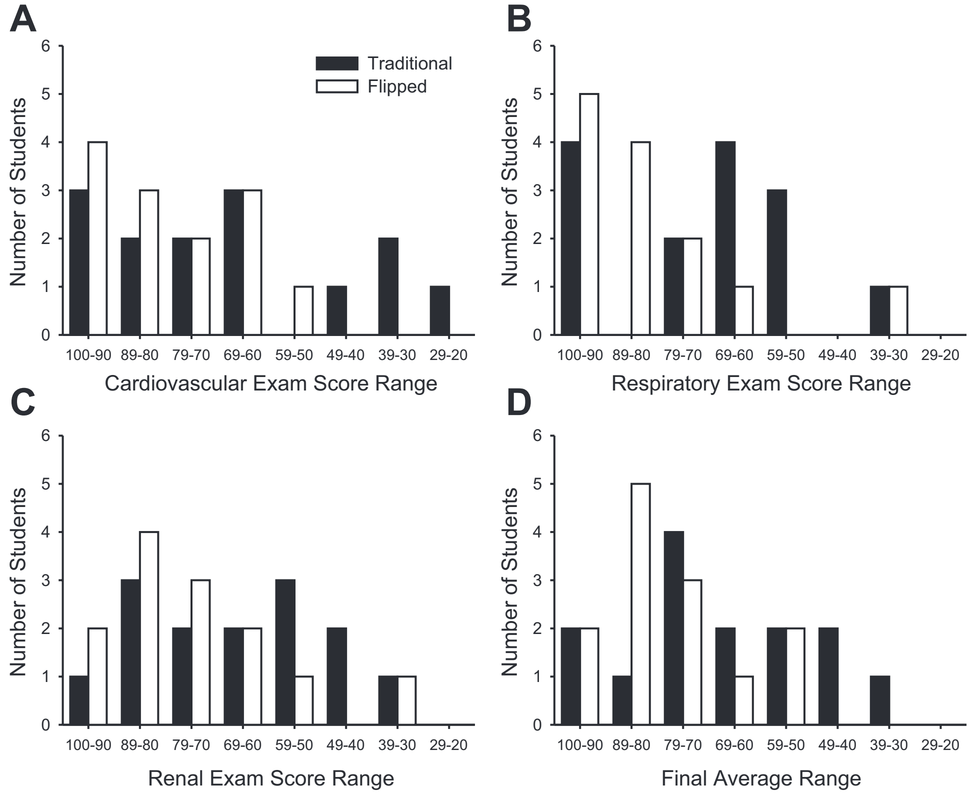

Fig. 2. Breakdown of student performance on cardiovascular, respiratory, and renal physiology exams in traditional versus flipped classroom models.

utility was highly variable. All students felt that routine quizzes given at the beginning of each session motivated much greater preclass preparation than they were accustomed and that the quizzes facilitated classroom discussion on important concepts (Table 2). All students reported that the flipped model was unique in their experience (not shown), and most had a relatively low degree of initial enthusiasm for this format. At the conclusion of the course, there was a slight increase in student enthusiasm for this format (Table 2). For this question, opinions varied greatly with approximately half of the students reporting increased enthusiasm after the experience and the other half indicating continued or worsened dissatisfaction.

A summary of comments from students on their favorite or least favorite aspects of the format is shown in Table 3. The most commonly reported aspect that students favored was the environment created for discussion during class session. One student commented that the increased preclass preparation allowed them to come up with more thoughtful or direct questions for the discussion period. Others felt that the quizzes forced them to stay up to date with the material and thus made studying for the exams easier. Negative comments included the feeling that the format increased workload and, therefore, that the effort did not reflect the number of credits. Several students complained that quizzes were conducted without allowing time for questions, which is something that could be easily adjusted (Table 3).

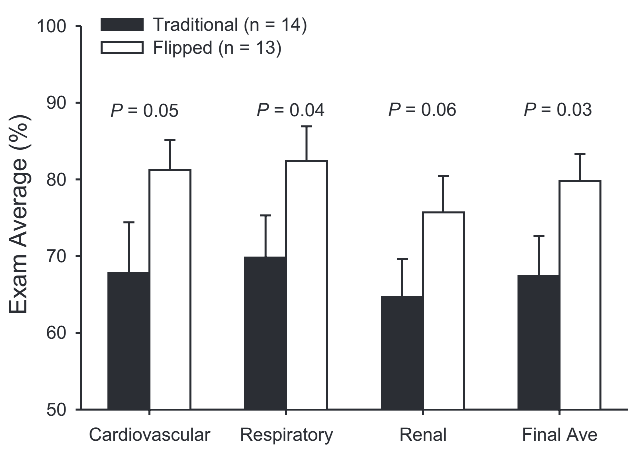

Fig. 3. Overall exam averages on cardiovascular, respiratory, and renal physiology exams in traditional versus flipped classroom models.

DISCUSSION

This study was designed to directly evaluate the effectiveness of a traditional lecture-based curriculum versus a modified flipped classroom curriculum of cardiovascular, respiratory, and renal physiology delivered to first-year graduate students. Within a comparable group of first-year graduate students, the flipped model appeared to have strong positive effect on overall student performance (Fig. 3). Our findings provide the first direct comparison of traditional versus flipped classroom models in which students were subjected to the same instructors, course material, lectures, and exams.

Opinions vary on the specifics of what comprises a flipped model, but it is fairly clear that its primary tenet is the focus on active, preclass preparation, thus allowing classroom time to focus on problems or discussions, again involving more active learning. The availability of archived video lectures at our institution presented the opportunity to investigate the utility of flipping, in which we envisioned the preclass preparation as watching the same lecture provided to the "control" traditional

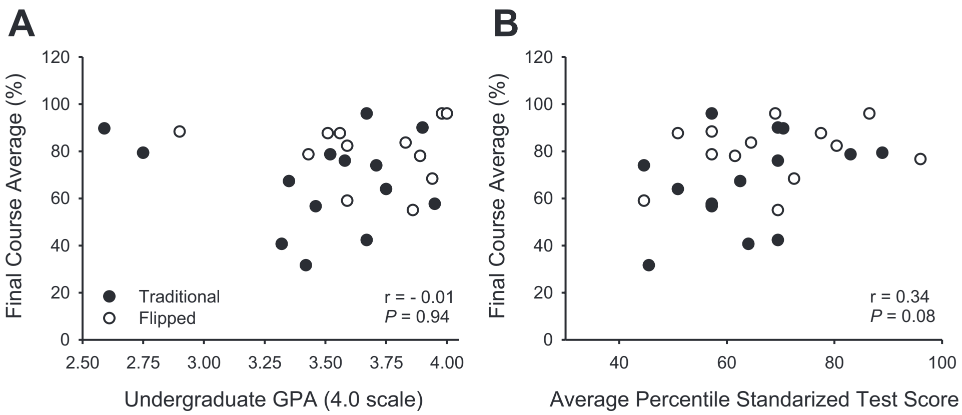

Fig. 4. Correlation between undergraduate grade point average (GPA; *A*) and average percentile scores on standardized exams (*B*) on final cumulative exam averages for students in traditional versus flipped classroom models.

format group. Our findings indicate that actual attendance of lectures in person is not particularly important to overall student learning or performance on exams.

In some flipped versions, the classroom session would comprise team-based learning or PBL, in which the instructor may be viewed more as a facilitator or coach. We recognize a certain appeal to this approach, especially if didactic lectures have already been viewed. However, in the present study, we chose to give quizzes or have written homework assignments conducted at the beginning of each class followed immediately by discussion during the remainder of the class session. Relative to our prior experience in this course, this format allowed us (the faculty) to better engage the students in discussion, i.e., students in the flipped format asked more specific questions over key concepts with other students asking pertinent followup questions.

Quizzes and homework scores were graded and assigned a weight of 25% to the final course grade (~1% per exercise). Student grades on quizzes were not factored into the exam scores shown in Figs. 2 and 3. While undergraduate GPA and standardized exam scores did not correlate with student performance (Fig. 4), average quiz scores of students in the modified flipped course strongly predicted cumulative final course grades (P = 0.002; Fig. 5). Nevertheless, the intent of the quizzes was to ensure that the students had viewed the lectures and studied the material so that they would be prepared for the discussion portion of the class. Since all students uniformly reported that the use of quizzes forced them to study "more," we cannot determine whether the better performance in the flipped course was due to *1*) increased studying, *2*) added value of discussions and problem solving, and/or *3*) a combination of both of these factors. Regardless, we submit that incorporation of frequent in-class quizzes was essential in compelling students to not only watch the prerecorded lectures but to actively study and learn the material before each class. Whether incorporation of quizzes in the traditional course would have improved student exam scores in this format remains to be determined. Regardless, our findings indicate that the flipped model, with frequent quizzes, is a highly effective means in which to educate graduate physiology students.

The role of frequent quizzes appears to have a strong positive effect on resultant test scores; however, other possibilities exist. For example, in the traditional class, the content was presented in a slightly shorter time period with two exams, whereas the flipped class was slightly longer and independent exams were conducted for each of the three component sec-

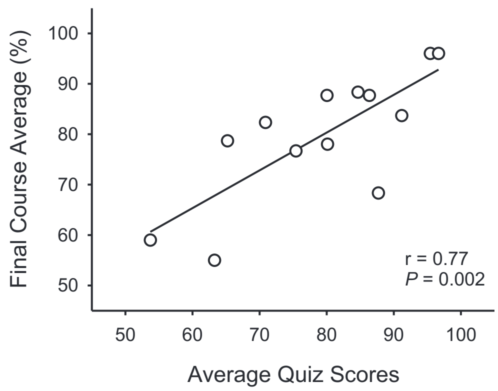

Fig. 5. Relationship between average quiz scores and final cumulative exam averages for students in the flipped classroom model.

Table 2. *Student perspectives on the modified flipped model*

	All Students
Questions regarding the use of course materials	
Compared with other courses, the online material used in this course was (*1* = much greater; *5* = much less than normal)	1.8 ± 0.8
Consistently watched videos before coming to class (*1* = always; *5* = never)	1.5 ± 1.1
Consistently rewatched videos (*1* = always; *5* = never)	3.5 ± 1.5
Aware of recommendation of texts (*1* = very aware; *5* = unaware)	1.6 ± 1.0
Used textbooks routinely (*1* = significant use; *5* = never)	3.1 ± 1.6
Questions on the use of quizzes	
Knowledge of quizzes forced greater than normal preclass preparation (*1* = much greater than normal; *5* = less than normal)	1.3 ± 0.5
Use of quizzes effectively facilitated discussion of concepts during the class session (*1* = much greater than normal; *5* = less than normal)	1.7 ± 0.8
Questions on the impression of value of the format	
Format helped to grasp concepts (*1* = strongly agree; *5* = strongly disagree)	2.4 ± 1.3
Initial enthusiasm for course format (*1* = high; *5* = low)	3.2 ± 1.5
Impression of course format changed at the end of the course (*1* = more enthusiastic; *3* = no change; *5* = less enthusiastic)	2.5 ± 1.1

Table 3. *Paraphrased comments from the student survey regarding students' opinions of the flipped model*

	Number of Comments
Favorite aspects of the course format	
Relaxed discussion generated in class and opportunity to ask questions	5
Having access to recorded lectures for review	3
Increased class preparation allowed for better exam preparation	2
Ability to ask questions was enhanced by better preclass preparation	1
Quiz forces the need to stay "on top" of the material	1
Least favorite aspects of the course format	
Too much time required or effort not indicative of course credits	6
Not having in-class learning experience before quiz or prefer to allow time for questions before quiz	5
Anxiety created by the daily quiz format	1
Multiple-choice format of exams did not match preparations	1

tions. Although we cannot account for the overall effect of the difference in the number of exams, it is important to point out that both formats were subjected to only one cardiovascular exam, which revealed the same effect on the flipped model. Although the results of this study indicate a great potential for the flipped classroom approach, there are some concerns and areas for continued refinement. Interestingly, students were not overly enthusiastic about this approach; however, we were encouraged that student perceptions were slightly more favorable at the end (relative to the beginning) of the course (Table 2). It is curious that some students still retained unfavorable views of the course format while simultaneously reporting that this format facilitated their ability to learn. One reason for the negative opinions relates to the apparent increase in workload (the most cited negative opinion in Table 3). In a manner of speaking, the requirement to watch lectures followed by an hour-long discussion essentially doubles student contact/study hours. In combination with the increased study time for quizzes, students in this course likely put in significantly more time than students in our previous courses, which may have contributed to these negative feelings, albeit with positive effects on overall performance.

In conclusion, our initial experience with a version of a flipped classroom model for cardiovascular, respiratory, and renal physiology was largely positive. We advocate that such a model could be adapted fairly easily at institutions with sufficient technical support to facilitate delivery of prerecorded lectures to students. Based on student feedback, we suggest that the use of homework and in-class quizzes was a critical motivating factor that likely contributed to the better student participation in classroom discussion and ultimately to increased student performance. In addition, this model provided the instructors with significantly more class time to emphasize important concepts and/or engage students in problem-solving exercises while also retaining the assurance that students were provided with important background information provided by didactic lectures. Taken together, our findings support that the flipped classroom model is a highly effective means in which to disseminate key physiological concepts to graduate students.

DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the author(s).

AUTHOR CONTRIBUTIONS

Author contributions: J.D.T., M.S., and D.P.B. conception and design of research; J.D.T., M.S., and D.P.B. performed experiments; J.D.T. and D.P.B. analyzed data; J.D.T., M.S., and D.P.B. interpreted results of experiments; J.D.T. and D.P.B. prepared figures; J.D.T. and D.P.B. drafted manuscript; J.D.T., M.S., and D.P.B. edited and revised manuscript; J.D.T., M.S., and D.P.B. approved final version of manuscript.

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