Adv Physiol Educ 37: 347–355, 2013;
doi:10.1152/advan.00050.2013.

A comparison of traditional and engaging lecture methods in a large, professional-level course

Cynthia J. Miller,[1] Jacquee McNear,[1] and Michael J. Metz[2]

[1]*Department of Physiology and Biophysics, School of Medicine, University of Louisville, Louisville, Kentucky; and*

[2]*Department of General Dentistry and Oral Medicine, School of Dentistry, University of Louisville, Louisville, Kentucky*

Submitted 22 May 2013; accepted in final form 10 October 2013

Miller CJ, McNear J, Metz MJ. A comparison of traditional and engaging lecture methods in a large, professional-level course. *Adv Physiol Educ* 37: 347–355, 2013; doi:10.1152/advan.00050.2013.—In engaging lectures, also referred to as broken or interactive lectures, students are given short periods of lecture followed by "breaks" that can consist of 1-min papers, problem sets, brainstorming sessions, or open discussion. While many studies have shown positive effects when engaging lectures are used in undergraduate settings, the literature surrounding use of the learning technique for professional students is inconclusive. The novelty of this study design allowed a direct comparison of engaging physiology lectures versus didactic lecture formats in the same cohort of 120 first-year School of Dentistry DMD students. All students were taught five physiological systems using traditional lecture methods and six physiological systems using engaging lecture methods. The use of engaging lectures led to a statistically significant higher average on unit exams compared with traditional didactic lectures (8.6% higher, $P < 0.05$). Furthermore, students demonstrated an improved long-term retention of information via higher scores on the comprehensive final exam (22.9% higher in engaging lecture sections, $P < 0.05$). Many qualitative improvements were also indicated via student surveys and evaluations, including an increased perceived effectiveness of lectures, decrease in distractions during lecture, and increased confidence with the material. The development of engaging lecture activities requires a significant amount of instructor preparation and limits the time available to provide traditional lectures. However, the positive results of this study suggest the need for a restructuring of the physiology curriculum to incorporate more engaging lectures to improve both the qualitative experiences and performance levels of professional students.

active learning; engaging lectures; student motivation; large classes

FROM A YOUNG AGE, children are taught to use active learning techniques to master complex tasks or concepts. One could hardly imagine giving an hour-long lecture to a kindergartner on how to tie their shoes or memorize the alphabet; instead, we teach them to use an analogy, sing a song, trace letters, or other active strategies. Many of the issues that teachers encounter are congruent at all levels of education; thus, the active methods that are used to help young children learn are also applicable to professional students (23). Despite this knowledge, over the course of a student's education, teachers use fewer active learning strategies and become progressively reliant on more passive PowerPoint presentations and lectures. By the time students reach professional-level classrooms, there is almost an exclusive reliance on traditional didactic lectures.

Address for reprint requests and other correspondence: C. J. Miller, School of Medicine, Univ. of Louisville, HSC A-1115, 500 S. Preston St., Louisville, KY 40292 (e-mail: cjmill04@louisville.edu).

Active learning is a student-centered teaching technique that uses various interactive, multimodal strategies to create a more engaging classroom setting compared with the traditional didactic lecture. The purpose of using active learning is to keep students engaged in the material to provide an environment that increases student performance while also motivating the students to learn, increasing classroom satisfaction, and facilitating higher-level thinking skills. In comparison, the traditional didactic lecture creates an instructor-centered classroom setting in which students are more passive listeners than active learners. This lecture type does not include open student interactions and instead focuses more on exposing students to course material (38). However, there is evidence showing that lectures can be an effective method of teaching when used properly and can help to organize and transmit content knowledge efficiently (34). Indeed, lectures have the benefits of providing the lecturer's personal overview of the material, integrating information from multiple sources, and clarifying complex information (22). On the other hand, lectures may be less effective when courses require the application of facts or critical thinking tasks (34). This could be a significant issue in physiology courses, in which it is necessary to transfer and apply information from the related fields of biology, chemistry, physics, etc. (23). While many research studies have focused on the complete replacement of didactic lectures with active learning, it is important to recognize that the two teaching styles do not represent a simple dichotomy (28). Many studies have emphasized the importance of having a sound lecture as a guiding tool for incorporating active learning in the classroom; thus, there are several proponents of an integration of the two teaching methods (7).

The umbrella term of active learning encompasses various methodologies, with each serving the purpose of fostering an active classroom. One example methodology, as used in this study, is known as engaging lectures, also referred to as broken or interactive lectures. In engaging lectures, students are given short periods of lecture followed by "breaks" that may consist of 1-min papers, problem sets, brainstorming sessions, or open discussion. These breaks are incorporated into the lecture to improve student performance, increase alertness, promote engagement, and allow immediate application of course material (11, 20, 28). Furthermore, students can work in small groups during these activities to foster a collaborative learning environment. Peer instruction has been shown to enhance critical thinking and problem-solving abilities (8). This small-group interactivity among students may be especially important in large classroom settings, and there is supporting literature showing that large groups can benefit from an interactive lecture style (14, 19).

One important component of engaging lectures is the use of formative assessment. This assessment strategy allows for

immediate application of the material, which, in return, facilitates open discussion, instructor feedback, awareness of misconceptions, and identification of difficult concepts (6, 19, 21). Having frequent assessments allows students to gauge their comprehension of the material at increments throughout the duration of the class, enabling students to immediately acknowledge their strengths or weaknesses to improve their understanding. Formative assessment is also beneficial for the instructor given that it allows the instructor to evaluate the comprehension level of the class, which permits the identification of concepts that need further explanation or discussion (19).

Recent literature has investigated the efficacy of using engaging lectures at the undergraduate level, with many studies indicating that active learning strategies improved students' comprehension of physiology in undergraduate coursework (23). Furthermore, undergraduate physiology students have been shown to favor active learning over traditional inactive learning given that active environments improves content knowledge as well as self-efficacy (38). In addition, interactive lectures have been shown to increase student alertness, motivation, and interest in undergraduate physiology courses (11). The use of "lectorials" (a combination between a traditional lecture and a tutorial) has been shown to help students understand content as well as maintain interest during class (7). A recent review (23) of the literature regarding active learning at the undergraduate level concluded that active learning is beneficial because it helps students tackle difficult subjects.

While the evidence for active learning at the undergraduate level is largely supportive, there is a greater amount of variability in the results found at the professional level. Studies have shown that first-year medical students prefer multiple learning modalities and are more receptive to lectures that are adaptable to various learning styles (21). Additionally, residents in pediatrics self-reported a preference for more interactive learning styles (36). The use of web-based lectures in a medical physiology course was shown to free up traditional lecture time, thereby allowing more in-class time to be devoted to student-faculty interactions (12). However, it has also been shown that medical physiology students express negative perceptions of engaging lectures, arguing that student-centered classrooms take away from adequate instructor guidance (18). This may suggest that students who are accustomed to traditional lecture styles are less inclined to adapt to new teaching methods. On the other hand, the use of an interactive PowerPoint show in medical neurobiology classes was positively evaluated by students but resulted in only modest score improvements on challenging exam questions (16). In operative dental school courses, the use of an interactive audience response system resulted in higher scores in posttests given directly after the lecture but showed no significant differences in the summative unit or final exams (10).

Based on the inconsistent literature, the primary objective of this study was to evaluate the impact of engaging lectures on student performance in a large, professional-level dental physiology course. The novelty of this study design allowed a direct comparison of the success of engaging lectures versus didactic lectures with the same student body. All students were taught five physiological systems using traditional lecture methods and six physiological systems using engaging lecture methods. The goal of the study was to determine if engaging lectures could produce a significant increase in student performance on unit and final exams. Furthermore, surveys were completed to analyze the ability of engaging lectures to improve students' perception of the course, ability to pay attention, motivation to study, and confidence with the material.

METHODS

Participants and course design. This study was completed at the University of Louisville School of Dentistry (Louisville, KY). The Dental Physiology course is a general science course for first-year DMD students, with an enrollment of 120 students. The course is currently team taught by five faculty members in the Department of Physiology and Biophysics. The School of Dentistry requires mandatory attendance of all students, and attendance is taken daily through content-related quizzes in the physiology course. The Dental Physiology course follows a system-based approach divided into 11 sections. The course has historically been taught using traditional didactic lectures for 2 h for 3 times/wk.

Research design. Figure 1 shows the general setup of the study, in which five of the physiological systems were taught using traditional lecture methods and six of the physiological systems were taught using engaging lecture methods. Overall, there were 42 contact hours of traditional lecture and 39 contact hours of engaging lectures. Using a team-based teaching approach, there were four different professors who taught the traditional lectures and one professor who taught all of the engaging lectures. The professor that taught the engaging lectures also served as the course director and Principle Investigator (PI) of this study.

Instructional materials. The engaging lectures consisted of 10–15 min of lecture followed by an activity that allowed students to actively apply the content to which they had just been exposed. In the 39 contact hours of engaging lectures, there were 125 active learning segments. These activities included problems or prompts that required students to brainstorm outcomes, classify components, compare/contrast pathologies, match terminology and definitions, complete case studies, solve mathematical equations, complete Venn diagrams, watch professor-designed video clips and complete worksheets, do "think-pair-share" activities, write 1-min papers, etc. All of the activities were developed exclusively by the PI of the study using guidelines and suggestions from the large body of literature on active learning techniques (1–3, 31).

The activities ranged in duration from 1 to 20 min. In almost all of the activities, students were encouraged to work in small groups of two to four students. Each activity was followed by a class debriefing in which students were called upon to share their findings with the

Section of Material	Lecture Method	Lecture Hours
Membrane Physiology	Engaging	3
Physiology of Body Fluids	Engaging	2
Muscle Physiology	Engaging	4
Cardiac Physiology	Traditional	8
Circulatory Physiology	Engaging	10
Respiratory Physiology	Traditional	10
Renal Physiology	Engaging	10
Acid/Base Physiology	Traditional	4
Gastrointestinal Physiology	Traditional	10
Neurophysiology	Traditional	10
Endocrine Physiology	Engaging	10

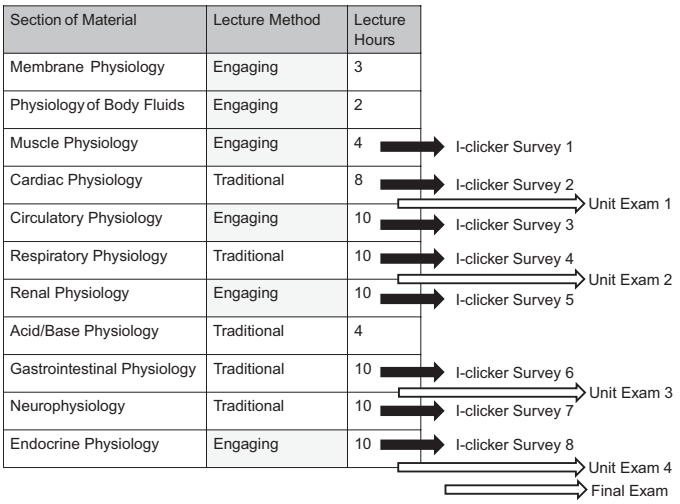

Fig. 1. Schedule for lectures, clicker surveys, and exams.

class. Rather than call on specific students, random characteristics were used to determine which students would respond. These included the student with the longest hair, the student with the most writing instruments on their desk, the student with the brightest piece of clothing, the student who arrived last to class, etc. This ensured that over the course of the semester, all of the members of the large class had an opportunity to share their results.

Assessment. Unit exam and final exam scores were collected for all sections. The unit exams consisted of multiple-choice questions, with 2 questions/lecture hour. The comprehensive final exam also consisted of multiple-choice questions, with 1 question/lecture hour from every section of the course. These questions were developed by each of the lecturers and peer reviewed by other teaching faculty members in the department to ensure proper content level and clarity. After the grading of the exams, students were given an opportunity to review the exam questions under professor supervision but were not allowed to make any notes or keep the exams.

Surveys occurred following the schedule shown in Fig. 1. Students completed eight anonymous clicker surveys in class using a personal response clicker system (i>clicker, Macmillan New Ventures, New York, NY). These clicker surveys were administered before the unit exams over the content to analyze students' perceived effectiveness of the lecturers, level of distraction during lectures, motivation to study, and confidence with the material. There were four surveys that examined student perceptions of the traditional lectures and four surveys that examined the engaging lectures. All of the traditional lecture survey responses were compiled and compared with responses from the engaging lecture sections. The first clicker survey was administered by an outside faculty member from another department, and the remaining seven surveys were conducted by the physiology class student representative upon election. The clicker surveys consisted of 11 questions with Likert-scale responses, as shown in the RESULTS. Unless otherwise indicated, for the Likert scale, *1* = strongly disagree, *2* = disagree, *3* = neither agree nor disagree, *4* = agree, and *5* = strongly agree.

Students completed online end-of-course evaluations for the overall course and for each of the individual instructors in the course. There were two open-ended prompts on this evaluation:

1. What are the most important features to retain in this course?

2. What are the most important changes you would suggest for this course?

On these evaluations, many of the students wrote about their experience with active learning methods, so their unprompted reflections have been included in the present study. All instructor names on the evaluations have been replaced with "Dr. X" for anonymity.

Data analysis and Institutional Review Board approval. Statistical analyses were performed using Origin software (version 8.1, OriginLab, Northampton, MA), as shown in the figures, with statistical significance defined as $P < 0.05$. This study was determined to be Institutional Review Board exempt by the University of Louisville (tracking no. 12.0077, 5/7/2012).

RESULTS

Exam performance. Student exam performance using traditional lectures versus engaging lectures was compared (Table 1). There was a statistically higher unit exam average in the sections using engaging lectures than in the sections using traditional lectures (8.6% increase, $P < 0.05$ by Student's *t*-test). These results suggest that the engaging lectures produced higher student performance levels than traditional lectures on unit exams. On the final exams, the engaging lecture sections had a statistically significant 22.9% higher average than the sections using traditional lectures ($P < .05$ by Student's *t*-test). This indicates that the engaging lectures may be important not only for initial comprehension of the information on unit exams but also for long-term retention of information for final exams.

Table 1. *Comparison of unit and final exam scores with traditional and engaging lectures*

	Unit Exams			Final Exams		
	Mean	SD	Number of sections	Mean	SD	Number of sections
Traditional lecture	78.66	5.58	5	70.58	13.06	5
Engaging lecture	87.25*	2.18	6	93.49*	4.55	6

The average student scores for each of the 11 sections of material were compiled, and comparisons were made between traditional and engaging lecture formats. *$P < 0.05$, traditional vs. engaging lectures by Student's *t*-test.

Clicker surveys and comments from course evaluations. Clicker surveys were given over the course of the semester to determine students' perceived effectiveness of the lecturers, level of distraction during lectures, motivation to study, and confidence with the material. The goal was ascertain whether these qualitative indexes differed between those sections using traditional lectures versus those using engaging lectures.

Perceived effectiveness of lectures. Figure 2 shows a comparison of the students' perceived effectiveness of lectures. When the engaging lecture method was used, Likert scale responses indicated a statistically significantly increase in response values. Students revealed that they found the lectures to be more helpful and more engaging and interesting when the active learning format was used. This was further supported by the following anonymous student comments on the end-of-course university evaluations.

Student comments on a traditional lecturer:

> I was very confused during Dr. X's lectures. Dr. X seems knowledgeable on the subject, but for some reason the teaching style just didn't click with me.

> Provide a different method to help explain material. Took nothing from lecture.

Student comments on the engaging lecturer:

> Dr. X makes learning fun and kind of tricks you into remembering things.

> Please keep teaching. Your methods are much more geared toward active learning, which creates a better atmosphere to apply what we're learning. As opposed to simply reading and trying to retain information, I feel your section actually pushed me to understand what I learn, not just memorize.

Level of student distractions. Figure 3 shows a comparison of the level of student distractions. When traditional lectures were used, students reported that they found it more difficult to pay attention, were diverting their attention to other activities, sent more electronic forms of communication (e-mails, text messages, etc), and had more difficulty staying awake. Thus, the engaging lectures were better able to maintain the attention level of the students. These findings were corroborated by the following student comments on the end-of-course evaluations.

Student comments on a traditional lecturer:

> Please add more active learning to the class, lectures are just extremely dry and do not push us to pay attention.

> It may sound offensive or funny, but drowsiness really is a problem and severely limits learning.

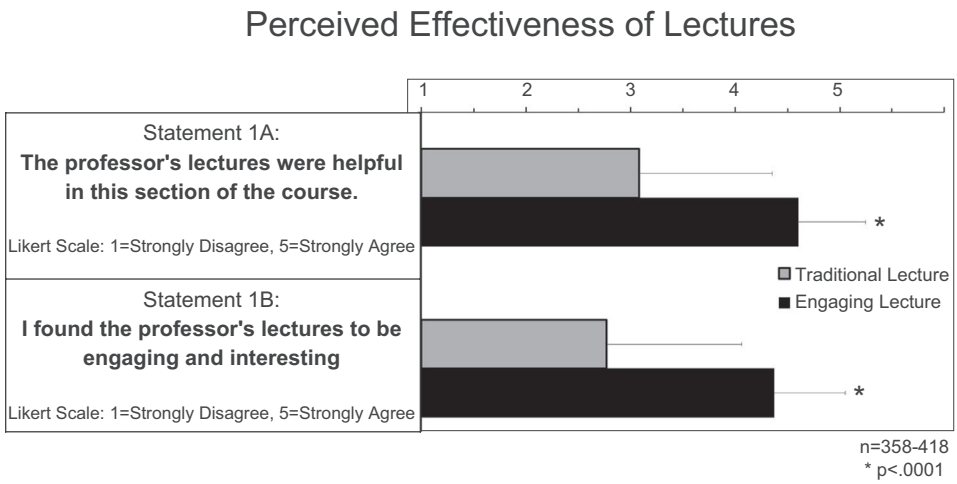

Fig. 2. Anonymous clicker survey results on the perceived effectiveness of lectures. Students completed clicker surveys after four sections of engaging lectures and four sections of traditional lectures. Results were compiled for all of the traditional lecture responses versus engaging lecture responses. The prompt for each of the statements is shown followed by the Likert scale used. In the Likert scale, *1* = strongly disagree, *2* = disagree, *3* = neither agree nor disagree, *4* = agree, and *5* = strongly agree. Data are presented as means ± SD; n = 358–418 responses. *$P < 0.0001$ by Mann-Whitney *U*-test.

Please make lectures worth attending.

Student comments on the engaging lecturer:

Exciting, kept me awake and motivated. Made the content easy to understand.

In all sections of the course, students reported on the clicker surveys (Fig. 3) that they were overwhelmed by things outside of the course, such as other classes, clinical duties, personal responsibilities, etc.

Motivation to study. In Fig. 4, the clicker survey results are shown on the students' motivation to study. It was reported that students found it more helpful to read their notes on their own time in the engaging lecture sections than in the traditional lecture sections. However, there were no significant differences between the two teaching methods in the student's motivation to study outside of class ($P = 0.17$). This topic was elaborated on by the following student comments on the end-of-term course evaluations.

Student comments on a traditional lecturer:

A good chunk of Dr. X's material didn't seem to make any sense as Dr. X lectured. I had to learn these bits all on my own . . .

Student comments on the engaging lecturer:

I spend the least amount of time reviewing the material because so much is learned in class.

Student confidence with the material. As shown in Fig. 5, in the engaging lecture sections, students felt that they had a better understanding of the material and that they would be better able to perform well on the exam. This was reiterated in the following course evaluation comments.

Student comments on a traditional lecturer:

I learned very little in the lectures and had to teach myself all the material. Still not competent with material . . .

Student comments on the engaging lecturer:

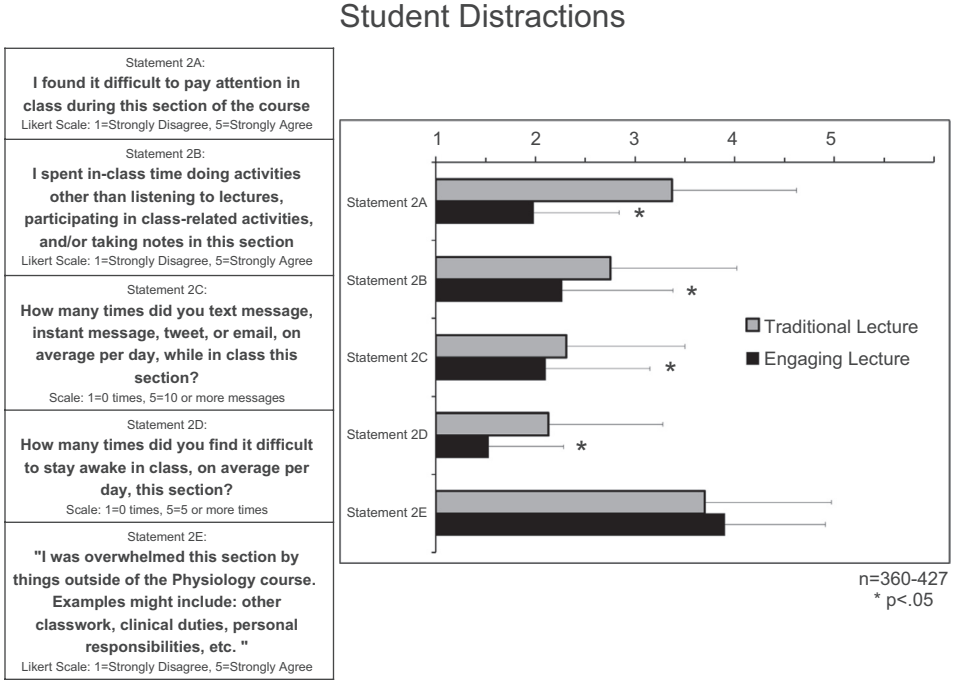

Fig. 3. Anonymous clicker survey results on student distractions. Students completed clicker surveys after four sections of engaging lectures and four sections of traditional lectures. Results were compiled for all of the traditional lecture responses versus engaging lecture responses. The prompt for each of the statements is shown followed by the scale used. For the 2C scale, *1* = 0 messages, *2* = 1–3 messages, *3* = 4–6 messages, *4* = 7–9 messages, and *5* = 10 or more messages. For the 2D scale: *1* = 0 times, *2* = 1–2 times, *3* = 3 times, *4* = 4 times, and *5* = 5 or more times. Data are presented as means ± SD; n = 360–427 responses. *$P < 0.05$ by Mann-Whitney *U*-test.

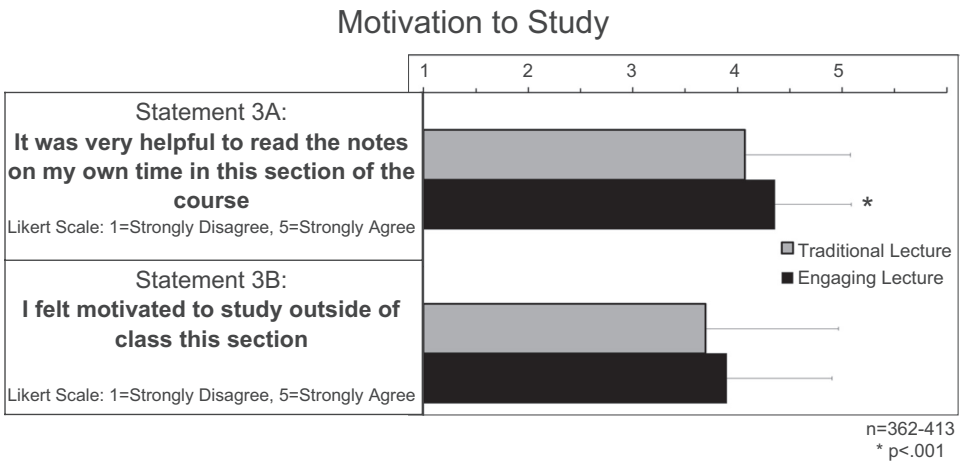

Fig. 4. Anonymous clicker survey results on students' motivation to study. Students completed clicker surveys after four sections of engaging lectures and four sections of traditional lectures. Results were compiled for all of the traditional lecture responses versus engaging lecture responses. The prompt for each of the statements is shown followed by the Likert scale used. Data are presented as means ± SD; $n = 362–413$ responses. $*P < 0.001$ by Mann-Whitney U-test.

> I left Dr. X's classes feeling as if I had actually learned something!!
>
> The notes and exercises in class helped so much to digest the huge volume of material we were required to learn.

Instructor observations from the engaging lecturer. On the first day of the semester, it was necessary to clearly establish with the class how the engaging lectures would be conducted and what was expected of the students. While there was some initial reluctance from the students to speak in front of the class, it was emphasized that errors in reasoning were to be expected given the complexity of the material. Indeed, the very point of the exercises was to elucidate and immediately correct mistakes often made by students.

Students quickly adapted to the engaging lectures, and there was full, enthusiastic participation in the activities throughout the course. However, as the course director, it was noted that there was a growing discontent among the students for those lectures that were presented traditionally. It became difficult at times to manage student-faculty relations and faculty frustrations concerning this issue. While there was an improvement in the overall student evaluation of the course, from 4.2 in 2011 to 4.6 in 2012 (on a 5-point scale), the students' overall evaluations of the traditional lecturers fell by a full point from 2011 to 2012.

Students also indicated that they had difficulty switching from one method to another. One student response on the anonymous course evaluations stated:

> The course needs more consistency. One topic to the next we went from Dr. X's approach (engaging lecturer) to an approach very different. This is very distracting when we are on such a tight timeline.

Thus, there may be a benefit to establishing a more uniform teaching style throughout the team-taught course. While this study was designed to allow a direct comparison between teaching methods in the same cohort of students, in retrospect it is not recommended to completely divide the teaching methods in a team-taught course.

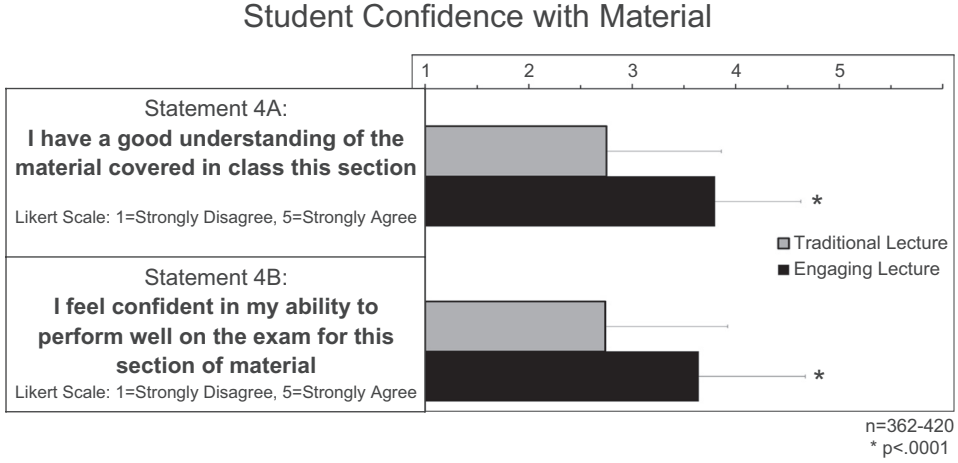

Fig. 5. Anonymous clicker survey results on students' confidence with the material. Students completed clicker surveys after four sections of engaging lectures and four sections of traditional lectures. Results were compiled for all of the traditional lecture responses versus engaging lecture responses. The prompt for each of the statements is shown followed by the Likert scale used. Data are presented as means ± SD; $n = 362–420$ responses. $*P < 0.0001$ by Mann-Whitney U-test.

DISCUSSION

Over the past two decades, there have been many criticisms over the widespread use of traditional lecture methods in professional schools (21, 25, 37). However, despite some of the inherent limitations of this teaching method, traditional lectures continue to be a main component of medical and dental school curricula across the nation. While much of the current literature focuses on a complete replacement of lectures with active learning techniques, some recent publications have examined the potential to integrate active and traditional lecture formats (11, 20, 28). The engaging lecture technique involves the insertion of periodic "breaks" during the lecture period, in which students are allowed to apply the information that they have just been exposed to in lecture.

Since the literature regarding the use of engaging lectures at the professional level is inconclusive, this study aimed to elucidate the efficacy of this teaching method with professional dental students. One confounding variable in many of the reported studies is that different years, semesters, or sections of the same course were compared. This could result in significant differences in the makeup of the students, including their backgrounds, academic abilities, educational environment, etc. Thus, the team-taught format of the course provided a unique opportunity to directly compare different teaching methods with the same group of professional dental students.

The results of this study supported the original hypothesis that engaging lectures would produce an increase in student performance on unit and final exams. The average unit exam scores were significantly higher (8.6%) in the engaging lecture sections than in the traditional lecture sections, suggesting that that the integration of engaging lectures enhances student comprehension. Furthermore, the engaging lecture final exam scores were 22.9% higher than the traditional lecture final exam scores. These results are comparable to studies comparing traditional lectures to other active learning techniques in undergraduate courses. Rich et al. (27) found that the use of problem-based learning modules with undergraduate dental students increased performance on both midterm and final exams. The improved final exam scores from the present study imply that the use of engaging lectures increases the retention rate of the students, allowing them to preserve content knowledge over longer periods of time. Indeed, a study (35) has shown that the incorporation of active learning techniques via interactive software in a third-year medical school course results in higher retention rates compared with students who were taught with a traditional lecture-based format.

While a quantitative improvement in student performance was the primary objective of this study, it was also necessary to examine the students' qualitative perceptions of the engaging lecture format. Studies have indicated that incorporation of active learning techniques can improve students' enjoyment of classes, even when performance gains are not found (17). Student responses to anonymous clicker surveys supported our original hypotheses that engaging lectures could improve students' perception of the course, ability to pay attention, and confidence with the material. Interestingly, students' motivation to study was not shown to have any significant differences between the two teaching methods.

On the anonymous clicker surveys and evaluation comments, students indicated that they found the engaging lectures to be more helpful in the course, more engaging, and more interesting. This suggests student recognition of the effectiveness of the active learning method and a positive perception of the active learning technique. Students also reported that the engaging lectures improved their understanding of the material and confidence for the exams. They proposed that the learning activities allowed them to "digest" the large amount of material in class with immediate application. It has been suggested that active teaching methods must be used if students are expected to comprehend a large amount of material (6).

Furthermore, students also reported that they were less distracted in the engaging lectures than in the traditional lectures. During traditional lectures, there were higher reported incidences of texting, e-mailing, or tweeting in class, students falling asleep, and students using class time to do outside activities that did not relate to the content being covered. This suggests that the traditional lectures are not able to maintain the attention of the students as well as the engaging lectures, which has been supported in the literature (13). It has been demonstrated that student attention spans decline after ~15 min of lecture (33). Thus, the engaging format, which includes 10- to 15-min lecture periods followed by interactive breaks, greatly compliments the concentration capacity of the students. The engaging lectures may be better able to keep students' attention by breaking up the class time into smaller segments, which changes the pace of the lecture to regain the attention of the students (28). It has been reported that even historical lecturers of the 1900s recognized the importance of holding the attention of their audiences. Faraday (25), for example, saw no need for lectures that surpassed an hour in length, recognizing that his audience's attention span was restricted. In addition to distractions within the classroom, students in all sections reported that they were overwhelmed by things outside of the physiology course, such as other classes, clinical duties, and personal responsibilities. This is not surprising given the rigor of the first year of the DMD program and the high expectations set forth by the faculty and administration.

In relation to the motivational index, students reported that it was more helpful to read the notes on their own time when engaging lectures were used than with traditional lectures. It should be noted that the notes were custom designed by the professors and printed free of charge for all students. In the engaging lecture sections, many of the prompts and activities were included in the text of the notes, with spaces left for students to complete them. Thus, the students' indication that it was more helpful to read the notes from the engaging lectures may have been biased by the different styles of notes.

Interestingly, there were no reported differences between the students' motivation to study in the traditional versus engaging lecture formats ($P = 0.17$). This finding parallels the results from another study (38) that measured the effects of active learning techniques on motivation. Comments on the course evaluations suggested that students felt they learned more within the engaging lectures and thus needed to devote less time to studying outside of class. Given the rigorous schedule of professional students, the decreased time-on-task needed to master the subjects could be very beneficial. However, given the importance of repeated retrievals in knowledge acquisition, the perceived effectiveness of engaging lectures could also be a risk factor in ultimate student success. If students feel confident with the material from lectures alone, they may foster

a perceived idea of knowledge that does not truly exist. This could result in decreased motivation to prepare outside of class, leading to decreased success in the course. Although student motivation did not appear to influence student success in this study, Ernst and Colthorpe (11) demonstrated that interactive lectures enhanced student motivation as well as increased student expectation of success. A meta-analysis (29) reported that motivation has been shown to be one of the best predictors of student performance.

Overall, there were 62 student comments on the evaluations that positively evaluated the engaging lectures and 21 student suggestions for traditional lecturers to include more active learning. There was one student comment that negatively assessed the engaging lecture, which stated, "At times the pace during lecture was a little too slow, especially with the in-class activity." Thus, although this study indicated that the majority of students may prefer the engaging lecture format, there may be a select group of students that show a preference for the traditional lecture. This has been reported in another study (18), which indicated that medical physiology students had negative perceptions of engaging lectures.

Given the strong academic improvements and overall student support for the engaging lectures that were found in this study, it can be inferred that there are many beneficial components of the engaging lecture method. One potential benefit of engaging lectures could be more efficient comprehension of the material due to immediate application of material. As previously mentioned, engaging lectures use the formative assessment strategy, which has been shown to improve student comprehension by allowing immediate application of physiology concepts (6). While some formative assessments focus only on basic recall of information, the engaging lecture activities in the present study often incorporated more advanced tasks, requiring students to solve mathematical problems, hypothesize outcomes, or compare/contrast different physiological phenomena. As noted by Cortright et al. (8), the engaging method of pausing several times throughout a lecture increases student comprehension because it allows mastery of material as well as mastery of meaningful learning.

Second, the engaging lecture format emphasizes the use of collaborative learning, where students and faculty members work together cohesively to achieve the goals of the classroom. Collaborative learning is beneficial for students in that it increases students' learning gains, encourages a deeper understanding of physiology, and promotes classroom discussion (19). Collaborative testing has also been studied, and the results show that students perform better on quizzes when working in groups than when working as individuals (26). In addition, allowing students to take tests in groups has been demonstrated to reduce text anxiety and help prepare students for the collaborative working environments they will most likely encounter in their careers (30). Blumenfeld et al. (5) agrees that group learning can be a powerful tool but stresses that its benefits are only revealed when the group is used correctly. The unique method of calling upon students using random traits, as described in METHODS, may have been an integral component of the positive results found in this study by making students accountable for their work in the active learning breaks.

The collaborative nature of the engaging lecture activities and the switch to a student-centered learning approach may be important for the development of lifelong learners. These are learners who are able to learn independently, self-educate, and use critical thinking skills to solve novel problems (21). One study (6) has shown that active classroom methods play a pivotal role in creating lifelong learners. Also, another study (15) has stressed that current teaching practices should be guided by the learning principles that foster long-term retention. By encouraging students to think independently and use critical thinking skills, engaging lectures may instill in students the importance of becoming learners for a lifetime.

Despite the many benefits of the engaging lecture format there are a few issues that need to be further considered. One confounding variable in this study was that the PI was the only lecturer involved in the engaging learning sections. It is possible that some characteristic of the PI, other than the use of active learning segments, could have produced the results seen in the study. More specifically, as the PI taught 39 h in the course and served as the course director, it is possible that a significant rapport with students was established due to the increased contact hours that could affect performance. On the other hand, an increased rapport could have been formed due to the increase in faculty-student interactions during the engaging lectures. It should be examined in future studies whether similar results can be achieved if traditional lecturers begin to adopt the engaging lecture format. It will be interesting to determine the feasibility of traditional lecturers adopting engaging lecture styles as well as faculty and student perceptions of these changes. A previous study (32) has indicated that there are significant faculty concerns regarding the implementation of active learning in physiology curricula, and even faculty who are interested in adopting the learning technique may face challenges.

One of the biggest concerns to face with the incorporation of engaging lectures is the amount of content that can be covered in the class time allowed. This is perhaps the biggest argument against the incorporation of active learning, and one that can certainly not be easily dismissed. However, this argument relies on the idea that what is said during a traditional lecture is learned by the students. According to the Edgar Dale Cone of Experience, after 2 wk, students tend to remember 20% of what they hear and 90% of what they say and do. This model therefore weakens the argument that students learn primarily by listening passively (9). This is perhaps most eloquently stated by Angelo and Cross (1): that "teaching without learning is just talking." To make the most of the class time allotted, content may also be delivered through alternative forms, for example, requiring students to read their textbook or to access videos on their own time. Knight and Wood (19) designed a study demonstrating that engaging activities can be incorporated without sacrificing content. In their study, students were required to accept greater responsibility for learning the material outside of class, thus allowing the course content to be retained.

Furthermore, the time concerns regarding active learning techniques also relies on the idea that obtaining content is of more use to students than grasping concepts. Given the ever-increasing amount of knowledge that students are expected to digest, it may be more important to teach students how to use information rather than learning specific facts. Since students have almost unlimited access to an abundance of factual information through the internet and other technologies, the

requirement for students to retain specific facts in their long-term memory is becoming less important (19). Thus, modern-day classrooms may need to shift the importance of concept over content, reducing the delivery of factual content and instead teaching the application of concepts.

Another potential issue with the use of engaging lectures is the significant amount of instructor preparation required to create the activities. It should be noted that 125 learning activities does require a substantial amount of time to create and revise. However, numerous websites are available that provide free, peer-reviewed physiology learning tools, including the American Physiological Society Archive of Teaching Resources (http://www.apsarchive.org/) and MedEdPORTAL (https://www.mededportal.org/). Furthermore, several resources exist that provide easy-to-use templates to create activities for those interested in active learning strategies (1–3, 31). In addition, there are studies that have been shown to successfully incorporate engaging classroom activities without requiring a great amount of preparation time (8). The results of the present study suggest that the instructor preparation time is clearly beneficial due to the increased performance levels and qualitative experiences of the students.

The success of this study indicates a need to examine the "flipped classroom" curricular approach currently being used at many schools. Students are given the opportunity to access key content information online, outside of class time, and class meetings are used for problem-solving, discussions, or other applications of the material. The flipped classroom format has been indicated to improve the quality of student learning as well as student engagement in the classroom (4). It would be interesting in future studies to compare the effectiveness of engaging lectures versus a completely flipped classroom.

In conclusion, it was found that the use of engaging lectures led to a statistically significant improvement in student performance on unit exams. Furthermore, students demonstrated an improved long-term retention of information via increased scores on the comprehensive final exam. Many qualitative improvements were also indicated via student surveys and evaluations, including an increased perceived effectiveness of lectures, decrease in distractions during lecture, and increased confidence with the material. While there is abundant literature supporting the use of engaging lectures with undergraduate students, the positive results of this study suggest that engaging lectures and other active learning formats may also be beneficial for the highly successful students in professional schools. This indicates a need for restructuring of the physiology curriculum and widespread reform within medical and dental schools to include more engaging lectures to improve both the qualitative experiences and performance levels of students. By incorporating active learning techniques from kindergarten through professional programs, there may be a higher likelihood of forming lifelong learners who are able to critically think and work together collaboratively.

DISCLOSURES

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

AUTHOR CONTRIBUTIONS

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

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