#4. APPENDICES SUPPORTING THE TEACHING PORTFOLIO:
The appendices “should consist of judiciously chosen evidence that adequately supports the narrative section of the Teaching Portfolio.” P. Seldin, et al 2010

**DOMAIN 4: EDUCATIONAL SCHOLARSHIP / RESEARCH – ERICA SUCHMAN**

- Example products of educational research activities
  - Reprint of a representative peer reviewed publication,
  - Abstract and title page of a funded educational grant,
  - Peer reviewed presentations abstracts

**Session title ASMCUE 2016**
Creating Frequent Online Quizzes that Enhance Lasting Learning

**Abstract:**
Frequent assessments are important to learning because they help students to avoid last-minute cramming before an exam, and they can help students gauge their own knowledge and understanding. Here, we conducted a 4-semester study to determine the efficacy of frequent online quizzing in a general microbiology lecture course. Our data show that when compared to students who did not take online quizzes, students performed better on exams during the semester but not on the comprehensive final exam. These results suggest that when students get to practice the material before the exam, they may learn the concepts better in the short term, but they seem to forget what they learned by the end of the semester. We conclude, therefore, that perhaps integrating review questions into each of the online quizzes will better promote long-term retention on the final, comprehensive exam.

**Publications**
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Running Title: Protein Translation Classroom Flip Activity

Sources of Support: Department of Microbiology, Immunology and Pathology, Colorado State University

Abstract

It is generally accepted within the education community that active learning is superior to traditional lecturing alone. Many science educators, however, are reluctant to give up classroom time for activities because they fear that they will not have time to cover as much content. Classroom flipping has been gaining momentum in higher education as one way to engage students in the classroom while still exposing students to the same volume of course content. The activity presented here demonstrates how flipping one lecture period can be used in conjunction with an engaging in-class activity to teach a concept that is often difficult for students to learn through lecture alone. Specifically, we asked students to view a lecture video on bacterial protein translation before coming to class. We then used the classroom period to conduct a hands-on activity that allowed students to interact with magnetic pieces representing the components of protein translation to generate a protein from a given piece of DNA. Survey feedback data showed that students perceived this activity as helpful to their learning of the material, and over ninety percent of the students were able to correctly answer questions pertaining to translation on summative assessments following the flipped lecture and hands-on activity. Further investigation is needed to determine if the hands-on activity itself increases student learning outcomes.

Keywords: classroom flipping; active learning; protein translation; magnets; hands-on; activity; information flow and genetics

INTRODUCTION

Active learning advocates contend that when students do something they learn it better than if they just hear and see it (2). Therefore, we developed an activity that allows students to perform the process of bacterial protein translation using a hands-on model during a regular class period of a large enrollment (150 students) general microbiology course.
Here, we combined a hands-on activity with a classroom flip, because classroom flipping has been shown to increase student attendance, promote higher engagement, and stimulates more than twice the learning (1). Students were asked to watch a 30-minute lecture video before attending class on the day of the activity. This allowed us to dedicate an entire class period for the activity and for formative assessment. According to student feedback, most students liked the flipped class format, and most thought the activity helped them to learn translation. Overall, the activity and classroom flip presented here were useful for allowing students to interact with challenging course material in a way they found helpful to their understanding.

**PROCEDURE.**

*Flipped Lecture:* A 30-minute lecture capture video was created using Echo 360 software and posted on the class website. The video shows the instructor giving a PowerPoint lecture (Appendix 6) covering the step-by-step process of protein translation in bacteria. After watching the lecture, the students should understand how ribosomes “read” mRNA to form a growing peptide using tRNA and the genetic code, and they should be able to calculate the number of ATP/GTP expended during each step. Students were asked to watch the lecture video before coming to class on the day of the activity.

*In-Class Protein Translation Activity:* This activity was designed for a 50-minute class period and could be carried out in almost any classroom type including lecture halls with or without desk surfaces. At the beginning of class, students are to form groups of no more than three people to allow each member the chance to manipulate the kit pieces. Each group receives an Instructions Sheet – Student Copy (Appendix 1), a metal board, and one kit envelope containing the magnetic pieces (Figure 1). The Instructions Sheet – Student Copy lists the kit contents, provides the DNA sequence encoding the protein, and walks the students through the process of translation in bacteria. The caveat here is that students will have received a previous lecture about transcription, so they should know how to correctly choose between the two mRNAs included in the kit. The 12” x 12” metal board can be purchased at home improvement stores, and duct tape should be applied to the edges of the metal board if they are sharp. The magnetic pieces were generated in Word and printed on magnetic printer paper (3270 Avery Magnet Sheets) using an ink jet printer, as laser jet printers can damage the magnetic
paper. The amino acids and tRNAs have Velcro strips strategically placed on them to allow the students to attach the correct amino acid to the correct tRNA and to form “peptide bonds” between amino acids on the growing peptide chain (Figure 1). The 50S ribosomal subunit has a defined P-site and an A-site onto which the tRNAs can be placed such that the tRNA anti-codon lines up perfectly with the codons in the mRNA.

Groups should be given 25 minutes to pick the correct mRNA and translate a protein spelling something in English when using the one-letter amino acid code. There is a blank at the end of the sheet for students to write down their translated protein and calculate the number of ATP/GTP expended. It is recommended that the instructor walk around the classroom during this time and interact with struggling students. There are several distractors built into this activity (discussed in the Instructions Sheet – Instructor Copy, Appendix 2), and depending on the students’ backgrounds in protein translation, many may experience difficulty getting started. An example of a distractor is an AUG sequence placed before the Shine-Dalgarno (AGGA) sequence. Many students will begin making codons at this AUG rather than at the first AUG following the AGGA sequence.

Once 25 minutes are up, most of the groups should have successfully translated a protein that says “RAMS.” The remaining minutes of class can be dedicated to the iClicker Quiz (formative assessment; Appendix 4), which takes about 20 minutes, leaving 5 minutes for clean-up.

CONCLUSION

Protein translation is a dynamic process that is difficult to understand on a static piece of paper or slide. We have developed an in-class activity that can be used in almost any type of classroom and which allows students to interact with the material in a meaningful, hands-on way. Using classroom flipping, an entire class period can be freed up for this interactive experience during which the student has access to immediate feedback from the instructor, as well as the opportunity to teach and learn from peers. We conducted an anonymous poll after this activity and found that students liked the flipped class format, but not for every lecture (data not shown), and most of them perceived that the activity helped them learn the process of protein translation (Figure 2). While further investigation is needed, limited preliminary data suggests that the activity did not help students perform better on exam questions pertaining to
transcription/translation during one semester (Appendix 3, Figure1). However, summative assessment data showed that the majority of students (91%) achieved the learning outcome, namely, that students will be able to translate a protein from a given piece of DNA (Appendix 3, Figure 2). Further studies with large $n$ values would be needed to determine whether the activity significantly increases student learning.

ACKNOWLEDGEMENTS

The development of this activity was supported by the Department of Microbiology, Immunology and Pathology at Colorado State University. The author presented this activity at ASMCUE 2014.

REFERENCES


FIGURES
FIGURE 1. Magnets representing components of bacterial protein translation on a metal board. Each tRNA has a Velcro strip (arrows) for amino acid attachment. Likewise, each amino acid has Velcro underneath so it can be attached to the correct tRNA. Each amino acid also has two strips of Velcro on its front side edges allowing for the formation of “peptide bonds” to create a growing peptide chain. (See Appendix 5 for templates.)

The in-class protein translation activity helped me learn the material.

- a. Strongly agree
- b. Agree
- c. Disagree
- d. Strongly disagree
- e. No opinion

FIGURE 2. Student feedback about the classroom flip and whether this activity helped them to learn protein translation.

Most students perceived that the activity helped them learn the process of translation. (n=113 students)

SUPPLEMENTAL MATERIALS:

Appendix 1: Instructions Sheet – Student Copy
Appendix 2: Instructions Sheet – Instructor Copy
Appendix 3: Summative Assessment Data
Appendix 4: iClicker Quiz
Appendix 5: Templates for Printable Magnetic Pieces
Appendix 6: Flipped Lecture PowerPoint Slides


Encouraging Microbiology Students To Think Like Scientists

Instead of urging students to memorize new materials, teach them to understand concepts fully and then put them to use

Erica Suchman

Like many instructors, I went to a university where lectures were the norm. Because that strategy seemed to work so well, I emulated that approach when I began teaching microbiology to college students.

After many years of teaching, however, I had an epiphany. It came while reviewing a diagram with one of my lecture students. She drew it perfectly on her last exam, yet realized that she did not fully understand parts of what she had drawn so expertly. I soon realized that my star student—one whose urge to understand material was so strong that she visited me to discuss material she supposedly had mastered—did not genuinely understand diagrams that she could perfectly reproduce.

I found myself wondering how many other students merely reproduce but do not understand diagrams or other materials from lectures. Soon, I began questioning students about these diagrams and other items that were described in lectures. To my dismay, although the vast majority of my students could draw those diagrams, they did not understand them. Thus began my quest to determine how better to teach my students what the diagrams mean, how to move them past merely memorizing the information from lectures, and how to assess authentically their understanding of the materials in the course. By authentic I mean testing their ability to understand the diagrams and know when and how to apply the material to new situations—not their ability to memorize diagrams.

Searching for Solutions

All teachers should have great mentors. One of mine, Spencer Benson (currently at the University of Macau in China), taught me about backwards design. Following this method, a teacher first decides what skills, abilities, and knowledge he or she wants students to have at the end of a learning activity and then develops the means for determining whether the students have acquired those skills. Only then does the teacher develop a curriculum that will help students achieve the intended outcomes.

This process was opposite to how I was designing my courses. I followed a more conventional approach by developing a list of topics, lectures to cover those topics, and assessments to determine how well students mastered those materials. Upon reflection, however, I realized that I was not teaching my students the skills that I wanted them to have, primarily the ability to think critically about the material I was teaching. Furthermore, my assessments did not really evaluate what I thought was most important.

I strive to follow the advice of many experts, including recent ASM President Jo Handelsman of Yale University and the U.S. Office of Science and Technology Policy, who recommend using scientific evidence to drive one’s teaching methods and to identify which approaches really work.

SUMMARY

➤ Teachers can benefit from attending workshops, reading about teaching, and having mentors.
➤ Instructors should use evidence-based teaching strategies.
➤ Backwards design can be used to determine whether learning outcomes, classroom activity design, and assignments are aligned.
➤ Student-centered learning forces students to practice thinking like scientists, while building their confidence in their ability to do so.
➤ Unless classroom activities and student assessments reflect the skills that a teacher is trying to impart to his or her students, they will not realize that these are important skills for them to develop.
A tremendous amount of evidence indicates that students learn more when teaching is more student-centered, meaning the students are not simply listening to lectures but that they are also interacting with information during class periods.

My department invests heavily in professional development and sends me each year to the ASM Conference for Undergraduate Educators (ASMCUE). Participating in these annual conferences enables me to explore alternative teaching techniques from many great biology teachers who attend the meeting. Each year I return from ASMCUE with ideas that help me to improve the learning experiences of my students.

Thus I gladly adopt ideas from others that help my students learn to think like scientists, meaning that I owe a great deal of thanks to ASM for creating this venue for exchanging ideas about teaching and learning. I encourage all educators to attend this conference or others like it because doing so can help to improve the student-learning environment. Indeed, after nearly 20 years of attending ASMCUE, I still gain new ideas each year for making such improvements.

Furthermore, access to education journals such as the ASM *Journal of Microbiology & Biology Education* (JMBE) (http://jmbe.asm.org/index.php/jmbe) and *CBE Life Science Education* (http://www.lifescied.org/), which is published by the American Society for Cell Biology, can help microbiology, cell biology, and other specialty biology teachers explore new ideas without having to leave their offices. I would argue that teaching without revisiting the newest information on teaching and learning is equivalent to performing research without keeping up on the literature in your field of study.

**Implementing Significant Change Gradually**

Importantly, I did not immediately change everything in my approach to teaching. Instead, every semester I try to improve or add at least one thing to each of my courses to address my most challenging teaching issues. I always keep a list of things to improve, and I seek constantly for new ways to address these issues. If I tried to implement all such improvements in one semester, it would have overwhelmed me and my
students. So my suggestion is change something every semester. I view teaching as a work in progress.

The first additions to my courses were problem-based, group projects. Topics my students struggled with the most—for example, metabolism and protein translation—became the subject matter for “group exams,” in which groups of students work on data-driven problems for a week and then take an in-class examination when all members of each group decide together on the best answers to turn in. This approach allows me to grade 20 to 30 group papers rather than 80 to 120 individual exams. The exam questions are designed so students must develop their own answers: all data are fabricated, and there is nowhere to look up answers. I do not use real data to avoid students searching for expert opinions, rather than taking the risk of being wrong.

Over the years, this student-centered learning activity has been improved in response to perceived weaknesses. Earlier, many students complained that other members of their groups would not listen and chose instead to record incorrect answers that penalized them. So I added a page on which to record dissents, enabling individual students to disagree with the answers submitted by their groups. Although they rarely submit such dissents, adding the option eliminated this complaint.

To deal with students who allowed other students do all the work, I first asked each student to evaluate all other members of his or her group. However, students found it awkward to evaluate each other and rarely used this approach to identify or correct those who were not doing their fair share of the work. Luckily, in 2004, I learned about a new technology, called classroom response systems or clickers, through which students may answer questions anonymously (to one another) during class. The next semester I added clicker questions to my lectures and clicker quizzes to the end of each group exam. Once the group exams are turned in, everyone in the class takes a quiz covering the same material but now using their clickers. Individual students must score more than 70% correct to earn the score that their group does, or else they get 70% of the group’s score, because they obviously were not an active participant. This approach has greatly improved student participation.

**Importance of Clickers, Inducing Individuals To Think for Themselves**

The clickers are a very important, maybe even revolutionary, tool in my teaching. I repeatedly tell students that I do not want them to memorize material, that they need to know how to use it and apply it to new situations. However, some students, who do not appreciate what I mean, continue to memorize material and assume that means they can use it. If we do not give them practice applying those concepts, they may never gain that skill.

Although lectures and occasional homework assignments in which students practice applying concepts are preferable to confronting students during exams with their weaknesses, the lectures and homework are only marginally better. Instead, students must practice skills regularly. Indeed, my students now understand the importance of applying concepts to new situations because they are asked to do so in every class period, as well as outside class every week.

Generally I present a concept, often with a diagram exemplifying that concept—for example, regulation of the Lac operon. Then I ask students questions about a different gene and its regulation, again, often including fabricated data. Students use their clickers to answer the new questions. If the majority cannot answer correctly, I say to them, “Turn to your neighbor and convince them your answer is correct, and if you agree, explain your rationale to one another.” By simply doing this, the percentage of correct answers goes up dramatically—on average, 22% in my class—without me saying anything else.

This peer-to-peer teaching allows students to develop a deeper understanding of the material while affording them opportunities to articulate new concepts. Furthermore, it shows them different ways in which I expect them to use the material being taught. These clicker questions are not worth credit, hence students feel free to answer with whatever answers that they believe are correct. Three times during each the semester, I teach “flipped classes” where my students watch a 15-minutes lecture before the class after which we do active learning activities for the entire class, using their clickers to gauge their understanding. Randomly chosen class periods where students receive extra credit if present in class, as demonstrated by their having answered questions with
their clickers, provides an incentive to regularly attend classes and participate in them.

I wanted a way to encourage students to study more but did not want more grading to do. Because students benefit from frequent low-stakes opportunities to apply knowledge to new situations, I have my students take five online quizzes individually, in addition to the five group exams that they all take. Thus, they have a group exam, online quiz, or midterm test almost every week. They can take each online quiz up to 10 times and will get credit for their highest score (20 points out of 700). These quizzes have 20 pools of questions. Each pool tests a different concept (e.g., determine the mRNA produced from a given piece of DNA) and contains multiple questions. Each time students take the exam, they get a different randomly chosen question from each pool, and all 20 concepts will be tested, but with slightly different questions each time.

Students are given their scores and told which questions they missed, but not the correct answers. While I realize that the nature of these online quizzes allows students to get answers from other students, my goal is not to test them on these concepts, but to make them practice them so they will perform better on exams and have greater long-term retention of material. The beauty of these online assessments is that I do not do any grading, and each student’s scores automatically load into my learning management center’s grade book. After the initial and not trivial time commitment required to develop these assessments, very little work is required to make this resource available.

**Another Teaching Epiphany**

My exams have changed dramatically over the years. While listening to Robert Duke of the University of Texas, Austin, a music professor and expert on learning, I had another epiphany about teaching. He posed a simple question. If it is not an important point, why is it on your exam?

I realized that my exams were full of questions that promoted memorization instead of understanding. If there is one thing I learned from my own teaching, students will try to...
learn what they believe they will be tested on. Previously, my exams were teaching them that if they memorized diagrams and trivial information, they could succeed in courses I taught. If I wanted to change how my students learned, I was going to have to change how I assessed them. My students now know that I will never ask them to draw a diagram that we have gone over in class. In fact I allow my students to bring to exams one 8½ by 11 handwritten sheet that includes anything we talked about in class, to prove to them I will not ask them any memorization questions. I ask questions about systems that we never discussed, forcing them to apply the concepts that we did discuss.

After many years of following this practice, I believe that my intended learning outcomes are being clearly articulated to my students, my classroom sessions are designed to teach them the skills I value, and the students know that I will assess their learning in ways that require more than memorization. Does that mean that my approach to teaching is perfect? Of course not, there is a long list of things to improve. One of the things I love about teaching is that, if you are doing it right, there is always another challenge to face.

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Suggested Reading


The Use of Online Pre-Lab Assessments Compared with Written Pre-Lab Assignments Requiring Experimental Result Prediction Shows No Difference in Student Performance

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INTRODUCTION

The use of pre-lab assignments that encourage students to prepare for a laboratory classroom session are a commonly used teaching technique to help alleviate the problem of students showing up for lab under-prepared to participate in the laboratory sessions, leading to decreased learning (3). Petroy-Kelly created two online modules for use in a teaching laboratory that dramatically increased student performance. Although there is literature indicating that students who take courses online perform similarly to those enrolled in laboratory courses (2) and research showing that students who write essays on computers do not perform as well as those who handwrite essays (4), a search of The Education Resources Information Center (ERIC) and the Journal of Microbiology and Biology Education (JMBE) found no studies comparing the effect of students handwriting pre-labs versus completing online pre-lab assessments. Like many universities, Colorado State University biology laboratory courses often have enrollments upwards of 30 to 50 students. Moving the pre-laboratory assessments online would therefore have a large impact on the time and graduate teaching resources required to teach these larger laboratory courses. However, we were concerned that changing to online assessments and eliminating the weekly writing of pre-labs might lead to a deterioration of students’ writing skills that would be reflected on course examinations (which are entirely written, no multiple choice) or weekly laboratory reports.

PROCEDURE

Colorado State University’s senior level Virology and Cell Culture laboratory course, like many university science laboratory courses, routinely has an enrollment of 30 or more students. In a semester, students were completing 17 pre-labs requiring them to calculate dilutions, analyze fabricated experimental data, predict and explain expected results, as well as explain the rationale for experimental design based on descriptions of the assays from their lab manual. These questions were mostly at higher Bloom’s levels and were designed to meet the course objective of teaching students to interpret data. For many years this was done by providing students questions in their lab manual. Students were required to complete these questions before lab periods and turn them in at the beginning of lab. There were many issues with this system: first and foremost grading these pre-labs, which often have over 20 questions, was incredibly time consuming, requiring many hours of teaching assistant time. As the teaching assistants were also grading weekly and often lengthy laboratory reports, they were routinely grading two or more written assessments each week. Furthermore, students often started lab with misconceptions that were not corrected until the teaching assistant was able to grade and return the pre-lab. Studies show that students prefer immediate feedback, even if it means it is computer generated, which they feel they benefit from more than written feedback provided at a later date (1). Lastly, to control costs to the students, the lab manual was printed in black and white, prohibiting the inclusion of images of experiments requiring color interpretations (such as ELISA assays) in pre-lab assessment. However, images of all assays performed in the course were available for students on the course website for use in answering pre-laboratory questions. To address these concerns in 2013, 17 online pre-lab assessments were created using our learning management system, Blackboard. Questions were created based on the questions provided in the lab manual, which students were instructed to use to prepare for, and consult during, the online assessments. Although a small percentage of questions were designed to make sure students knew what equipment, dilutions, solutions, etc. would be required for the lab session (Bloom’s level 1 or 2), all pre-labs required students to predict results based on data similar to the types they would be generating during their lab exercises (Bloom’s level 3 or 4). Virology requires a great deal of math to perform dilutions and to determine tissue culture infectious dose (TCID₅₀), multiplicity of infection (MOI), concentrations of virus, culture cells, and neutralizing antibodies. Students often struggle with this math, and all pre-labs required students to practice this math using novel data. Students were allowed to take each assessment three times.
times, and they were told which questions they missed but were not given the correct answer. Their highest score was recorded. Questions referring to images of data were added, allowing students to practice data interpretation. For example, images of hemagglutination inhibition assays are shown and students must make conclusions about the likelihood of a virus causing a current outbreak based on the data. These questions were in direct alignment with the learning objectives of the course, and were reflective of the way they would be assessed on examinations, although never identical.

Scores on examinations and written laboratory reports were compared for two semesters where pre-labs were handwritten (2011 and 2012) or completed online (2013 and 2014) (Table 1). No obvious difference was seen in pre-lab scores, lab report scores, or examinations.

CONCLUSIONS

When exam scores, lab report scores, and pre-lab assessment scores were compared across four years with two years each using either written or online pre-laboratory assessments, no obvious difference was noted in exam scores on any of the three midterms, written final exam, nor the practical exam, with similar scores and standard deviations being observed in all years. All examinations except the practical were handwritten, with no multiple-choice questions, and were graded by the author. Although the midterms were different each time, the final practical and written exams were exactly the same in all four semesters and hence represent a direct comparison. Neither was there an obvious difference in the quality of the laboratory reports turned in, as evidenced by similar average scores and standard deviations, over four years, graded by three different teaching assistants. These results indicate that using online pre-labs to prepare students for laboratory sessions leads to learning equivalent to answering handwritten pre-lab assignments and does not result in a decrease in the quality of written expression. This may indicate that the pre-lab assessments were not helping students learn to articulate their scientific knowledge as efficiently as the laboratory reports. On the other hand, giving students immediate feedback about their comprehension may allow students to come to lab with a better understanding of the material, compensating for the reduced opportunities to practice scientific writing (1). It is also possible that the 22 written lab reports provided a sufficient number of writing assignments to achieve writing proficiency. Although creating online assessments involved a significant time commitment and a great deal of evaluation and modification over time, online pre-labs significantly reduced the amount of grading, without reducing student learning and or writing ability, allowing a reduction in the number of teaching assistants required per section. Once established and modified based on student feedback, online pre-labs required very little time of the instructor and teaching assistants.

ACKNOWLEDGMENTS

Funding to create the online learning assessments was provided by the Colorado State University Institute for Learning and Teaching. I would like to thank Bret Abadie, an honor student, for his work helping to create these online assessments. The author declares that there are no conflicts of interest.

REFERENCES


<table>
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<tr>
<th>Average Scores</th>
<th>2011 Written Pre-Labs (n = 30)</th>
<th>2012 Written Pre-Labs (n = 38)</th>
<th>2013 Online Pre-Labs (n = 27)</th>
<th>2014 Online Pre-Labs (n = 41)</th>
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<td>Midterm 1</td>
<td>85.9 ± 9.6</td>
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<td>77.9 ± 18.3</td>
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<td>87.1 ± 10.1</td>
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<td>79.5 ± 18.9</td>
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<td>Midterm 3</td>
<td>85.3 ± 10.99</td>
<td>85.5 ± 8.6</td>
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<td>Final writtena</td>
<td>89.0 ± 6.8</td>
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<td>Final practicala</td>
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<td>All exams n = 5</td>
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<td>82.4</td>
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<td>Lab report n = 22</td>
<td>90.7 ± 4.0</td>
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a Exams were identical in all semesters. Marks are given ± standard deviation.
Changing academic culture to improve undergraduate STEM education

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Improving undergraduate science, technology, engineering, and math (STEM) education requires faculty with the skills, resources, and time to create active learning environments that foster student engagement. Current faculty hiring, promotion, and tenure practices at many universities do not measure, reward, nor encourage faculty pursuit of these skills. A cultural change is needed to foster improvement.

Introduction
Our economy requires a strong work force of college-educated STEM majors, and highly debated projections indicate the needs of the workforce will outstrip the supply. What is clear, according to the statistics compiled by the National Center for Education Statistics (NCES), which is tasked with collecting, analyzing, and reporting data related to education in the United States, is that many students, particularly members of under-represented groups and low-income students, leave STEM majors early in their academic careers (http://nces.ed.gov/pubs2014/2014001rev.pdf) [1]. To meet the future needs of our workforce, and ensure STEM employment access to all members of society, mechanisms to remedy this situation are needed. Why then is undergraduate instruction, particularly of introductory courses so often relegated to part-time, temporary, or non-tenure track faculty? I would argue, what the literature supports, that introductory courses are where a universities’ best, most recognized, and rewarded educators should be teaching, because this is where their talent is most needed [2]. A recent report by the American Association of University Professors shows data that at an average doctoral degree conferring research university only 25.5% of people providing instruction are tenured or on the tenure track, a number that has been consistently shrinking since they began collecting data in 1975 when it was 44.5% (http://www.aaup.org/sites/default/files/files/AAUP-InstrStaff2011-April2014.pdf). The question that has long gone unanswered is why is one of arguably the most important jobs of a university not worthy of tenure?

Fostering improvement in STEM education
Ample literature demonstrates that faculty who create active engaging classrooms have better student outcomes [1,3]. That literature will not be discussed here other than drawing attention to the meta-analysis of Freeman et al. [4] of 225 education studies that found a statistically significant increase in examination scores and pass rates for courses that utilize active learning over traditional lecture formats, and found similar results for grand mean effect sizes to other smaller meta-analyses [5,6]. It is the rare tenure track faculty member, usually pressured to maintain an active research program, who has the time to also keep up to date on both general and STEM-specific education literature and successfully implement new pedagogies in response. Furthermore, at most universities, there are few incentives to do so. Thus traditional tenure track research faculty members are unlikely to be the impetus for significant change. To improve undergraduate STEM education, institutes of higher education need to develop meaningful ways to evaluate the scholarship that teachers use in their teaching. I urge the creation of tenure track teaching positions that allow the stability, resources, and faculty development necessary to allow content experts to become effective pedagogy experts and productive members of the national STEM education community, and utilization of these faculty in introductory courses. While this model has been adopted at some institutions, it is not a common or consistently utilized practice, and when utilized the promotion and tenure requirements of such positions are often unclear. This will require a change in academic cultural attitudes about teaching; namely, recognizing that excellent teaching requires skill and is a form of scholarship. Current promotion and tenure packages rarely assess or give credit to teaching scholarship. The situation is amplified in the sciences where few faculty feel qualified to serve as teaching scholarship evaluators. As a result, evaluation of teaching often consists of analysis of the number of courses taught and student evaluations, which some claim are poor predictors of faculty teaching performance (http://www.aaup.org/report/observations-association%E2%80%99s-1975-statement-teaching-evaluation) [7] while others believe them to be reliable indicators of teaching quality [8]. However, most are in agreement that student evaluations alone do not capture all of the important aspects of effective teaching. In the quest for more reliable teaching evaluation methods, Nobel laureate Carl Wieman created the Science Education Initiative that provides documents for creating teaching inventories and guidance on classroom observation protocols (http://www.cwsei.ubc.ca/resources/tools.htm). He and his colleagues convincingly argue that currently most universities have no idea what type of classroom teaching is occurring, because there are no mechanisms to capture
this information in traditional promotion and tenure packages [9]. However, they stop short of providing guidance about how to evaluate faculty effectiveness for the purpose of promotion and tenure using these data. I suggest that universities utilize classroom observation protocols and classroom teaching inventory for faculty with primary teaching roles to produce teaching portfolios for inclusion in their promotion and tenure packages. Documenting efforts to improve undergraduate education should be an essential part of a teaching faculty’s promotion and tenure package. These faculty should be encouraged to document how they use educational research to guide their teaching methods (scientific teaching) [10,11], and this should be viewed as an alternative but equal form of scholarly activity [10–13]. I would suggest, however, that to encourage a cultural shift that recognizes teaching scholarship teachers must share their scholarship much like a researcher must share their findings. Therefore, to obtain tenure a primarily teaching faculty member must also demonstrate how they have contributed to the learning environment outside of their classroom.

Many of the ideas presented here are hardly new; it has been 24 years since Boyer [12] implored those in higher education to recognize and reward teaching scholarship. Although scientific teaching is gaining traction in some STEM education communities, little of the necessary cultural change regarding academic recognition of the scholarship involved in teaching suggested by earlier researchers have occurred [10–13]. At many universities, teaching faculty members are still treated as less skilled and valued members of the discipline.

One may question then, why have this conversation again now? The answer is that there appear to be reasons to be optimistic that the time is ripe for change. The rising costs of higher education has brought the issue of education quality to the attention of politicians. President Obama and our political bodies are currently debating ways to improve higher education, including a focus on monitoring and publishing student graduation and employment rates. This gives administrators a clear incentive to focus resources on quality teaching and student retention (http://www.whitehouse.gov/the-press-office/2013/08/22/fact-sheet-president-a-plan-make-college-more-affordable-better-bargain-). Furthermore, Alberts et al. [14] recently implored us to rescue biomedical research from a system that creates too many PhDs without adequate research funding to support their future careers as research scientists. The authors suggest that one strategy to mitigate this problem is to broaden the career paths available to graduate students. Perhaps it is time to create stable academic faculty positions for people who are interested in creating rich and meaningful curricula based on scientific teaching principals, who demonstrate teaching scholarship and are willing to share their pedagogy with other educators both within their university and at a national level. This could promote improved teaching in classrooms all over the country. However, to do this, it is imperative that we develop metrics that recognize teaching scholarship and integrate these metrics into traditional promotion and tenure packages. Critical to the success of this plan is that these metrics become widely adopted so that faculty who serve as external evaluators are able to provide meaningful evaluation of primarily teaching faculty. Lastly, but equally important, faculty must be rewarded for scholarly teaching, thereby encouraging both traditional and teaching faculty to take a scholarly approach to their teaching.

The question then becomes what does a primarily teaching faculty member worthy of tenure look like? In my opinion, such a faculty member should be able to demonstrate use of a scholarly approach in designing and assessing their courses. They must demonstrate clearly articulated learning outcomes, create class periods designed to help students reach these learning outcomes using scientific teaching, implement clearly aligned student learning outcome assessments, and provide timely and useful feedback to students. Currently, the types of materials that would demonstrate this type of teaching (teaching portfolios) are rarely included in promotion and tenure packages. I would argue that this makes it nearly impossible to assess teacher effectiveness. At Colorado State University, a group of University Distinguished Teaching Scholars advocate for the use of teaching portfolios that include these components in the promotion and tenure process (http://tilt.colostate.edu/sotl/taskforces/teaching/recommendations.pdf). The use of classroom observation protocols and a classroom teaching inventory would greatly aid faculty in creation of teaching portfolios to document their teaching scholarship. Furthermore, like all faculty members, they must demonstrate a record of disseminating their scholarship to other faculty members within and outside of their home institution. This can be achieved by publications in education journals, creation and dissemination of curriculum materials, education grant reviews, pedagogy publication reviews, presentations at or organization of education meetings, and participation in education initiatives of professional societies. Furthermore, they should provide service by serving on education-oriented committees at their home institution. In short, they should serve a role as an education leader in the department, college, university, and at the national level. However, it is important to point out that due to the time needed to teach at this level, expectations surrounding these scholarly pursuits should not be equivalent to those of faculty with much lower teaching loads. Although obtaining extramural funding for education initiatives is always a benefit, the scarcity of these funding opportunities makes obtaining these funds an unrealistic expectation for promotion and tenure; however, faculty should demonstrate efforts to obtain such funding by grant submission.

**Concluding remarks**

As President Obama points out in his call for higher education reform, since 1990 the US has fallen from number one to number 12 in 4-year degree attainment among 25–34 year olds (http://www.whitehouse.gov/issues/education/higher-education). Until the academic culture changes to recognize and reward faculty with the skills and expertise to help engage STEM majors, I fear we will continue to have this same conversation as the US falls further and further behind in the education of STEM majors.
Acknowledgments
I would like to thank Steve Hines, Lori Kogan, Phil Mixter, and Sherry Stewart for their critical analysis of the ideas presented here.

References
5 Ruiz-Primo, M.A. et al. (2011) Impact of undergraduate science course innovations on learning. Science 331, 1269–1270
Evaluating the Impact of a Classroom Response System in a Microbiology Course

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The use of a Classroom Response System (CRS) was evaluated in two sections, A and B, of a large lecture microbiology course. In Section B the instructor used the CRS technology at the beginning of the class period posing a question on content from the previous class. Students could earn extra credit if they answered the question correctly. In Section A, the class also began with an extra credit CRS question. However CRS questions were integrated into the lecture during the entire class period. We compared the two classes to see if augmenting lectures with this technology increased student learning, confidence, attendance, and the instructor’s ability to respond to student’s misconceptions, over simply using the CRS as a quizzing tool. Student performance was compared using shared examination questions. The questions were categorized by how the content had been presented in class. All questions came from instructors’ common lecture content, some without CRS use, and some questions where Instructor A used both lecture and CRS questions. Although Section A students scored significantly better on both types of examination questions, there was no demonstrable difference in learning based on CRS question participation. However, student survey data showed that students in Section A expressed higher confidence levels in their learning and knowledge and indicated that they interacted more with other students than did the students in Section B. In addition, Instructor A recorded more modifications to lecture content and recorded more student interaction in the course than did Instructor B.

Because of increasing enrollments and tighter budgets, colleges are offering larger classes as a way to save money (5, 12). Consequently, faculty-student ratios in many introductory courses range from 1:100 to 1:500. While studies show mixed results in determining what effect class size has on student performance, a trend does emerge—new students or students with lower achievement levels have trouble in larger classes (3, 9).

The current theory of learning, constructivism, is one where learning is an interpretive, recursive, building process whereby learners actively participate in the learning process in order to make meaning of new information and constructs so as to internalize this understanding as part of their own knowledge base (10). Therefore, attention to the limits of large class sizes is essential in order to maximize student achievement. Large classes inhibit types of instructional methods, strategies, and activities that are consistent with constructivism in four ways. First, learners need to make meaning of the new information in order to assimilate it into their existing knowledge base (19). Without meaning, information is often forgotten after a short period of time. As a result, learners need to interact with this new information in some way. Large classes limit this interaction, and the brief time allotted for instruction constrains the types of instructional strategies and activities that can be used to allow students to interact with new information.

Second, research on learning shows that individuals make meaning in a variety of ways and that these ways may not be the same for each individual (6). Using instructional methods in addition to the lecture method helps to meet the needs of all learners. Yet large classes are not conducive to instructional methods other than lecture.

Third, learning takes place in social settings through interaction with others (19). In other words, learners need to interact with others in order to make sense of new information prior to internalizing it (19). Again, large classes are not organized so that interaction between the instructor and students or among students can take place easily.

Finally, constructivism has expanded the role of assessment from primarily summative forms, assessments used to evaluate student learning at the end of a period of time or unit of study, to include formative forms, assessments that are conducted during instruction to inform ongoing instruction (1, 15, 16, 17). By using formative assessment during instruction, instructors gain information about students’ understanding of the course material and then use that information to adapt and modify instruction to correct misunderstandings and gaps before they are internalized by the student. However, the number of students in large classes makes it virtually impossible to gauge the learning of more than a few students during the class period, therefore, until recently, meaningful formative assessment has been difficult in large classes.

Classroom Response System (CRS) technology holds promise for remedying these weaknesses. (CRS is also known as Audience Response System, Interactive Response System, Personal Response System, and Student Response System.) In order to understand how CRS allows the transformation of large classes into learning settings
congruent with constructivism, one must first understand how these systems operate.

CRS technology consists of an instructor’s computer, wall-mounted receivers, and a handheld personal data transmitter (PDT) registered to each student. Classroom wall-mounted receivers are connected to the instructor’s computer (as is each student’s PDT). During instruction, the instructor poses a multiple-choice question, and students respond by aiming their PDT toward a wall receiver and pressing a button that corresponds to their answer choice. The wall receivers transmit the information to the instructor’s computer where the results are tallied by answer chosen and displayed on a screen for the entire class to view. In addition, the data are stored. The PDT is registered in each student’s name so that the results can be broken out by student.

The transformation of large classes into more interactive learning communities can be accomplished with CRS technology in the following ways. First, the PDT requires participation on the part of the student. Because the PDT is registered to each student, the student becomes accountable for his/her learning and communicating that learning by answering all the questions that are posed throughout the class period. Second, the instructor can facilitate paired discussion by asking students to discuss the question with a peer and then answer using the PDT. One successful method is for the instructor to pose a selected response question to which the students individually respond using their PDTs. Based on the results, the instructor then asks students to discuss the answers with a peer and decide if they want to change their answer. The instructor poses the question again, and students have another opportunity to respond. Based on the responses, the instructor can choose to move forward, reteach the information, and/or go over each question explaining the reasons for each answer choice. These instructional strategies allow students to actively participate in instruction and interact with peers to make meaning of new information. The instructor uses the real-time information gained through the use of the CRS to make teaching modifications. As such, the traditional teacher-centered classes are made over into more interactive, student-centered classes and an environment that accommodates more learning styles.

Current research has documented a variety of benefits as a result of using CRS. For example, studies showed that use of CRS increased students’ attendance, advance preparation for class (4, 14), attentiveness and enthusiasm (2, 4, 8, 9, 14, 20), and in-class participation (4, 8, 14, 20). Studies have also noted students reporting more enjoyment in classes because of CRS (4, 8, 9, 14, 20). To illustrate, research on CRS technology in physics indicated that attendance in CRS courses and students’ satisfaction with the courses was higher. This same research showed that students’ confidence in their own learning increased (8).

However, research into the effects of CRS technology on student learning is mixed. Slain, Abate, Hodges, Stamatakis, and Wolak (18) studied students in a doctoral pharmacy program over a 2-year period. They found that students’ scores on examinations increased with the use of CRS technology. Judson and Sawada’s (11) review of research on CRS technology in higher education noted that student learning increased when the CRS technology was paired with constructivist-oriented pedagogy such as actively engaging students with new information, but did not increase when paired with behaviorist-oriented pedagogy, where students passively received information. Paschal (13) compared two sections of a systems physiology course, one that used CRS technology and one that did not. She found that student learning was at least as good or better in the sections that used CRS technology than in the sections that did not.

With all this in mind, we looked to evaluate our own implementation of the CRS technology in a general microbiology course over a period of two semesters. We wanted to know if the ways we were employing the CRS system (i) increased opportunities for formative assessment of student learning that led to changes in instruction, (ii) increased student attendance, (iii) increased student learning, and (iv) increased student confidence in their own learning.

METHODS

Class characteristics. General Microbiology is an introductory microbiology course taught at the junior level with 80% of the class being either juniors or seniors. Students enrolled represented approximately 30 different majors of which only 10% were microbiology majors. Course prerequisites included general biology and second semester chemistry. Two sections, A and B, were taught each semester with one senior faculty member responsible for each section. Enrollment in Section A was 143 students and in Section B was 84 students. There is no required laboratory component to this course.

Course instruction. The course consisted of three 1-hour lectures per week for a total of 40 days of classroom instruction. Students were involved in group learning projects throughout the semester; they also took four examinations, including a comprehensive 2-hour final. There were 700 total possible points during the semester, and the students’ grades were calculated using the percentage of the total points earned, so that an A equaled 90 to 100%, a B equaled 80 to 89%, and so forth.

The classroom response system. The instructors in both sections used the eInstruction system provided by the book publisher McGraw Hill. Students could opt to purchase a personal data transmitter (PDT) for use during the semester, with each transmitter assigned a unique PDT number so that students could be tracked after registering their PDT. During class, each instructor asked a multiple-choice question, and students responded by aiming their PDT towards a receiver and pressing the button that corresponded with their answer. The receiver recorded the responses and transmitted the information to the instructor’s computer, which then projected a compilation of the results onto a large screen for the entire class to see. These results were summarized by percentage of response for each answer. To strengthen
academic integrity and reduce the sharing of answers, instructors gave students 1 minute or less to respond to questions.

**Use in the classrooms.** In Section B the instructor used the CRS technology at the beginning of the class period by posing a question on content from the previous class. Fifteen times during the semester questions were selected, and students who answered correctly received one point of extra credit (for a total of 15 possible points throughout the semester). Students were not told which days would be counted for credit. This section was taught Monday, Wednesday, and Friday 12:10 to 1:00 p.m.

In Section A, the class also began with an extra credit CRS question. In addition, the instructor posed CRS questions throughout the lecture. Nineteen times during the semester students answered a question, then had a formal opportunity to discuss the question with other students and were then asked to reanswer the question. The percentage of students giving each possible answer to the question the first time it was asked and then after discussion was captured by the CRS program. These questions were not worth any credit. This section was taught Monday, Wednesday, and Friday 9:00 to 9:50 a.m.

Even though students could attain extra credit for CRS questions only through purchasing a PDT, a small number of students did not purchase one. To our knowledge, the reasonable $15 cost of the PDT was not a barrier toward student purchase. Neither instructor has ever had a student ask for an alternative to purchasing the PDT. Moreover, those students not purchasing a PDT still benefited from participating in the CRS interactive student discussions and associated active learning exercises. Additional extra credit opportunities that do not require PDT purchase, such as receiving credit for summarizing microbiology stories in the news, exist in both sections.

**Data sources and analysis.** One source of data came from a daily instructor’s journal, where each instructor recorded the number of CRS questions used in class that day, the number of times students were instructed to formally interact with each other, and the number of times the instructor modified instruction based on the answers to the CRS questions. The captured data from the CRS program comprised the second data source. A third data source was an analysis of student examination performance on the four formal examinations. Each examination contained 10 to 14 questions. Each examination contained 10 to 14 questions about the course content that were identical in both sections. Approximately five to seven of these identical questions were based on content presented using the same instructional delivery method (lecture) for both classes. The remaining questions were also identical; however, the instructional delivery in the two sections differed. In Section B, these questions came from information presented only during the lecture. However, in Section A the information was supplemented using CRS questions, which were sometimes followed by student-peer discussions and a reanswering opportunity. The individual instructors wrote the remaining examination questions differently for each section. For the first two formal examinations, the Section A instructor wrote the shared exam questions, and for the last two examinations the Section B instructor wrote the shared exam questions. In both cases instructors reviewed the questions and agreed that they matched the content from their course.

**Statistical analysis of student examination performance.** A multivariable statistical analysis of variance (ANOVA) with section, exam, and question type as fixed effects and questions with type and exam as a random effect was performed. Question types were questions that were either covered by lecture only in both classes or by CRS questions only in Section A. The differences were considered to be significant if $P \leq 0.05$.

**Analysis of student perceptions of learning, confidence, and study habits.** During the last lecture, a survey was given to each class which asked students to rate each statement about their experiences with the CRS on a scale of 1 to 5; indicate the statement they agreed with most about their experiences with the CRS on a scale of 1 to 5; with 5 being strongly agree; 4 somewhat agree; 3 somewhat disagree; 2 strongly disagree; and 1 not applicable. Mantel-Haenszel chi-square analysis of differences between survey results for each question in the two sections was performed. The differences were considered to be significant if $P \leq 0.05$. The Mantel-Haenszel chi-square test analyzes correlation between rows and columns of a table and is appropriate when rows and columns are ordinal scales or one is dichotomous. In our study the question responses are ordinal, while the rater scale is dichotomous.

**RESULTS**

**Faculty restructuring of instruction based on CRS technology use.** To determine if integrating CRS questions throughout the lectures changed instruction or how students interacted with each other, each instructor kept a daily journal where he/she recorded how many times students were asked CRS questions, how many times students were instructed to interact with other students in a formal manner, and the number of changes the instructor made during the lecture due to feedback from CRS questions. The results are summarized in Table 1. The Section B instructor indicated modifying the planned lecture only once due to responses on the CRS questions, whereas the Section A instructor indicated modifying the planned lecture 84 times in response to the information gained from the CRS questions.

**Increased student interaction was impacted based on how CRS technology was used.** First, the number of students who opted to purchase the PDT differed based on how the CRS technology was used. In Section A where CRS questions were integrated throughout the lecture, 95.3% of students chose to purchase the optional PDT. However in Section B, where the PDT was used just for extra credit beginning of class quizzes, only 87.2% of students chose to purchase the PDT. Second, in Section A students participated in class via CRS 84 more times than students in Section B. Furthermore, Section A students were provided formal time to discuss a
topic with other students 20 more times than those in Section B. (Table 1).

Instructors also monitored student attendance through students’ use of the CRS technology. Of students purchasing the optional PDT, the average percentage of students attending class was approximately equal for each section each day (72.8 versus 74.8%).

**Student performance during instruction.** The percentage of students answering the questions correctly at the beginning of the class in both sections was comparable (78.2 versus 82.0% average or 86.0 versus 88.4% median). In Section A, student scores on CRS questions improved dramatically when they were allowed to discuss a question and then reanswer it, an option unavailable in Section B where questions were asked only at the beginning of class (Fig. 1). In fact, every time this technique was used, student scores improved, with an average gain of 22%.

**Student performance on examinations.** Student performance was analyzed using common examination items. When students in both classes were asked identical questions that were either covered by lecture only in both classes (non-CRSQ) or by CRS questions in only section A where CRS questions were used to augment lecture (CRSQ), we theorized that we would see an improvement in performance on CRSQ versus non-CRSQ only in section A. However, what we found was that the students in Section A performed better on both types of questions than students

<table>
<thead>
<tr>
<th>TABLE 1. Instructor record of interactions with students and between students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section</td>
</tr>
<tr>
<td>--------</td>
</tr>
<tr>
<td>A</td>
</tr>
<tr>
<td>B</td>
</tr>
</tbody>
</table>

<sup>a</sup>40 lectures total.

FIG.1. Comparison of scores of students answering CRS questions during lecture. Score 1 (light bar) is the percentage of correct scores when students answered the question after being given a brief lecture on the topic by the instructor. Students were then instructed to discuss the question and reanswer. Score 2 (dark bar) is the percent correct upon reanswering.
in Section B (Fig. 2).

**Statistical analysis of what factors were significant in differences in performance.** When statistical analysis of the factors accounting for this variance was performed, it was found that only the section and the exam were statistically significant as indicated by a $P$ value of less than 0.05 (Tables 2 and 3). No statistical significance was found between question types (CRSQ versus non-CRSQ) even when analyzed with section, exam, or both. However, students in Section A performed better on all question types; and this was statistically significant as is indicated by a $P$ value of $<0.0001$. However, as they failed to perform better on CRS-specific questions, we cannot say that this improvement is a result of participating with CRS.

**Students in CRS-integrated course expressed more confidence in their knowledge and felt more engaged than students in the nonintegrated course.** At the end of the semester students were asked to fill out a student learning survey (Fig. 3); responses were tallied and a statistical analysis was performed. On five out of eight of the survey questions, students in the CRS-integrated question section gave a statistically significant more favorable response about their confidence, participation, and ability to give feedback than students in the course where CRS questions were only asked at the beginning of class ($P \leq 0.05$) (Tables 4 and 5). Three questions showed a high significance ($P = 0.0003–0.0004$) when the responses from Section A (CRS-augmented lectures) were compared to the responses from Section B (CRS nonaugmented lectures). In Section A, 72.7% of students responded that they Strongly Agree or Somewhat Agree that they interacted more with other students due to CRS use (Question 2) versus 31.4% in Section B. In Section A, 80% of students responded that they Strongly Agree or Somewhat Agree that they had a higher than normal ability to give the instructor feedback about their level of understanding due to CRS use (Question 4) versus 42.9% in Section B. In Section A, 80.3% responded Strongly Agree or Somewhat Agree that they felt CRS use had increased their confidence in forming relationships amongst concepts (Question 6) versus 42.9% in Section B.

A somewhat less striking but still significant difference existed between the two sections for two questions pertaining to their confidence about their learning and performance (Question 1) and their ability to give feedback (Question 4). However, as they failed to perform better on CRS-specific questions, we cannot say that this improvement is a result of participating with CRS.

**FIG. 2.** The average student performance on six or seven exam questions that were identical in each section and were either covered by lecture only in both classes (non-CRSQ) or by clicker questions in only Section A (CRSQ). Section A (light bar) is the section that used CRS questions during lecture; Section B (darker bar) used CRS questions only as quizzes at the beginning of class. Standard deviation of scores is indicated by error bars.
knowledge levels. In Section A, 72.7% responded Strongly Agree or Somewhat Agree that they felt CRS use had decreased their doubt about their learning progress (Question 1) versus 43.5% in Section B ($P = 0.0462$). In Section A, 83.5% responded Strongly Agree or Somewhat Agree that they felt CRS use had increased their confidence in the knowledge level they had obtained (Question 3) versus 60% in Section B ($P = 0.0215$). Students in Section A did not give a statistically significant more favorable response on the questions pertaining to the instructor making instructional changes based on CRS responses or the two questions about the effect of CRS questions on their study habits.

### TABLE 2. Statistical analysis of variance

<table>
<thead>
<tr>
<th>Fixed effect tested</th>
<th>$F$ value</th>
<th>$P$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section</td>
<td>33.02</td>
<td>&lt;0.0001*</td>
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<tr>
<td>Exam</td>
<td>3.73</td>
<td>0.0182*</td>
</tr>
<tr>
<td>Section*Exam</td>
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<td>Question type</td>
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<td>0.9971</td>
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<tr>
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<tr>
<td>Exam*Question type</td>
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<td>0.9823</td>
</tr>
<tr>
<td>Section<em>Exam</em>Question type</td>
<td>1.35</td>
<td>0.2711</td>
</tr>
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</table>

*The differences were considered to be significant if $P \leq 0.05$.

### TABLE 3. Least square means for statistically significant variables

<table>
<thead>
<tr>
<th>Effect tested</th>
<th>Estimate</th>
<th>Standard error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section A</td>
<td>83.69</td>
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<tr>
<td>Section B</td>
<td>72.78</td>
<td>1.22</td>
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<td>Exam 1</td>
<td>88.80</td>
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</tr>
<tr>
<td>Exam 2</td>
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<td>3.83</td>
</tr>
<tr>
<td>Exam 3</td>
<td>72.38</td>
<td>3.57</td>
</tr>
<tr>
<td>Exam 4</td>
<td>74.76</td>
<td>3.84</td>
</tr>
</tbody>
</table>

### TABLE 4. End of semester survey results

<table>
<thead>
<tr>
<th>Question no.</th>
<th>Answer</th>
<th>Avg. score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5 (strongly agree)</td>
<td>4 (somewhat agree)</td>
</tr>
<tr>
<td>Section A</td>
<td>Section</td>
<td>Section</td>
</tr>
<tr>
<td>1</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>19</td>
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<td>5</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td>5</td>
<td>3</td>
</tr>
</tbody>
</table>

* $n = 55/143$ 38.50%.

* $n = 35/84$ 41.70%.


**Circle the appropriate number**

1) I experienced less doubt about my learning progress in this course than in other large classes because the clicker method provided me more opportunities to compare my course knowledge with that of others in the class.

2) I experienced greater interaction and participated in more debate with my class peers as a result of using the clicker method in this class than I experienced in other large classes where this instructional method is not used.

3) I experienced greater confidence levels in the knowledge I attained in this course as a result of the more active learning methods that the clicker system encouraged, such as regularly talking over course information with my classmates.

4) Compared to other large courses I have taken, I gave the instructor more feedback about what I know in this course because of the opportunities that the clicker method provided.

5) At least once, I noticed that the instructor quickly adjusted or changed the way course information was presented to the class in response to how we students answered questions using the clicker method.

6) By using the clicker method, I developed greater confidence in my ability to form relationships among this course’s central concepts, principles, and processes than in other large classes that do not use the clicker method. I felt like I made better connections among the course information items.

7) I experienced more out-of-class, course-related discussions with my fellow classmates than I usually do in other large class because of the more frequent in-class peer discussions encouraged by the clicker method.

8) I studied more in this course than in other large courses, in part, because I wanted to prepare myself for the clicker questioning and resulting peer discussions sessions.

FIG.3. End of the semester student learning questionnaire.

**DISCUSSION**

The current literature on CRS technology has reported the following outcomes: increased student attentiveness and enthusiasm for the course, increased student engagement in class, and increased student understanding of subject matter (4, 8, 14, 18, and 20). Our study shows that instructors who actively use CRS technology as an instructional tool to involve students and as a formative assessment tool to gauge understanding throughout a class session do seem to have a greater awareness of student difficulties, as indicated by the increased number of changes made to instruction during a class over the course of the semester (84 lecture modifications). Therefore, the frequency of CRS use during a lecture appears to impact formative course improvements. Interestingly, although the Section A instructor indicated making 84 changes in the course due to student responses to CRS questions during instruction and the Section B instructor only indicated making a single change, students in both classes responded similarly to the survey item, “At least once, I noticed that the instructor quickly adjusted or changed the way course information

<table>
<thead>
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<th>Question no.</th>
<th>P value</th>
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</thead>
<tbody>
<tr>
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<tr>
<td>8</td>
<td>0.6965</td>
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</tbody>
</table>

The differences were considered to be significant if \( P \leq 0.05 \).
was presented to the class in response to how we students answered questions using the PDT.” Section A’s response level stood at 3.38 compared to 3.06 for Section B, a difference that was not statistically significant. However, the students may not recognize going over the answer to a question where the class did poorly as a change to the course as the instructor does.

Students did however notice the increased interaction with other students in the course, as indicated by the large (4.14 versus 3.46) and most statistically significant ($P = 0.0004$) difference in survey responses for the two sections on question 2 of the survey, “I experienced greater interaction and participated in more debate with my class peers as a result of using the PDT in this class than I experienced in other large classes where this instructional method is not used.”

Most interestingly, on all three survey questions that dealt with student confidence in their learning, knowledge, and ability to make connections among the course’s central concepts, the students in Section A (where the CRS questions were actively used throughout the lectures) responded more favorably at a statistically significant level. This is congruent with the research and literature on teaching and learning that states that learners learn in a variety of ways, need to be actively involved in the learning process, and need to engage with others to make meaning of new information.

Even though increased attendance in courses using CRS is well documented, there is little information about whether the type of use affects student attendance. Of students purchasing the optional PDT, the average percentage of students attending class was approximately equal for each section each day (72.8 versus 74.8%). However, 8% more students chose to purchase the optional PDT in Section A where CRS questions were used to augment the lectures, so attendance may have actually been slightly higher in this section. We do not have any data on the attendance habits of the 4.7% of students in Section A and 12.8% of students in Section B who chose not to purchase the PDT.

Though it is a tenuous link at best, we had hoped that the use of CRS technology would motivate students to study more. However, students in both sections responded similarly that they somewhat disagreed that the use of CRS motivated them to study more or interact more outside of class with other students.

Our hypothesis based on the literature (14) was that students in Section A would perform better when comparing the student scores in Section A to those in Section B on exam questions that cover the same material. This study contradicts this position with evidence of even exam performance from both sections. We believe that our data support expanding use of CRS technology ‘beyond quizzing activity for increasing students’ learning and confidence in their learning.

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REFERENCES


