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Blended Learning Improves Science Education

Brent R. Stockwell,[1,2,3,*] Melissa S. Stockwell,[4,5,6] Michael Cennamo,[7] and Elise Jiang[1]
[1]Howard Hughes Medical Institute, Department of Biological Sciences, Columbia University, Northwest Corner Building, MC 4846, 550 West 120th Street, New York, NY 10027, USA
[2]Department of Chemistry, Columbia University, New York, NY 10027, USA
[3]Department of Systems Biology, Columbia University, New York, NY 10032, USA
[4]Department of Pediatrics, Columbia University, New York, NY 10032, USA
[5]Department of Population and Family Health, Mailman School of Public Health, Columbia University, New York, NY 10032, USA
[6]NewYork-Presbyterian Hospital, New York, NY 10032, USA
[7]Columbia Center for New Media Teaching and Learning, Columbia University, New York, NY 10027, USA
*Correspondence: bstockwell@columbia.edu
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Blended learning is an emerging paradigm for science education but has not been rigorously assessed. We performed a randomized controlled trial of blended learning. We found that in-class problem solving improved exam performance, and video assignments increased attendance and satisfaction. This validates a new model for science communication and education.

Blended Learning Is an Emerging Instructional Pedagogy

At the undergraduate level, science is most commonly taught using a lecture and textbook format. In this pedagogical approach, students are assigned a textbook to read at home before class and listen to an instructor lecture on the assigned material during class. Although this approach to learning is effective for some students, it is suboptimal for many undergraduate students and may contribute to students leaving the sciences (Handelsman, 2007).

Recognition of the limitations of the traditional instructional approach to science using a textbook and lecture format has led to suggestions for examining alternative methodologies (Handelsman, 2007). In recent years, online learning options, including massive open online courses (MOOCs), have become increasingly available as a means to produce learning in students who cannot attend classes in person and have been proposed as alternative learning paradigms (Reich, 2015). However, the low completion rates of online courses, such as MOOCs, and the importance of instructor-student and student-student interactions in classrooms have suggested that online learning alone is unlikely to be the most effective strategy for teaching and learning (Glazer, 2012; Reich, 2015).

Nonetheless, the online learning paradigm offers valuable tools that could supplement or replace aspects of the traditional lecture-and-textbook-based approach to teaching and learning (Glazer, 2012). First, pre-class online video assignments may offer advantages over textbook assignments, especially for introductory science courses with complex and dense material that is unfamiliar to beginning students (Kagohara, 2010). Reading a textbook engages mainly visual, language comprehension, and cognitive neural pathways and requires that the reader is able to select the most relevant material for application to the course (Wandell, 2011). Video instruction, on the other hand, adds auditory engagement to visual, language comprehension and cognitive processes, and allows for more varied emphasis of the importance of content. Video assignments are typically more engaging for a large introductory science course and may stimulate greater engagement with the course material.

In addition, listening to a lecture in class involves mostly recording and recalling information, which are lower levels of Bloom's taxonomy of learning (Bloom, 1956). In contrast, solving problems in real time during class forces students to synthesize and apply knowledge as they process it (Amador et al., 2006). A historical comparison has shown that a structured course with in class problem solving improves performance and reduces the achievement gap (Haak et al., 2011). Moreover, a survey of pre/post-test data in physics courses revealed that interactive teaching improved student learning (Hake, 1998). Finally, low-stakes formative assessments improved exam performance when compared across students in different class sections with different teachers (Roediger et al., 2011). Thus, active, problem-based learning may improve student performance on exams (Che et al., 1998; Knight and Wood, 2005).

We wondered if pre-class video assignments and in-class problem solving would result in increased engagement, satisfaction and more effective learning. While it has been suggested that these techniques in some contexts and in isolation improve learning (Fitzgerald and Li, 2015; Freeman et al., 2014; Glazer, 2012; Handelsman, 2007), studies involving undergraduate science education have generally not been conducted as randomized controlled trials under otherwise identical conditions with the same material and the same instructor. Rather, they have been conducted using different instructors or different course materials, making it difficult to assess if changes seen were due specifically to the teaching methods. We endeavored to rigorously examine whether video-based preparation and in-class problem solving increase student engagement, as indicated by class attendance, and ultimately exam performance, for undergraduate science students.

A Randomized Controlled Trial to Evaluate Blended Learning

A total of 172 students enrolled in Biochemistry I: Structure and Metabolism,

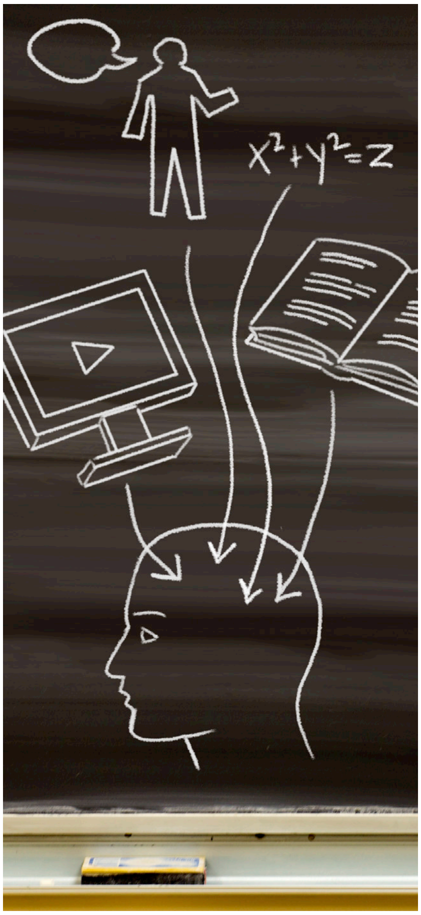

Figure 1. Blended Learning Combines Different Means of Content Delivery

an undergraduate biochemistry course at Columbia University, were invited to participate in a randomized controlled trial in the fall of 2014. A total of 111 students enrolled in the study. We used a two-by-two study design, in which we compared the effects of both video versus textbook pre-class assignments and lecturing with instructor-demonstrated problems versus lecturing with student problem-solving in class. Students were randomized to one of four arms: (1) textbook preparation for lecture, (2) video preparation for lecture, (3) textbook preparation for problem-solving class, or (4) video preparation for problem-solving class (Figure 2). The students were stratified for randomization by gender and prior exam performance (low: lower third versus high: upper two-thirds) into each of the four arms to ensure equal representation of these students in each study arm; 54% of students in the study (60/111) were male (Figure 2).

In advance of class, students were provided either a link to a video or a link to a textbook reading, covering the same material, as per their randomization assignment; students were instructed not to review other materials and had little incentive to do so, since the study results were not included in their grade, as participation was voluntary, and since there was no assigned textbook for the course for them to otherwise consult. During class, students either listened to an instructor-delivered lecture or listened to the same lecture material interspersed with instructions to solve problems related to the presented material, again as per their randomization arm. To ensure that the content was the same in each class, the students who attended the lecture were also provided with the same problems and their solutions, but these were explained by the instructor rather than being solved by the students. Thus, the difference between the lecture and problem-solving class formats was not in the content but rather whether the students actively solved the presented problems or were simply told the answers as part of the lecture. All lectures were provided by the same instructor.

The first outcome measured was class attendance. Since participation was voluntary, students were able to discontinue participation at any point in the study. We analyzed whether the rate of class attendance after receiving the preparation material was different between the students who received a video versus textbook pre-class assignment. Indeed, we found that more students randomized to the pre-class video assignment attended class (84%, 47/56) compared with those randomized to the textbook assignment (67%, 37/55) ($p = 0.04$, Pearson's chi-square test) (Figure 2). In other words, twice as many students chose not to attend class after receiving a textbook assignment (18/55; 32.7%) compared to those who received a video assignment (9/56; 16.1%). This result was consistent with the hypothesis that a video is a more engaging way to present new and complex material to students and stimulates students to be interested in learning more about the topic by attending class.

To test this hypothesis, we examined the level of satisfaction among the students with the preparation material. There was significant improvement in satisfaction with the preparation material among the students who received the video assignment (4.3/5.0) compared to students who received a textbook assignment (2.9/5.0) ($p < 0.0001$, Mann-Whitney test) (Figure 2). This is consistent with the fact that fewer students who received the textbook assignment chose to attend class and suggests that textbook preparation for a science class is less satisfactory and engaging for students compared to assignments that involve watching a video.

At the end of each class, students took a 20 min online, multiple-choice exam, while still present in class, to test their understanding of the material. First, in order to test whether the exam measured the same performance characteristics found in the rest of the course, we compared exam performance for students with a higher prior exam performance versus a lower one. Indeed, we found that prior exam performance (high versus low) correlated with the study exam performance: the median exam scores for students in the high prior exam group (73/100) was significantly ($p = 0.006$, Mann Whitney test) greater than the median exam score for students in the low prior exam group (60/100), suggesting that the students exerted their typical effort and exhibited similar performance characteristics, despite the fact that participation was voluntary.

We then examined the performance of the four study arms on the end-of-class exam to determine the effects of teaching pedagogy on student performance. We found that the median exam score increased within each arm, from arm 1 (textbook preparation, in-class lecture; 61/100) to arm 2 (video preparation, in-class lecture; 67/100) to arm 3 (textbook preparation, in-class problem solving; 73/100) to arm 4 (video preparation, in-class problem solving; 80/100) (Figure 2). Indeed, the students in the arm that experienced fully blended learning, with video preparation and in class problem solving, had the highest median exam score (80/100).

We found that the most significant intervention was the implementation of student-centered problem solving during class, as the median score on the exam

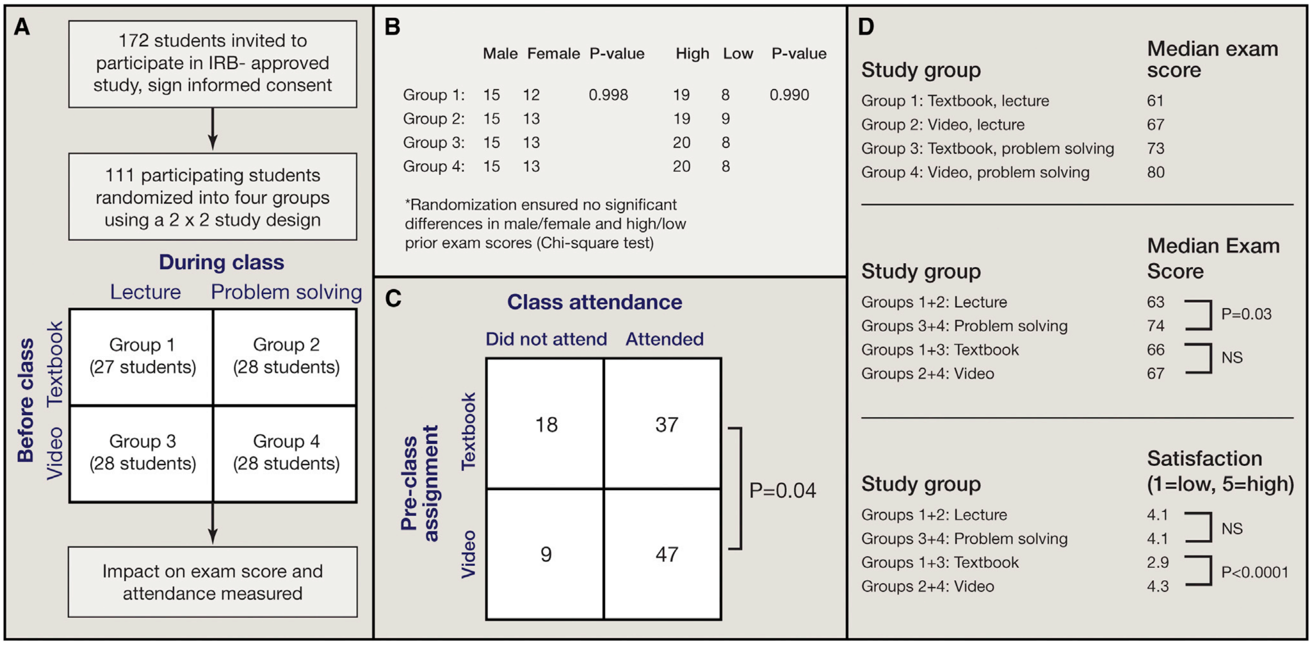

Figure 2. Randomized Controlled Trial to Evaluate Teaching and Learning Strategies for Undergraduate Biochemistry

(A) The study followed the indicated scheme, in which students were invited to participate voluntarily in a study and asked to indicate their informed consent. They were randomized into one of four groups, receiving either a textbook or video assignment before class and either a lecture or a lecture with problem solving during class. The impact on attendance and exam score was then measured.

(B) Equivalent numbers of male and female students and students with high and low prior exam scores were assigned to each group.

(C) Students who received a video assignment were more likely to attend class than students who received a textbook assignment. The number of students who attended or did not attend class after receiving a video or textbook assignment is indicated.

(D) Students who solved problems in class performed better than students who only listened to a lecture. The median score of each group of students on the end of class exam is indicated (out of 100 possible points). The comparison of scores is shown for the students in the lecture and problem-solving groups. Video assignments were more satisfying to students than textbook assignments; students were asked to rate how satisfied they were with their pre-class assignment on a scale of 1 (low satisfaction) to 5 (high satisfaction).

was higher for those who were randomized to the lecture-plus-problem-solving class (74/100) compared to those randomized to the lecture-only class, irrespective of preparation material (63/100) ($p = 0.03$, Mann Whitney test) (Figure 2). We also compared the exam scores of students in the textbook versus video preparation groups but found no statistically significant difference in this relatively modest sample size, despite the trend toward higher scores in the group that received the video assignment.

We recognized that the instructor in a randomized controlled trial may exhibit unconscious bias. We sought to measure this objectively by evaluating student satisfaction with the lecture and problem-solving classes. Student satisfaction did not differ significantly between students who attended the problem-solving versus lecture classes (4.1 versus 4.1, out of 5.0, $p = 0.99$, Mann-Whitney test) (Figure 2). This suggests that the traditional lecture was engaging and of high quality and that the difference in exam performance was not due to unconscious instructor bias in the delivery of the lecture material. Moreover, it suggests that student satisfaction alone is not a reliable indicator of learning gains and that institutions and instructors should be cautious in evaluating pedagogical methods using only student satisfaction measures, which are the typical metrics used in course evaluations. Indeed, objective measures of learning gains may ultimately be the most accurate means of assessing courses.

Overall, we conclude that providing students with problems to solve during class results in significantly improved exam performance, compared to simply having the instructor describe the same problems and their solutions during the course of the lecture.

Implications for Science Education

In recent years, there has been a growing interest in improving science education to increase the diversity of individuals who choose science careers and to broaden the pool of scientifically literate citizens globally. The traditional textbook-and-lecture approach to teaching undergraduate science, while effective for a subset of individuals, is not the most effective means of stimulating learning in the broadest group of students. We and others have sought to examine the effectiveness of an alternative pedagogy that replaces textbooks with video assignments and traditional lecturing with active, student-centered problem solving.

One result of this trial was that students who received a video assignment were both more likely to attend class and to rate their assignment as providing a higher degree of satisfaction, compared to students who received a textbook assignment. Thus, in this study, video assignments were more effective at stimulating student interest and engagement with the course material. Therefore, providing supplemental videos for science courses, either in place of, or in addition to, textbook assignments, may enhance student engagement and motivation.

A second finding was that students who listened to a traditional instructor-focused lecture underperformed students who actively solved problems during the class period. This was despite the fact that the students in these two groups rated their classes as equally satisfying. Thus, while students enjoyed passively listening to a lecture as much as being asked to solve problems during class, they learned the material better when they actively worked on problems, rather than simply being given the problems and answers as part of the lecture. Therefore, instructors may wish to provide frequent opportunities during class for students to apply the content presented to specific problems. This provides ongoing formative assessments for students to test their learning and refocuses student attention during an otherwise extended period of lecturing. In addition, asking a student to apply knowledge to new contexts may assist them in learning the material in a more effective way that allows them to extrapolate the knowledge to new situations in the future; a related case-based pedagogy has been used successfully in business, medical, and law schools.

One of the difficulties faced when trying to rigorously assess the effectiveness of teaching and learning strategies is the challenge of delivering identical content via the same instructor and same pool of students such that it is the teaching method that is being assessed and not other factors. A variety of strategies have attempted with limited success to deal with this challenge, such as historical comparisons among the students who take a particular class that has altered its methodology, comparisons among instructors who use different teaching methodologies, or comparisons among the same instructor using different teaching methodologies within one course but for different topics and at different points of time in the semester. We suggest that it is most effective to use the rigor and methodology of randomized controlled trials, which are able to measure the impact of patient interventions in health and biomedicine, to examine the impact of teaching approaches on student learning (Drits-Esser et al., 2014). By using the same content, the same instructor, the same point of time, and the same pool of students randomized to different conditions, we were able to minimize the impact of variables beyond the ones we sought to measure. In addition, the trial was conducted in a pragmatic fashion with students within their usual course with their usual peers and instructor and is therefore reflective of results in a real-world setting. It also demonstrates the feasibility of conducting such pragmatic education trials.

Unfortunately, we were only able to examine the effects of teaching style in one class. Additionally, we did not examine the long-term effect of these interventions on learning; it would be valuable to have students take another exam several months or even years after participating in the study to examine how well they retain the information. We propose that such longitudinal assessments of learning gains could be organized at the institutional level by regularly administering follow-up exams to students in specific majors who have completed the same required courses early in their program. Perhaps by coupling such programs with a compensation system for participation, the long-term impact of course structures and pedagogical methods could be assessed.

Overall, the results from this trial suggest that a blended teaching approach, which uses video assignments in advance of each class to stimulate interest in the topic and provide foundational knowledge, coupled with lectures having in-class problem solving, is a more effective strategy for science education compared with traditional approaches. It is worth noting that video assignments did not improve student exam performance on their own but did increase attendance and satisfaction. By providing foundational information pre-class, video assignments can also create time in class for active learning, such as student problem solving. Thus, video pre-class assignments can serve a critical role in the blended learning paradigm for education.

These results also illustrate the feasibility of using the clinical trial methodology in educational intervention evaluations. Blended learning approaches may help students learn information in a way that they can then translate to novel situations they will encounter in their academic and professional careers, which is the hallmark of effective learning. Institutions and instructors may wish to consider how to support blended learning paradigms in their science curricula.

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