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Molecules and Cells: Team-based and Multi-modal Learning Improves Comprehension and Increases Content Retention

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Abstract

This is an Evidence-Based paper which describes the impact of a form of team based (TBL) and multi-modal learning on short and long term content retention in a biomedical engineering course. Our previous work has demonstrated that students have varied learning preferences: visual, aural, kinesthetic, and read/write, with almost two-thirds preferring a multimodal approach. TBL enables us to integrate these preferences into an effective student-centric learning environment. Students scored significantly higher on the team-based assessments (group readiness assessment test or gRAT exams) than on the individual readiness assessments (iRAT exams) demonstrating the effectiveness of team based collaborative learning. In addition to the short-term knowledge gain acquired through peer instruction, we also measured long-term retention of final exam material four months' post-final. On both the final exam and the four month post-final retest, students scored significantly higher on material taught through TBL. ***Thus, team based learning, which includes a combination of reading, writing, kinesthetic and aural methods of learning, demonstrated significant short- and long-term gains in content retention***.

Background

The Johns Hopkins University Biomedical Engineering (BME) course *Molecules and Cells* is a mandatory class for BME majors, primarily taught during fall of their sophomore year. In addition, approximately ten percent of the class is composed of students from other engineering majors including material and mechanical engineering. For most students, it is their first challenging BME course, combining both biochemistry and cell biology with quantitative analysis. From the faculty's perspective, *Molecules and Cells* has the added complexity of student heterogeneity: over two-thirds of the students completed AP Biology in high school while the remainder have a weak biology background. In fall 2016, we gave the students (n=128) a pre-test prior at the start of the semester. Overall, students scored an average of 33%. The 72% of students who took AP or IB Biology scored significantly higher on the pretest (35.1 $\pm$ 10.6% vs 26.4 $\pm$ 12.1%, unpaired t-test $p<0.001$).

We had previously surveyed our students (n=99) to determine their learning style preferences[1]. Almost two-thirds of the students (62%) were multimodal, learning through a combination of visual, aural, read/write, or kinesthetic modes. For the 38% of students who preferred a single learning style, most preferred read/write (18%) modes of learning, while 9% had a visual learning preference, and 8% leaned towards kinesthetic. Traditional lectures, in which faculty present lecture notes for the entire period, was the preferred mode of learning for only 3% of students as illustrated in Figure 1[2].

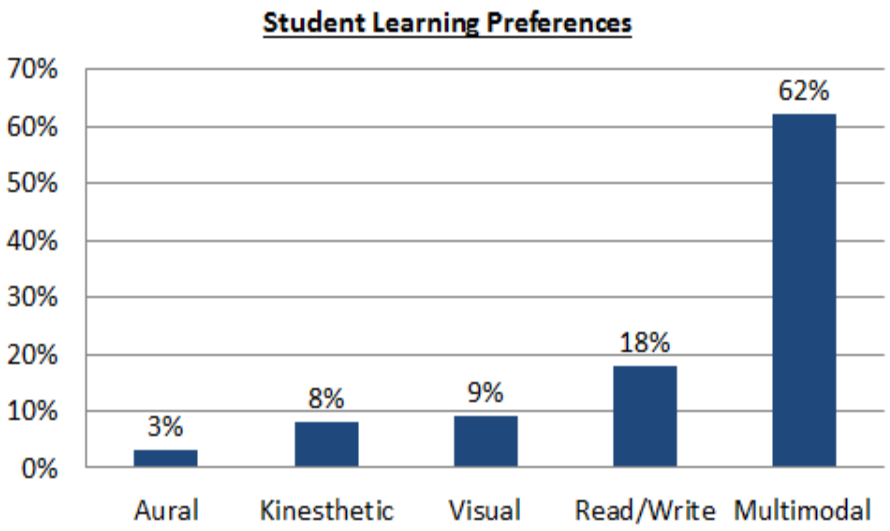


Figure 1: Data from VARK survey on student learning preferences (n= 99) in Molecules and Cells. Most students (62%) were multimodal, learning through a combination of visual, aural, read/write, or kinesthetic modes. For the students who preferred a single learning style, 18% preferred to learn through read/write activities, 9% visual, 8% kinesthetic, and 3% aural.

Given the diversity in both background preparation and learning style preferences for this course, we have found it best to teach using a variety of methods combining individual learning, faculty-led sessions, and peer learning as illustrated in Figure 2[2].

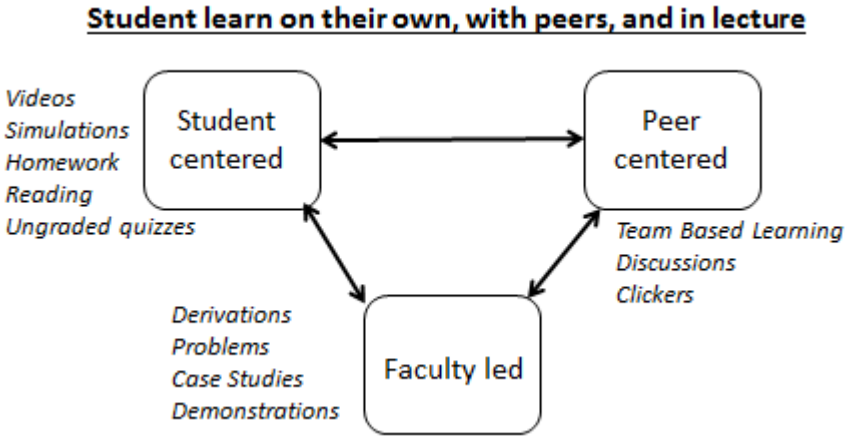


Figure 2: Learning is achieved through faculty-led, student-centered, and peer-based mechanisms.

The data in Table 1 summarize self-reported learning mechanisms from anonymous student end-of-semester surveys (n=115) from Fall 2016. The student-centered methods include numerous online resources, many of which were developed specifically for *Molecules and Cells*, such as ungraded quizzes (49%), videos and simulations (25%), and a student-generated test bank using PeerWise (27%) [11]. Most students not only attended lectures (91%) but also viewed the recorded lectures online (70%). The majority of students attended Thursday sections (66%) with the teaching assistant (TA) and 25-30 classmates to review homework and lecture content. A

number of students also participated in any of the eight office hours offered each week with faculty/TAs for individual or small group sessions (41%).

Table 1
Learning Mechanisms in *Molecules and Cells*

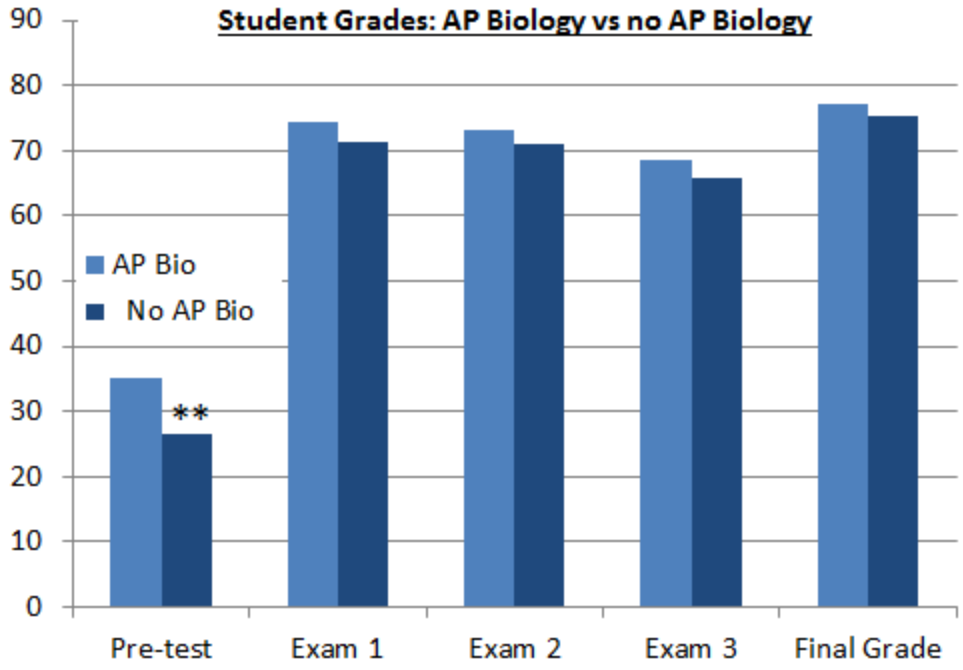
Downloaded and reviewed slides and lecture notes	97%
Attended lectures	91%
Viewed lecture online (Panopto)	70%
Worked with a study group	70%
Attended Thursday section	66%
Took the online self-check quizzes (ungraded)	49%
Attended office hours with the TAs and/or with faculty	41%
Answered extra Peerwise questions	27%
Viewed posted videos and simulations	25%

The faculty led sessions included lectures and team based activities. Table 1 also shows that students appreciated the value of these team-based activities, since 70% of the students met outside of class to work with a study group. This Evidence-Based Practice paper focuses on using one team-based learning activity incorporating individual and group quizzes, and the effect of that activity on long-term retention of the course material.

Course Structure

The course met three times a week for fifty minutes per session, with an additional TA-guided section once a week. Mondays and Wednesdays were used for lectures with frequent clicker questions[3], think/pair/share activities[4], and demonstrations. Fridays were used for team based learning and clinical/research discussions. First exposure to each week's course material was usually through short videos[5], readings[6], [7], simulations, and animations[8].

For example, during the module on enzymes, students viewed short videos, read sections of the textbooks, and practiced using simulations to gain an introduction to enzyme binding, kinetics, competitive and non-competitive inhibition, and allosteric modification. Lecture time was used to derive the Michaelis-Menten and Lineweaver-Burk equations and to graph data with various inhibitors and activators. Lectures included clinical case discussions with a variety of clicker questions on such topics as the enzyme inhibitor Sarin - a deadly nerve gas. The course was designed to expose students to material multiple times through multiple teaching methods. As illustrated in Figure 3, this approach resulted in students having a common level of understanding by end of the semester. Despite the fact that 72% of students who took AP or IB Biology scored significantly higher on the pretest, there was no significant difference in the grades for any of the three exams or in final class grades ($p>0.1$) between the AP/IB student scores and those that had a weaker background. We believe this is not only due to the multiple online resources available for students to catch-up, but also to the effectiveness the classroom activities, especially the individual and group quizzes used for team-based learned.



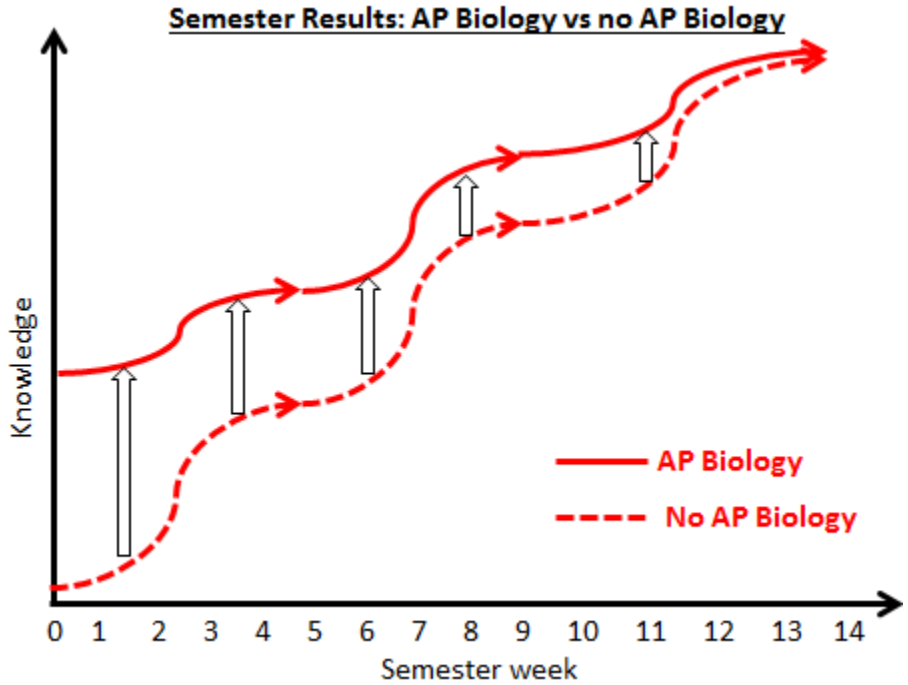


Figure 3a: Students started the semester with significantly (**) different backgrounds in molecular biology, based on scores on the pretest (n=130, unpaired t-test, p<0.0001, 35±11 vs 26±12). There was no significant difference between any of the exam grades or final course grade (77±8 vs 75±7, p>0.2) for students who had completed AP biology versus students who had not had AP biology.

Figure 3b: The combination of individual learning and classroom activities benefited every student such that they all achieved the course learning objectives prior to each of the exams.

Molecules and Cells is a required four-credit course in the Johns Hopkins University ABET accredited BME program. Students are told on the first day of the course that they should plan to spend ten to twelve hours on the course each week between attending the three lectures and Thursday section, completing the homework, and studying. We were concerned about the workload for this course and asked our students in a Blackboard survey to estimate their weekly time commitment to Molecules and Cells.

*On average, how much time did you spend preparing for Molecules and Cells **each week**. Include class time, Thursday section, homework, office hours and exam preparation.*

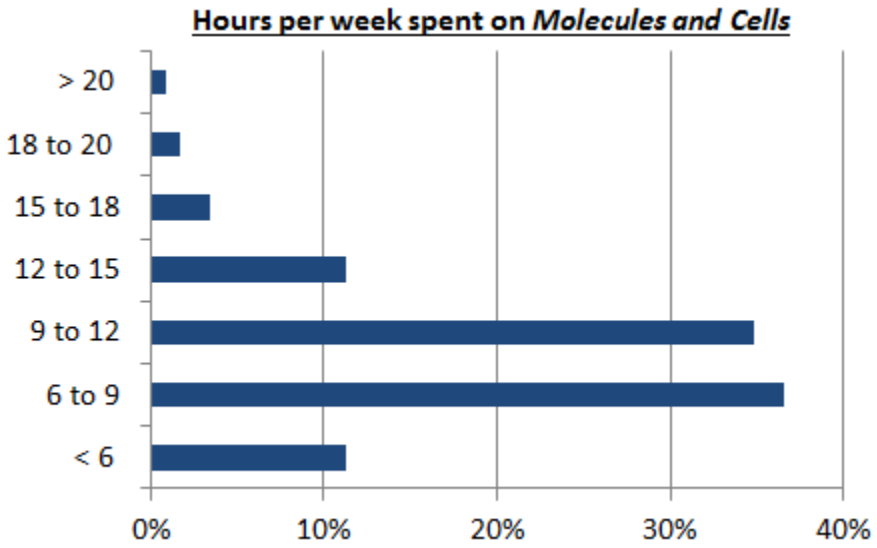


Figure 4: Students (n=115) self-reported hours per week spent on Molecules and Cells. 83% of students spent 12 or fewer hours per week on the course.

The time commitment results from one year are summarized in Figure 4 and indicate students spent an average of 9.7 $\pm$ 1.3 hours per week on the course, with 83% of students spending 12 hours or less each week (n=115). The data indicate that for a large majority of the students the time commitment required to succeed is reasonable for a four-credit course. These time commitment values are similar to data obtained in previous years (9.5 $\pm$1.2 over three years, n=342 students). The average grade for the course has remained relatively constant over the last nine years at 77.2$\pm$2.3.

Weekly Team Based Learning (TBL)

There has been substantial research documenting the value of team based learning on student understanding and comprehension [4], [5], [9], [10]. However, team based learning is only effective if each member of the team is prepared for the group discussion. In other words, the success of team based learning requires individual student preparedness. *Molecules and Cells* students hand in homework on Thursday and are then given the opportunity to discuss their solutions during teaching-assistant led sections prior to the Friday morning TBL exercise. Teams of five students were randomly grouped and worked together the entire semester on a total of nine team-based learning exercises. Students start the Friday class by taking a ten minute, ten

question, multiple choice test (iRAT-individual Readiness Assessment Test) which has been designed to challenge the students on the material covered that week. After students hand in their iRAT, they complete the same ten question quiz as a team (gRAT-group Readiness Assessment Test). The student iRAT/gRAT scores clearly demonstrated the effectiveness of team based collaboration as shown in Figure 5. In a class of 137 students, the average iRAT grade over the fall semester (9 quizzes) was 65.0 ± 13.3, while the average gRAT grade was 89.9 ± 11.6, significantly higher ($p<0.0001$).

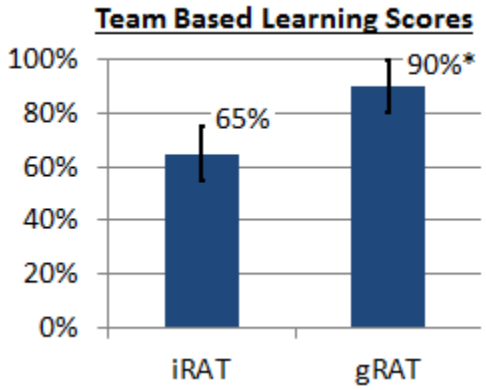


Figure 5: Students start the team-based learning (TBL) exercise by taking a ten minute, ten-question, multiple choice test (iRAT-individual Readiness Assessment Test). Following the iRAT, students complete the same ten-question quiz as a team (gRAT-group Readiness Assessment Test). In a class of 137 students, the average iRAT grade for nine quizzes was 65.0 ± 13.3, while the average gRAT grade was 89.9 ± 11.6, significantly higher ($p<0.0001$).

The student's grade on the iRAT/gRAT was calculated 50% from the iRAT, and 50% from the gRAT, thus students had an incentive to prepare for the TBL sessions. The gRATs are energetic, interactive sessions where each team member defends their reasoning for choosing one of the answers from a scratch-off sheet that provides immediate group feedback to the students. If the answer is incorrect, the team has an opportunity to continue their discussion until, through peer instruction, all members of the team understand the correct answer[9]. After the gRAT cards have been collected, faculty can quickly assess if there were problem areas and discuss those topics. As a result, students leave the Friday sessions with a much deeper understanding of the material covered that week[5].

We have found that the use of iRAT/gRAT assessments also tempers the student who tends to command group discussion while encouraging the more reserved student to participate. The instant feedback provided by the scratch off cards provides a system of checks and balances: when the vocal student pushes the group to answer a question incorrectly, the group's gRAT score is reduced and this decreases the controlling student's influence during the next discussion. In contrast, the reserved student's level of participation increases when he or she had the correct answer but did not make their knowledge evident to the group. In all cases, TBL sessions give students the opportunity to reinforce their understanding of the material through group debate. 93% of students believed TBLs were a useful learning experience, which is consistent with the literature[9]. Some student comments on TBL are provided in Table 2.

Table 2
Student Comments on Team Based Learning using iRATs and gRATs

I was skeptical of the gRAT before, but I am convinced by the superior performance yielded by group work over the semester.
I liked being able to assess my own knowledge first before discussing in a group setting. It is really helpful to discuss concepts with peers.
TBLs encourage me to keep up with lectures and they give me an idea of how much I know at that point.
At first I was unsatisfied with the fact that my final grade would depend on my group, but in the end, I found that listening to others' ideas actually helped me understand the thought process behind answering some of the questions better.
The TBL sections helped me master the material and keep up-to-date on what we were learning in class. I would like to have more of the sessions throughout the semester.
The TBLs always helped everyone keep on track with the material, and see what we are really expected to know from lecture in terms of difficulty of questions.
The TBLs kept me in check. It is an excellent way to make sure students are not falling behind.
The team-based aspect of the TBLs definitely helped me to get a better grip on the material and instant feedback helped significantly.
My favorite MoleCell activity, in retrospect, may have been the gRAT's; it was just somewhat fun and exciting to scratch off to find the right answer.
I really enjoyed the TBLs. I think they were a good way to make sure I knew that week's material. Additionally, it helps foster relationships between fellow BMEs.

The remainder of the Friday class time was used for discussion of current research and clinical topics relating to that week's topics. Sample post-TBL discussion subjects have included impediments to the development of Ebola and Malaria vaccines, the immune response to sugars, and new treatments for cancer. These discussions use current events to bridge the gap between needed background information and real-world applications.

Effect of Team Based Learning using iRATs and gRATs on Retention

Four months after the completion of the course, we retested (with IRB approval) the students using a subset of the original final exam. Questions from each faculty member were selected to mimic the difficulty of material within the original exam (35 points from the original 100). Retested questions for the retention exam came from a mix of TBL and non-TBL assessed materials. Questions were balanced in difficulty and question style (multiple choice, short response, quantitative, etc.). This retest was given during a regularly scheduled lecture in a required BME spring sophomore-level course which met for one hour. The students were not informed about the retest and consequently had not studied the material since the final exam. All of the students (n=91) were able to complete the retest of the exam within the one-hour time frame, thus eliminating a time constraint as a factor in their score. On average, students retained 84% of their knowledge. The original final exam grade of the 35-point subset was 79% (27.4 ± 3.6 points), while the re-test grade for those questions was 66% (22.9 ± 4.0 points). Exam retest scores were 16 ± 14% lower than their original test score ($p<0.0001$) (Figure 6)

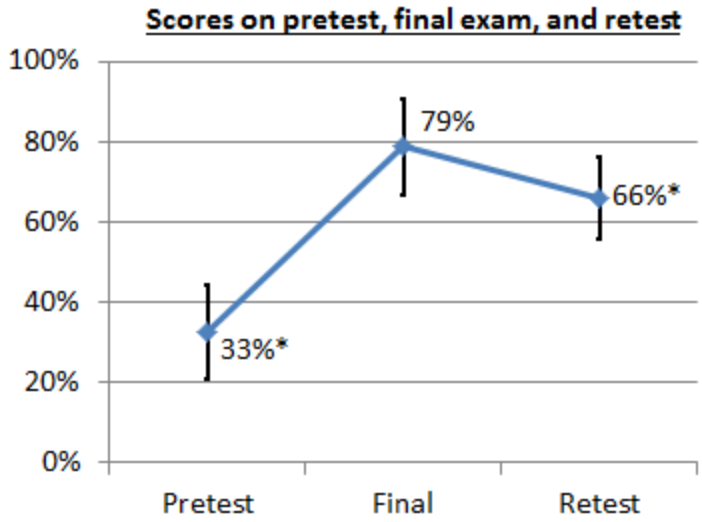


Figure 6: Scores on pretest, final exam, and retest. Students scored significantly lower on the pretest than on the final exam ($p<0.0001$). Students also scored significantly lower on the retest given four months after the final exam ($p<0.001$).

Although student scores decreased significantly on both TBL and non-TBL material, students still ***scored significantly higher on material taught with TBL*** on the both the final exam and the retest (Figure 7). The final exam score for the TBL taught material was 86.5±9.9%, while the final exam score on the material not taught with TBL was 67.0 ±14.9% (paired t-test, $p< 0.0001$). This increased effect of team based learning on retention was also evident four months later on the retest. On average, students scored 78.0±12.4% on the material taught using TBL, and 47.9±16.9% on the material taught without using TBL. This tells us that the students learned more and forgot less when using TBL.

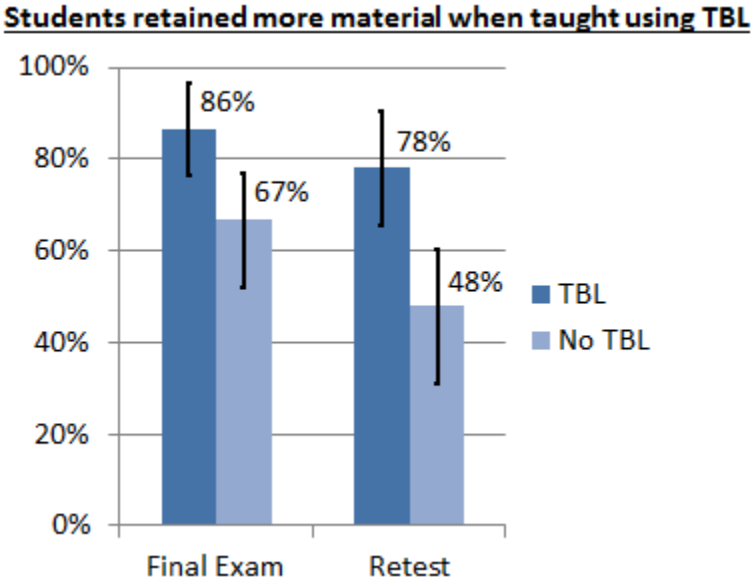


Figure 7: Students scored significantly higher on the final exam on material taught with TBL. ($p< 0.0001$). Student scores decreased significantly on both TBL and non-TBL taught material.

However, students scored significantly higher on the retest on material taught with TBL ($p < 0.0001$). In fact, students scored 20.6±1.6% more on questions covered by TBL quizzes ($p < 0.001$). TBL scores on the left.

When we analyzed the retest data in more detail on a student-by-student basis we found a surprising result. ***Ten percent of the students actually scored better in the four-month post-course retest than on the original exam***. Further analysis revealed that this increase was entirely due to an increase in material taught through TBL. The students had a significant increase in their TBL scores, from 76.6±11.6% to 86.2±9.3% ($p<0.0025$). These same students had a small, yet insignificant decrease in their score for the non-TBL material from 51.9±15.2% to 46.9±18.6% ($p>0.05$). Thus, any increase in score for these students was entirely due to improvement on the TBL-based material (Figure 8)

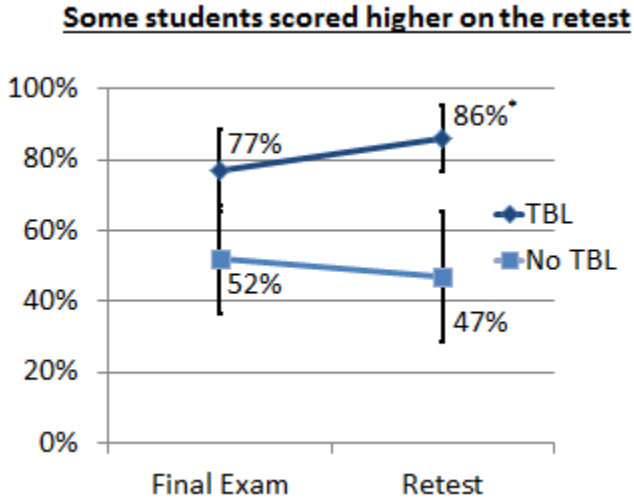


Figure 8: The nine students who increased their score on the retest significantly increased their TBL score from 76±11.6% to 86.2±9.3% ($p<0.0025$), top line - circles. These same students had a small, yet insignificant decrease in their score for the non-TBL material from 51.9±15.2% to 46.9±18.6% ($p>0.05$), bottom line - squares.*

Results and Summary

Despite the fact that students in *Molecules and Cells* start with diverse backgrounds, and likely have diverse learning preferences, by the end of the semester they achieve the course objectives. We used a variety of teaching methods to allow students to learn both individually and in a group setting[2]. Using lecture time for Team-Based Learning was a particularly effective method of ensuring that every student was actively engaged in the course. Students not only demonstrated short-term increases in understanding during the gRATs, but also a significant increase in long-term comprehension on the final exam. ***This increase in comprehension was not related to whether a student had taken an AP Biology course***. Students who had completed AP or IB biology started the course with a significantly higher score on their pretest. However, at the end of the semester, whether a student had taken an AP biology course had no impact on their final grade, as illustrated by Figure 9, and Figure 3a.

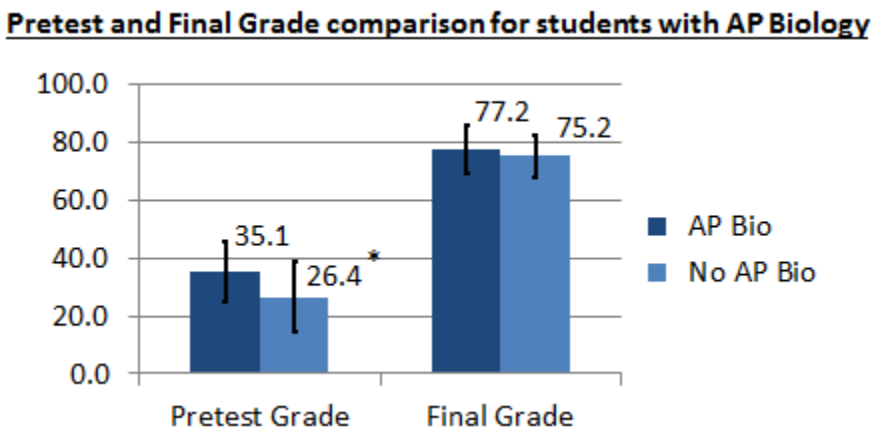


Figure 9: Students who had not taken AP or IB Biology scored significantly lower on a semester pre-test ($p<0.0001$). By the end of the semester, there was no significant difference in final grade between students who had taken AP or IB Biology and students who had not ($p>0.2$).

We have now been using the iRAT/gRAT quizzes, one aspect of team-based learning, for six years. During this period we have simultaneously increased the variety and depth of online resources for our students. Table 1 summarized the multiple learning mechanisms used by students throughout the semester, many of which contributed to the course outcomes, and consequently the student's final grade. Students could take advantage of opportunities to review the material numerous times through the diverse array of material posted on the course website including ungraded quizzes, recorded lectures[11], links to additional videos and simulations [8], and hundreds of multiple-choice questions from the peer-generated question bank made within PeerWise[12]. Some of these methods, such as downloading and reviewing the slides and lectures notes are used by almost all students (97%). However even lesser used resources such as viewing short videos (25%), answering extra multiple choice questions on Peerwise (27%), and taking ungraded online quizzes (49%) are vital in helping individual students to fill in their own knowledge gaps. ***We believe it is important for faculty to offer these methods, even if only used by a minority, to address the diversity in background and learning preferences.*** For example, while answering Peerwise questions was only used consistently by 27% of the students, these students each answered, on average, 117 multiple-choice questions.

In addition to offering students multiple methods to learn on their own, faculty need to critically consider the best methods to utilize class time. Our data indicate that a combination of faculty lectures interspersed with clicker questions, demonstrations, research and clinical applications, and team based activities benefit student comprehension. The significant increase in long-term retention of material taught using a form of team-based learning is especially relevant in planning classroom activities. Even four months after the final exam students remembered material taught using team-based learning significantly better than material taught through other methods. The team-based learning activities use in Molecules and Cells not only increased individual student learning, they also taught students the value of working as team. In the end-of-semester survey, 70% of students (n=115) said they worked with a study group outside of class.

Providing methods for students to learn material on their own, and reinforcing the material through team-based learning, demonstrated significant short- and long-term gains in content retention.

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Acknowledgment

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