Team-Based Learning Enhances Performance in Introductory Biology

Traditional lecture has been the instructional method of choice by faculty at many colleges and universities and is especially common in large introductory science courses. Unfortunately, lecturing alone is not the most effective way to promote learning (Handelsman et al. 2004; Knight and Wood 2005). Many students in introductory courses view science as overwhelming and believe that success in these courses depends on memorization of numerous facts and terms. This problem is often compounded by the fact that instructors in large-enrollment courses are not provided adequate assistance and there is little incentive to implement active learning exercises or other creative teaching approaches.

Fortunately, this past decade has seen an increased awareness of the value of active learning in the college classroom (Caccavo 2001; Lunsford and Herzog 1997; Tessier 2004, 2006, 2007). Some activities used by instructors include concept mapping, prescribed exercises (Freeman et al. 2007), think/pair/share, exam question writing, and others. Most studies indicate that active learning improves student learning and performance (Crouch and Mazur 2001; Ebert-May, Brewer, and Aldred 1997; Freeman et al. 2007; Knight and Wood 2005; Tessier 2007; Mazur 1997). Indeed, recommendations by the National Science Foundation and the National Research Council support an increased emphasis on active-learning approaches in higher education (NRC 1997; NSF 1996).

Personal response systems (PRS, or clickers) and collaborative (team-based) learning have received increased attention recently for their potential role in active learning. Handheld remote clickers can be linked to individual students and are often used to monitor class attendance, enhance student-professor interactions, provide immediate feedback, and record quiz or exam responses. Clickers have been shown to have either a neutral or positive effect on student performance in the classroom (reviewed in Caldwell 2007). Collaborative learning has also been used effectively, especially in smaller class settings. This learning approach takes the emphasis off the lecturer as the provider of knowledge and places it on students as constructors of their own knowledge. Cooperative-learning activities have been shown to enhance thinking, attitude, comprehension, and even social skills of students (reviewed in Lord 2001).
Given the problems associated with the traditional lecture method, the constraints associated with large classes, and the effectiveness of active learning, continued development and testing of efficient student-centered learning approaches are needed. This study explores the effectiveness of team-based learning (TBL) in a large-enrollment introductory biology class. Two sections of General Biology were taught in the same semester. One section used the traditional lecture and note-taking format, while the other was taught with a major TBL component that incorporated regular use of clickers. Student performance on exams, quizzes, and end-of-semester surveys was recorded in both sections. The results support the use of TBL as an effective, student-centered approach that enhances learning and energizes the learning environment.

Course format
Two sections of General Biology, enrolling approximately 200 students each, were taught during the fall semester of 2006. Both sections were taught during the morning hours on Mondays, Wednesdays, and Fridays. Students had no advanced indication of how their course would be structured when they enrolled in the class. Students in the lecture-based section spent each class period listening to the instructor present information and were expected to take notes, learn the material, and be able to apply their knowledge on exams. Supplemental information, such as outlines of lecture notes, practice questions, and exam study guides, were made available throughout the semester. Grades in this lecture section were based entirely on four multiple-choice exams, including a comprehensive final. Exams consisted of a combination of factual recall, application of knowledge, and generalized data-interpretation questions.

The second section of General Biology was taught using a TBL approach modified from Michaelson, Bauman Knight, and Fink (2004). Students were asked to self-organize into teams of four to six students during the second week of classes and these teams were maintained throughout the entire semester. The TBL section included traditional lectures twice per week (comparable to those given in the lecture section) as well as weekly learning assignments and quizzes known as readiness assessment tests (RATs). The learning assignments formed a cornerstone of the instructional approach in this section, and students were provided with these assignments for every chapter covered that semester. The learning assignments included questions that required extensive use of the textbook (Freeman 2005). These questions, written by the instructor, included some that required students to simply look up answers in their book, but also others that required students to describe processes, apply knowledge, make predictions, and draw conclusions based on experimental results. Students were asked to complete roughly two chapters each week.

The learning assignments were not collected or graded but were used as the basis of weekly multiple-choice RATs, as described in Michaelson, Bauman Knight, and Fink (2004). RATs consisted of multiple-choice questions, most of which were taken from the test bank included with the textbook (Freeman 2005), and were given on most Fridays throughout the semester. On RAT days, students were given around 10 minutes to discuss the learning-assignment questions with their teammates and were also encouraged to ask the instructor if they needed anything clarified. After discussion time, students were given between five and ten minutes to take the RAT individually. Individual RAT responses were recorded with iClickers provided to students free of charge. Students then gathered with their teammates to decide the best answer for each RAT question after individual RAT responses were recorded. Team responses were recorded with IF-AT (Immediate Feedback, Assessment Technique) scratch-off forms (Epstein Educational Enterprises). Teams earned full credit for first-try correct responses, but also earned partial credit if they got the correct answer on the second or third try. All students on a given team received the same team score. Students were encouraged to appeal
questions they considered unfair for any reason. An appeal consisted of a brief paragraph describing why the question was unfair or unclear and a reference to a page number in the textbook that helped justify their appeal. Learning assignments and RATs were made available to students in the lecture section to ensure both sections had access to comparable resources before each exam.

Analysis
A presemester comparison of both sections was made possible by an exam recently developed as part of the assessment program in the Department of Biology. The exam included 85 questions designed to assess departemental learning goals such as content knowledge and data interpretation. This presemester comparison represents a crucial component of this study because it provides a baseline comparison used to demonstrate differential learning in the lecture and TBL sections of General Biology.

Individual and team RAT scores and exam scores were recorded throughout the semester. In addition, a nongraded, end-of-semester survey was administered to students in both sections. The survey included five data-interpretation questions (direct assessment) taken from the textbook test bank (Freeman 2005) as well as indirect assessment questions on student perceptions of course format and attitudes about the use of clickers (included only on the TBL section survey). One-tailed t-tests were used to test for significant differences between mean responses in the lecture and TBL sections where appropriate. Final-grade distributions (based solely on exam scores) were compared between the two sections using a chi-squared test of independence.

Results
Results of the presemester assessment exam reveal that student performance in both the lecture and TBL sections was virtually identical with respect to content knowledge, ability to interpret data, and overall exam performance (Figure 1). Therefore, any differential performance seen throughout the semester between the lecture and TBL section is likely due to the instructional method used.

Differences in performance were observed between the lecture and TBL sections throughout the semester. Exam performance alone reveals that students in the TBL section tended to score higher than did students in the lecture section (Figure 2). Indeed, average scores on the first three exams were significantly higher in the TBL section than in the lecture section ($p < 0.05$). The main exception was the average score on the final exam, which was nearly identical in both sections (average score = 69.15% and 69.43% in lecture and TBL sections, respectively). Final-grade distributions, based solely on exam scores, were also significantly different between the two sections with students in the TBL section earning more As and Bs and fewer Ds and Fs than students in the lecture section ($X^2 = 10.91$, 4 d.f., $p < 0.05$).

End-of-semester survey responses provide a valuable, indirect comparison of student learning between the TBL and lecture-based approaches (Table 1). Students in both sections responded comparably on questions 1–3, which focused on their perceived ability to understand major concepts and use the scientific method to draw conclusions. The average and most frequent responses indicate that students in both sections tended to agree that they have a strong grasp of major concepts covered through-
out the course. Although students in both sections tended to agree that they understand how the scientific method is used, the most frequent response in the lecture section was "strongly agree," while students in the TBL section chose "agree" as the most frequent response. Average responses for questions 4 and 5 were significantly different between the two sections ($p < 0.05$). Students in the TBL section were more likely to agree that lecture note-taking is an effective way to learn than were students in the lecture section. On the other hand, students in the lecture section were more likely to agree that they would learn better if more in-class assignments were incorporated into the course.

Responses to questions pertinent to TBL and the use of clickers in the classroom indicate that students tend to agree that TBL and clickers are effective and valuable and should continue to be used in introductory biology courses (Table 2). Indeed, most students agreed that TBL helped them learn more effectively and think more deeply than would have lecture alone (questions 1 and 2). Most students also indicated that they did complete the learning assignments to the best of their ability (question 3). Students also agreed that it is fair for all team members to receive the same score for the team RATs (question 4) and that most team members completed their learning assignments on a regular basis and contributed to group discussions (question 5). Overall, students valued the TBL approach (question 6).

Students seemed to value the clickers, although perhaps not as much as the TBL approach in general (questions 6 and 10). Most students agreed that clickers helped make the class more interactive (question 7), but they didn't necessarily learn more than if clickers weren't used (question 8). Most students did find it helpful to see other student responses when clickers were used during class to gauge comprehension of concepts (question 9). Overall, students were neutral on their willingness to purchase a clicker with their own money (question 11).

Voluntary responses on teaching evaluation forms also provide indirect evidence that TBL enhances learning in general biology. A total of 109 students in the TBL section completed a voluntary teaching evaluation form and of those, 68 students included comments about the TBL approach. A total of 93 comments were made about TBL. Of those, 80 comments (86%) were positive and indicated that TBL promoted learning in introductory biology. Although the remaining 13 comments didn't suggest a negative attitude toward TBL, they did indicate that in-class activities took up too much time and that, as a result, the instructor rushed through lecture material too quickly. The majority of the positive com-
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ments (62.5%) identified the weekly RATS as being especially effective at promoting learning. The remaining positive comments identified the learning assignments themselves (28.8%) and the use of clickers (8.8%) as TBL components that were effective at promoting learning.

Discussion
The TBL approach outlined here can be used fairly easily in any large class, but does require an initial investment of time. The payoff is an enhanced learning environment that is enjoyable for students and instructor. Students are more dynamic, lively, engaged, and more likely to ask thought-provoking questions in the TBL format. The results presented here are consistent with other collaborative learning studies (Lord 2001; Tessier 2007) and warrant the continued development and testing of collaborative learning approaches.

Scores on multiple-choice exams were generally higher in the TBL section than in the lecture-based section (Figure 2). These results indicate that some component of TBL helped students comprehend material better than lecture alone did. It is unclear whether the learning assignments themselves, discussions of learning-assignment questions with classmates, or increased testing via weekly RATS is responsible for enhanced performance on exams. It is likely that the discussion of learning-assignment questions among classmates plays a big role in increased comprehension since results presented elsewhere indicate that students are able to perform well on exam questions that relate to concepts they have to teach to their classmates (Tessier 2007). In addition, the IF-AT forms used during team RATS likely contributed to higher exam scores in the TBL section, as these have been linked previously with increased learning, retention, and discussion (Cortright et al. 2003; Cotner, Baepler, and Kellerman 2008; Dihoff, Brosvic, and Epstein 2003; Dihoff et al. 2005; Epstein et al. 2002, 2003). Interestingly, the difference in exam performance between the TBL and lecture sections decreased as the semester progressed (Figure 2). This result may be due to a delayed ability of students in the lecture section to learn how to process and retain material presented in lecture format.

Surprisingly, scores on the comprehensive final exam were virtually identical between the two sections (Figure 2). This may indicate a lack of a long-term TBL effect (at least for exam performance), although results of end-of-semester surveys indicate otherwise (discussed below). The final-exam scores may also be partially explained by the fact that most of the questions (about 62%) focused on human physiology. Students in both sections likely believed they had a fair understanding of these concepts beforehand and may not have studied as much as they had on previous exams. The remaining 38% of the questions were comprehensive and were

TABLE 1
Responses on end-of-semester surveys administered to students in lecture and TBL sections of General Biology. Response choices were 1 = strongly agree; 2 = agree; 3 = neutral; 4 = disagree; and 5 = strongly disagree.

<table>
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<tr>
<th></th>
<th>Lecture section</th>
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<th>TBL section</th>
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<td></td>
<td>N = 107</td>
<td>N = 108</td>
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<tr>
<td></td>
<td>Mean</td>
<td>S.E.</td>
<td>Mode</td>
<td>% Agree/ Strongly agree</td>
<td>Mean</td>
<td>S.E.</td>
</tr>
<tr>
<td>1. I feel that I have a strong grasp of the major concepts covered in this course.</td>
<td>2.12</td>
<td>0.08</td>
<td>2</td>
<td>77.6</td>
<td>2.07</td>
<td>0.07</td>
</tr>
<tr>
<td>2. I understand how the scientific method is used to answer questions.</td>
<td>1.58</td>
<td>0.06</td>
<td>1</td>
<td>93.2</td>
<td>1.65</td>
<td>0.07</td>
</tr>
<tr>
<td>3. I feel confident in my ability to draw conclusions based on experimental data.</td>
<td>1.86</td>
<td>0.07</td>
<td>2</td>
<td>82.2</td>
<td>1.99</td>
<td>0.07</td>
</tr>
<tr>
<td>4. The lecture/note-taking format is an effective way for me to learn. **</td>
<td>2.16</td>
<td>0.09</td>
<td>1</td>
<td>70.1</td>
<td>1.72</td>
<td>0.09</td>
</tr>
<tr>
<td>5. I would learn better if more in-class assignments were incorporated into this course. **</td>
<td>2.16</td>
<td>0.01</td>
<td>3</td>
<td>64.5</td>
<td>2.81</td>
<td>0.1</td>
</tr>
</tbody>
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** = Significantly different (p < 0.05)
similar to ones presented on previous exams. One might expect comparable performances, regardless of teaching approach, on these questions.

Surveys administered to students at the end of the semester indicate that students taught via TBL were better able to interpret results and draw appropriate conclusions than were students taught via lecture alone (Figure 3). This is especially noteworthy since nationwide more of an emphasis is being placed on the process of science and less on memorization of facts and vocabulary. It should be noted that students were not given any advance warning of the survey. Therefore, the results presented hopefully reflect what students are capable of when put on the spot. These results are not surprising, given that TBL encourages students to consider concepts from multiple viewpoints.

The direct-assessment data previously described are somewhat contradictory to indirect-assessment data (Table 1). Interestingly, there is no indication of any perceived difference in students’ ability to understand major concepts, use the scientific method, and draw appropriate conclusions between lecture-based and TBL (Table 1). It is not clear how students decide to respond to statements such as those in Table 1. Perhaps they are not entirely aware of how their thought process has changed after completing a course or they don’t recognize the connection between statements such as those in Table 1 and the activities they participate in throughout the course. Either way, instructors should help students recognize how much they do accomplish by the end of a course. In addition, indirect assessment does not appear to represent the most accurate measure of student learning (over 82% of students in the lecture section agreed or strongly agreed that they feel confident in their ability to draw conclusions based on experimental data [Table 1], but the average score on those types of direct assessment questions was only 64% [Figure 3]). This is noteworthy considering the central role that student teaching evaluations (indirect assessment) play in promotion and tenure decisions at many institutions.

There does seem to be an inverse correlation between instructional format used and preferred by students (Table 1). Students in the TBL section felt that lecture was an effective way for them to learn while students in the lecture section felt they would have learned more if the course included more in-class assignments. Students likely form a perception of the path of least effort and probably prefer that method of instruction. If so, students in the TBL section (who were exposed to both teaching approaches) likely view lecture as an easy way to learn and may not appreciate the enhanced learning achieved through the TBL approach.

One concern about TBL is the fairness of all team members receiving the same team RAT score. Interestingly, over 84% of all students agreed or strongly agreed that it was fair for all team members to receive the same

<table>
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<th>TABLE 2</th>
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<tr>
<td>Responses on end-of-semester surveys administered to students in a TBL section of General Biology. Response choices were 1 = strongly agree; 2 = agree; 3 = neutral; 4 = disagree; and 5 = strongly disagree.</td>
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<thead>
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<tbody>
<tr>
<td>1. The team-based learning approach helped me learn concepts more effectively than lecture alone would have.</td>
<td>1.89</td>
<td>0.10</td>
<td>1 76.9</td>
</tr>
<tr>
<td>2. The team-based learning approach forced me to think more deeply about concepts than lecture alone would have.</td>
<td>2.06</td>
<td>0.09</td>
<td>2 72.2</td>
</tr>
<tr>
<td>3. I completed the “learning assignments” to the best of my ability.</td>
<td>1.87</td>
<td>0.08</td>
<td>2 85.2</td>
</tr>
<tr>
<td>4. I think it is fair for all team members to receive the same score for the team RATs.</td>
<td>1.81</td>
<td>0.09</td>
<td>1 84.3</td>
</tr>
<tr>
<td>5. At least one of the members in my team failed to do their work on a regular basis and, therefore, didn’t contribute to effective group discussions.</td>
<td>3.13</td>
<td>0.12</td>
<td>4 33.3</td>
</tr>
<tr>
<td>6. Team-based learning should continue to be used in General Biology.</td>
<td>1.73</td>
<td>0.08</td>
<td>1 85.2</td>
</tr>
<tr>
<td>7. The “clickers” were an effective tool at making the class interactive.</td>
<td>1.69</td>
<td>0.07</td>
<td>2 92.6</td>
</tr>
<tr>
<td>8. I learned more by using clickers in class than I would have if they weren’t used.</td>
<td>2.44</td>
<td>0.09</td>
<td>3 49.1</td>
</tr>
<tr>
<td>9. I found it helpful to see the responses of other students when asked clicker-based questions.</td>
<td>1.98</td>
<td>0.08</td>
<td>2 81.5</td>
</tr>
<tr>
<td>10. Clickers should continue to be used in General Biology.</td>
<td>1.89</td>
<td>0.08</td>
<td>2 80.6</td>
</tr>
<tr>
<td>11. I would be willing to pay $30–$50 for a clicker that could be used during my entire undergraduate education.</td>
<td>2.51</td>
<td>0.10</td>
<td>2 52.8</td>
</tr>
</tbody>
</table>
team RAT score (Table 2). Most students also tended to disagree that at least one of the team members failed to contribute to group discussions. Although there are ways to compensate for uneven contributions to a team, such as peer rankings (Michaelson, Bauman Knight, and Fink 2004), they don’t seem necessary in the settings described here and they have the potential to pit students against each other. Instructors should carefully weigh the benefits and consequences before adopting a peer-ranking format for any team-based assignment.

Students likely completed the learning assignments and contributed to group discussions because they were held accountable on an individual basis and to their teammates for the team RATs. The clickers made the individual RATs much more feasible than they would have been if Scantrons or some other grading system was used. Indeed, students felt that clickers made the class more interactive and should continue to be used in General Biology (Table 2). Although clickers were used occasionally for immediate feedback of student comprehension, their main use was simply in recording responses on individual RATs. This might explain the fact that most students were neutral when asked if they learned more by using clickers in class than if they weren’t used. The clickers did, however, provide an easy and efficient way to implement TBL on a weekly basis. Despite the extra cost, clickers can be valuable tools and the results presented here are consistent with those presented elsewhere (Beekes 2006; Caldwell 2007).

Conclusion
Team-based learning was effective not only at enhancing student learning and performance, but also at energizing the classroom and causing students to be more talkative and engaged with biology. Students appreciated this active-learning approach and were not dissuaded by the extra work involved. In fact, students in the TBL section were no more likely to drop the course than were students in the lecture section (9% of students enrolled in the lecture section withdrew while 8% of students in the TBL section withdrew). Students taught via TBL indicated that weekly learning assignments and RATs helped promote their learning. Clickers were crucial for recording individual RATs and they contributed to successful implementation of the TBL format outlined here. TBL can be easily implemented in most classes once the assignments and RATs are developed. Instructors leery of the extra time required with full-scale implementation of TBL might start with low-stakes team-based quizzes as a first step at enhancing student learning.

References

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