MEDICAL EDUCATION

Team-Based Learning in a Medical Gross Anatomy and Embryology Course

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The application of team-based learning (TBL) as a major component of a medical gross anatomy course was evaluated. TBL is a method of small group instruction that addresses some of the shortcomings of other small-group teaching approaches. The core components of TBL were instituted in 12 small group sessions in the course. Each session included objective-oriented assignments, an individual readiness assurance test, a group readiness assurance test and a group application problem. Peer evaluation was carried out on a regular basis. Scores from TBL session activities and course examinations were analyzed and compared to previous years' course performance. Student course evaluation data and faculty feedback were also collected. Student evaluation data and faculty response indicated strong support for the TBL method as it was implemented in the course. Faculty noted improvements in students' day-to-day preparedness and group problem solving skills. Students' mean scores on exams were not significantly different from those of previous years. There was, however, a significantly smaller variance in examination scores that was reflected in a lower course failure rate compared to previous years. Correlation analyses of TBL and examination performance suggested that individual readiness assurance test performance is a good predictor of examination performance. TBL proved to be a superior method for small group learning in our anatomy course. Student performance suggested that TBL may most benefit academically at-risk students who are forced to study more consistently, are provided regular feedback on their preparedness and given the opportunity to develop higher reasoning skills. Clin. Anat. 18:56–63, 2005. © 2004 Wiley-Liss, Inc.

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INTRODUCTION

Instructors of anatomy have recognized the importance of clinical application, active learning, and group problem solving in medical education and there have been numerous strategies employed to develop these skills (Schwartz, 1989; Scott, 1994; Holla et al., 1999; Geuna and Giacobini-Robecchi, 2002; Miller et al., 2002). We strive to promote active learning in the gross anatomy and embryology course (Human Structure) at our institution. The course has been centered around a full dissection lab and 23 case-based small group sessions supported by web-based materials and relatively few traditional content-based lectures (Nieder and Nagy, 2002). The small group sessions, designed to review anatomical content via case problems, have suffered from poor attendance, variable student preparation and inconsistent group problem-solving achievement. Although some students consistently attended the small group sessions and rated them highly in terms of helping them learn anatomy, the overall rating of the sessions has been mixed. Faculty in the course would concur that, despite specific preparatory assignments, few students come truly prepared to engage in active discourse and that too much time is spent in the sessions covering basic factual material rather than in applied problem solving.

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We explored strategies for making our small group sessions more meaningful and decided to try team-based learning (TBL), a teaching method first developed and described by Michaelson et al. (1997) for large classes in business school and adapted for limited use in basic science and postgraduate medical education at Baylor College of Medicine (Seidel and Richards, 2001; Haidet et al., 2002). Team-based learning has many features that make it applicable to undergraduate medical education courses in the pre-clinical sciences: it is a very "active learning" process that promotes both the learning of factual material as well as higher-level cognitive skills; it uses small groups (teams), and requires team members to work collaboratively; faculty are more engaged with the students than in traditional lecture or even many other small group formats and they know quickly what their students are achieving; it requires consistent student preparation and attendance; it gives students an opportunity to learn a great deal about working within teams and how to evaluate themselves and their peers through peer evaluation; it requires fewer faculty than traditional "small group" exercises or problem-based learning.

For the academic year 2002–2003, we instituted TBL in the small-group component of the course. TBL had not previously been implemented as a major graded learning component in a medical basic science course, but from experiences in other academic fields, we hypothesized that students would be better prepared and find the sessions more effective than our previous small group sessions. We hoped that because the TBL strategy forces students to keep up with the course material, academic performance (exam scores) of all students would improve, in comparison to previous years.

We describe the implementation of TBL into the Human Structure course and present the results of an end-of-course evaluation, which explored the student experience with TBL, data on student performance on individual and group TBL activities and exam scores. Three faculty members were responsible for the conduct of the TBL sessions and their experience with this different approach is also described.

MATERIALS AND METHODS

Establishment of Teams

The 97 students in the first-year medical class were assigned to 18 teams of five or six students each. The assignments were randomly generated except that provisions were made to prevent single gender teams. Students were informed that their team assignments would remain the same throughout the year. Two students did not complete the course (performance analyses are based on $n = 95$).

Team-Based Learning in the Course

The Human Structure course included multiple teaching modalities including traditional "live" embryology lectures, on-line gross anatomy lectures (web-based slide shows with audio streams; Nieder and Nagy, 2002), dissection lab and computer-aided instruction on sectional anatomy and imaging, including the *Beyond Vesalius* program and photo-based virtual reality programs developed at this institution (Nieder and Nagy, 1996; Nieder et al., 2000). Three anatomy department faculty delivered the basic anatomy and embryology lectures (live and on-line), taught in the TBL sessions and covered the dissection lab. Seven clinical faculty presented clinical correlation lectures and a graduate teaching assistant provided off-hours assistance in the lab. Students were scheduled for 140 hr of instruction (live lectures, lab and TBL) during the 9-week course. Because this was the only major course during this time, students had ample time for the independent learning aspects of the course (on-line lectures and other computer-aided instruction, reading, and lab review).

Twelve TBL sessions were scheduled into the 9-week timeframe of the course. Each 2-hr session included the typical elements of TBL including preparatory assignments; Individual Readiness Assurance Test (IRAT); Group Readiness Assurance Test (GRAT), and Group Application Problem (GAP). Peer evaluation, contributing to the course grade, was also included in the plan. Team-based learning activities comprised 25% of the course grade, whereas three major examinations contributed the remaining 75%. Students were required to score a 70% average on the three exams (without the TBL component) as well as a 70% overall course grade (including the TBL component) to pass the course.

A group consensus process determined the contribution of various TBL activities to the TBL grade on the first day of class. Students were asked to define a weighting system for individual performance (the IRATs), group performance (GRATs and GAPs) and peer evaluation. A constraint was that each portion must contribute between 20–60% of the total TBL grade. The distribution emerging from this consensus process was 20% individual performance, 50% group performance, and 30% peer evaluation. Each student's TBL grade was calculated using this distribution.

The 18 teams were divided into six groups of three teams (15–16 students total) each meeting in physi-

cally separate sessions. The limited number of faculty in the course required us to hold two simultaneous sessions at three times during the day to cover all students in the class.

Design of the TBL Sessions

Assignments. One week before the session, specific assignments were posted on the course web site. These included live and on-line lectures, textbook readings, computer exercises in sectional anatomy and imaging and dissection lab sessions. Along with the assignments, students received a list of objectives for the session. The TBL sessions were scheduled to allow adequate time for students to complete the assignments and study for the session.

Individual readiness assurance test. At the beginning of the session, a 10-question, closed book, multiple-choice quiz was administered with a 12-min time limit. Questions on the Individual Readiness Assurance Test (IRATs) were focused on the factual content from the assignments and required only limited reasoning or problem solving. The answers were recorded on computer "bubble sheets" for later grading.

Group readiness assurance test. Immediately after the IRAT, the same quiz was administered to the teams, with a 20-min time limit. The teams came to consensus answers and responded on "bubble sheets," also graded after the session.

RAT question discussion. Questions were reviewed by having the teams simultaneously show their answer using lettered cards. If team answers did not agree, the discrepancies were addressed by asking the teams to defend their answers. Once any misunderstandings of content or errors in reasoning were resolved, the instructor would move to the next question. If all teams displayed the same answer, the instructor asked if there were any lingering questions about the question or related content. If there were no issues, the instructor would either move directly to the next question, or might raise a secondary question to stimulate additional discussion. This discussion phase was scheduled for 25 min to complete the first hour of class.

Group application problem. Teams were given one or more clinical cases related to the day's topic with an accompanying set of multiple-choice questions. The cases included text describing the patient's history and physical examination findings. In some cases, additional data in the form of X-ray, CT, MRI, ultrasound images, or videos of the patient's symptoms were delivered via computers in the TBL session rooms. The cases and questions were crafted to require integration of anatomical facts and concepts

and a substantial amount of reasoning. Students had access to an anatomy atlas and medical dictionary, but no other books, notes, or online resources. Teams were given 30 min to work through the cases and record their answers. Questions from the group application problem (GAPs) were reviewed in a manner similar to the RAT question review.

Peer evaluation. At three points in the course, coinciding with the major examinations, students were required to fill out peer evaluation forms for members of their team. Peer evaluation consisted of two separate forms. The first form required students to allocate a fixed number of points (10 × the number of team peers) to their team peers with the stipulation that not all team peers could receive 10 points. This form, which was used as the peer evaluation component of the TBL grade, also requested a justification for the low and high scores assigned. Students would only receive their average peer evaluation score from these forms. A second form, used as a formative evaluation, required students to rate their peers in various aspects of cooperative learning skills, self-directed learning and interpersonal skills. Anonymous ratings and specific written comments were returned to the students. The faculty did not see these forms or use the information from this second form in grade determination.

Student Evaluation of TBL

The end-of-course evaluation gathered numerical data and comments about every aspect of the Human Structure course. A section of the evaluation, specific to the TBL component of the course, included seven items for graded response and solicited suggestions for improvement. All students completed the evaluation form before concluding the final TBL session.

Faculty Evaluation of TBL

Three full-time faculty participated in the implementation of TBL for the Human Structure course. They have all taught in the course for over ten years, conducting lectures, lab dissection, and small group instructions. Their comments about substituting TBL for the previous small group instruction format were recorded.

Statistical Analysis

Examination scores from 2002 were compared to those from 1999–2001. These were calculated from three major exams each consisting of a written board-type multiple choice portion (100 questions) and a practical including identification and secondary questions (50 questions). In constructing the written and practical exams, we made efforts to assure we were

TABLE 1. Students' Rating of Learning Venues and Resources

	Percent responding[a]					Mean rating
	Strongly agree	Agree	Neutral	Disagree	Strongly disagree	
The following were helpful to my learning:						
Lectures	15	44	25	14	3	3.53
Dissection labs	44	44	12	1	0	4.30
TBL sessions	49	34	12	4	0	4.28
Textbooks	28	47	20	5	0	3.98
On-line materials	68	31	1	0	0	4.67
Computer programs	29	54	10	5	1	4.05
TBL sessions helped me understand anatomical concepts	38	53	6	3	0	4.25
TBL encouraged clinical problem solving	50	45	2	3	0	4.41
TBL sessions encouraged questions, discussion and interaction	57	35	4	4	0	4.44
TBL sessions provided a good content review	39	48	6	5	1	4.19
TBL sessions forced me to study more consistently	68	23	3	3	2	4.53
There should be more TBL sessions, each covering smaller amounts of material	28	16	20	30	6	3.31
Having TBL contribute 25% to the final grade was appropriate	44	41	7	7	0	4.22

[a]Students responded on a 5-point scale to each of the query items. 5, strongly agree; 1, strongly disagree. N = 95.

testing the content to a consistent breadth and depth. The written exams were constructed from a common pool of questions, but for security reasons were not identical from year to year. Practical exams made use of the students' dissections, so were likewise different from year to year as well. The N (number of students completing the course) for each year were: 91 in 1999; 94 in 2000; 91 in 2001; and 95 in 2002. Examination scores were analyzed by the modified Levene equal variance test (F-test) to determine whether the variances in the groups are equal, followed by the Welch test ANOVA for unequal variances. Correlations between TBL scores and exam results were analyzed by linear regression. Statistical analyses were carried out using StatView (SAS Institute, Cary, NC) and NCSS (Kaysville, UT).

RESULTS

Student Evaluation of TBL

When asked to rate the various learning venues and resources in the course (Table 1), 83% of our students agreed or strongly agreed that TBL was helpful to their learning. Only the dissection lab and online resources (online supplemental lectures, video dissection guide, exam question bank, etc.) were rated higher. TBL sessions were deemed more helpful than traditional lectures by a considerable margin. In a focused evaluation on TBL, students believed TBL helped them understand course content and concepts, made them study more consistently and encouraged interaction, discussion, and clinical problem solving. The class was mixed on whether more frequent and

focused TBL sessions should be used. Finally, most students thought that having TBL comprise 25% of the course grade was appropriate.

Solicited open-ended comments were equally positive, but three major issues were frequently raised. The most contention was over the peer evaluation system that required at least some discrimination between team members. Students were very reluctant to do this and several students admitted that their team 'fixed' the scores so that everyone would receive a 10-point average score. Students, however, saw value in the formative portion of the peer evaluation. The second most frequent concern was over the security measures taken during the TBL sessions. In an effort to keep our TBL materials secure for use in subsequent years, students were neither permitted to keep copies of the RAT quizzes or GAPs, nor allowed to take notes during the sessions. Many students felt this compromised the effectiveness of the TBL sessions. The third concern was in the scheduling of the TBL sessions in relation to other class activities and extent of the assignments. Students felt that the amount of time needed to complete the assignment phase of the TBL sessions was inconsistent and sometimes inadequate.

Faculty Evaluation of TBL

All three of the faculty submitted comments about how they experienced TBL. There was consensus that it engaged students in unique and positive ways, that students came prepared, and that they want to continue to use the method rather than return to the previous format for small group instruction.
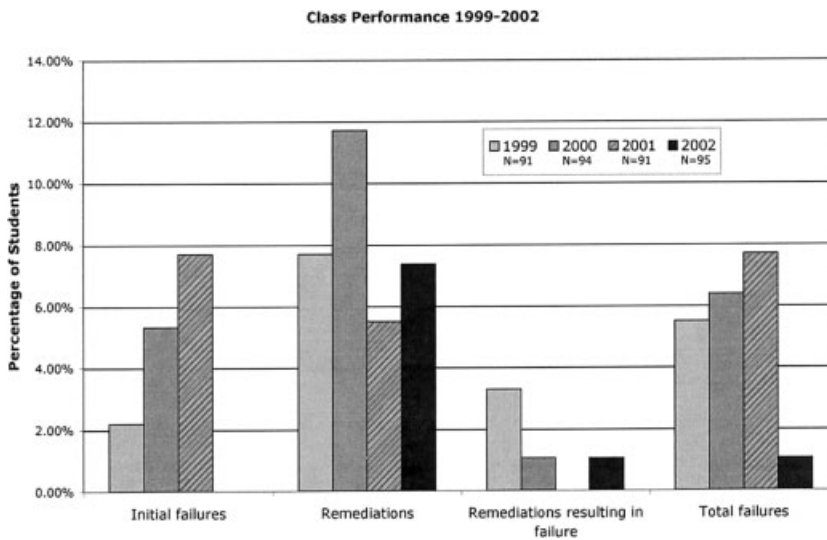
Fig. 1. Overall class performance in the Human Structure course in years 1999–2002. 'Initial failures' are those students achieving <60% average on major exams. 'Remediations' includes those students achieving an average ≥60% but <70%. 'Remediation resulting in failure' includes remediating students still not achieving 70% after the remediation retests. 'Total failures' are the sum of initial failures and failures after remediation. N = number of students in each class.

Class Performance

Students were required to achieve a 70% average in the course as well as a 70% average on their three major exams. As per course policy, those students scoring at least 60% were given the opportunity to remediate the course. Remediation consisted of a week of self-directed study and testing over the portion of the course on which the student performed most poorly. Their exam average was then recalculated with the retest score replacing the previous score and, if resulting in at least 70%, a course pass was awarded. Students scoring <60% failed the course without the opportunity for remediation. In 2002, all students achieved a 70% overall course average, but seven students fell below 70% for their exam average. All of these students scored in the 60–70% range, so were permitted to remediate. All but one of these students scored well enough in remediation to pass the course. In comparison, during the previous 3 years, the number of students failing outright was between 2–7 and the number of students in remediation ranged between 5–11 (Fig. 1). The total number of failures in previous years averaged six compared to the single failure in 2002. Examination scores were compared across years by ANOVA (Fig. 2). Although there was no significant difference between average exam scores over the 4 years, there was significantly less variance in scores in 2002, compared to other years, primarily accounted for by fewer students in the low end of the grade range.

Correlations Between Performance on TBL Activities and Exams

Student performance on the TBL session activities, peer evaluation scores, and scores on major exams were compared by linear regression analysis (summarized in Table 2). A significant ($P < 0.0001$) positive correlation was seen between individual students' performance on the IRAT and major exams.

As expected, teams consistently performed better on the GRAT than the individual members did on the same quizzes (IRATs). Average GRAT scores were 96.2% compared to average IRAT scores of 80.1%. The teams also consistently outperformed the highest scoring team member (average team high IRAT score = 88.1%). Teams whose members performed well on the IRATs also tended to do better on the GRAT, the results showing a significant correlation when calculated with individual IRAT scores or team-averaged IRAT scores. A significant correlation was also seen between GRAT scores and team high IRAT scores (i.e., teams' GRAT performance was correlated with the score of the best-performing team member). There was not, however, a significant correlation between the team members' performance on the IRAT, or performance on exams, and performance on the GAP. Nor was there a correlation between team GRAT performance and GAP performance.

The mechanism for peer evaluation necessarily resulted in a mean score of 100%. These scores were tightly grouped between 93–105% and showed a small, but statistically significant, correlation with both IRAT scores and exam scores.

DISCUSSION

We introduced team-based learning into our curriculum to address the shortcomings of typical small-group problem-solving exercises and improve the "active learning" experience for our students. Although
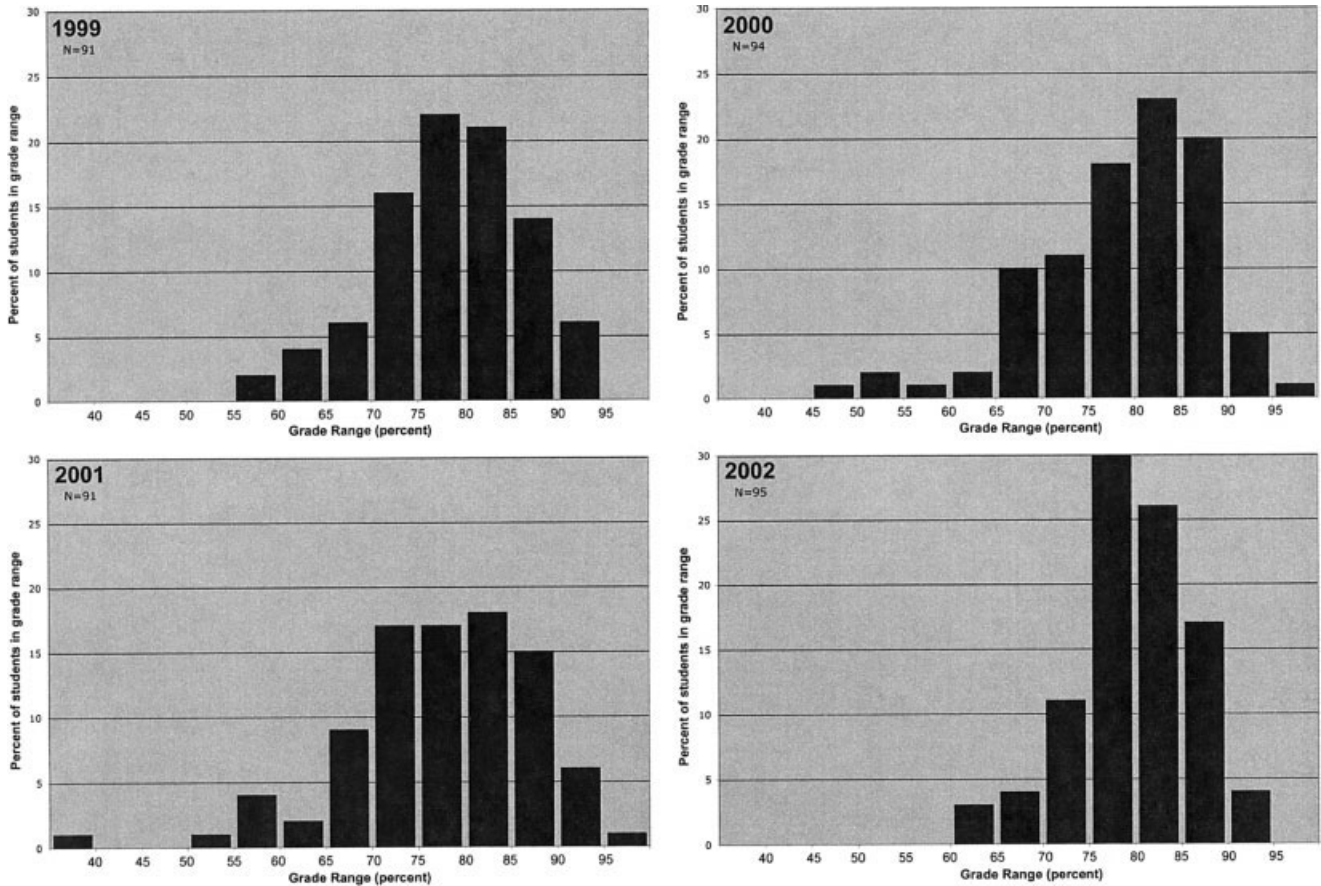
Fig. 2. Comparison of examination score distribution. Examination grades over the years 1999–2002 were analyzed by the modified Levene equal variance test that showed significantly lower variance in 2002 vs. the previous 3 years ($P = 0.0076$). The Welch ANOVA for unequal variances showed no significant differences between examination score means between years ($P = 0.344$).

TBL has been used in limited ways in undergraduate and graduate medical education there have been no reports of its application as a major graded component of a basic science course. We did not know how students would react to the increased accountability inherent in TBL, working intensively with each other in small groups on graded activities and having to evaluate their teammates. We also did not know what effect TBL might have on student examination performance.

Student evaluation of TBL indicates that it is a viable alternative to the typical small group discussion format for several reasons: they report that TBL helps them understand anatomical concepts; it encourages clinical problem solving; it encourages questions, discussion, and interaction; it provides good content review; and it helps them study consistently. Indeed, discussions with students both during and after the course showed that they felt they had to "keep up" with the material on a daily basis, in contrast to the more usual mode of "cramming" the last week before an exam. Our faculty also felt that it was a more

TABLE 2. Summary of Performance Correlation Analysis

Data factors	r	P (two-tailed)
Individual[a]		
IRAT vs. exams	0.7597	<0.0001
GRAT vs. exams	0.3804	<0.0001
GAP vs. exams	0.1187	0.2531
IRAT vs. GRAT	0.4290	<0.0001
IRAT vs. peer evaluation	0.3393	<0.0001
Exams vs. peer evaluation	0.2492	0.0149
Team[b]		
IRAT vs. exams	0.8118	<0.0001
GRAT vs. exams	0.7964	<0.0001
GAP vs. exams	0.3243	0.1896
IRAT vs. GRAT	0.7058	0.0010
IRAT vs. GAP	0.2177	0.3866
GRAT vs. GAP	0.3942	0.1047
High IRAT vs. GRAT	0.6470	0.0037

[a]Data from individual students' scores on the IRAT, GRAT, GAP, exams, and peer evaluation was compared by linear regression analysis. N = 95 for all data sets.
[b]Team members' scores on the IRAT and exams were averaged for each team. High IRAT is the best IRAT score among the team members. These values, along with the teams' GRAT and GAP scores were compared by linear regression analysis. N = 18 for all data sets.

productive strategy than the previous small group instruction format: attendance was near perfect; students came prepared; they were alert and engaged during sessions with more dialogue and debate during the sessions between students, between teams, and with faculty. Even though the TBL literature (Michaelsen, 2002a) emphasizes that the process can be effectively carried out in large groups (i.e., 100 students or more), we chose to run multiple TBL sessions with fewer students in smaller rooms. The faculty and students were comfortable with this more intimate arrangement that encouraged the involvement of all the students. The same activities could be carried out in the lecture hall venue, but we are not sure the outcome would be as positive.

Peer evaluation generated the most controversy with the students. They did not object to a checklist rating of their peers' behavior and giving narrative comments, however, they loathed having to score their peers for grading purposes. In particular, there was objection to the required discrimination between team mates (i.e., students could not give all their peers the same score). Michaelson (2002b) considers the peer assessment as one of the key components for the TBL paradigm because it helps to insure student accountability. Indeed, to create powerful and productive learning teams, there has to be more than the individual student's accountability to the instructor via an exam score, or the IRAT. The GRAT and the GAP exercises require each student to be prepared, but also to communicate effectively, work hard with others on the team, and help build a positive set of relationships within the team so that the team performs well. Our students seem to feel that the GRAT and the GAP, and "non-graded" part of the peer assessment were sufficient to ensure an individual's accountability to the team. Because this was such a contentious issue, it is likely that in future years peer evaluation will be streamlined and less restrictive. Alternative methods for peer evaluation have been described by Michaelsen and Fink (2002) that may be appropriate.

The use of TBL in other sciences (undergraduate general and organic chemistry) has resulted in significantly higher grades on standardized tests and fewer failures compared to the same courses taught by traditional means (Dinan, 2002). One of the major benefits of TBL in that context was retention of academically weaker students. Aside from the TBL experience, our course was very similar to that presented over the past few years, including the sequence of course content, the number of hours of dissection, specific faculty involved and their contact hours, and on-line resources available. Nevertheless,

at least some of the differences in class performance could be attributed to less obvious changes in the course. Also, we did not control for possible differences in our students' academic background or experiences that might better equip them for the course. With these caveats, there did seem to be a positive effect of TBL on exam performance. The mean exam score for our class was the same as in the previous several years, however, the grade distribution was not spread as much. In particular, the low-end tail of the curve was smaller, yielding fewer failures. We believe the reason for this may be that the IRATs forced students to stay current with the material—no student could afford to fall behind very much. The IRAT served as a "reality check" for students who may have mistakenly believed they were mastering the material to the required depth. There was indeed a strong correlation between individual students' IRAT scores and exam scores, making the IRAT a good predictor for students performance on major exams. Simple pop quizzes might have been used to serve this purpose, but the TBL approach, with the teams working through quiz questions, then applying the content to clinical problems seemed to provide a more productive feedback for these struggling students. The relative compression of the exam scores toward the mean also resulted in fewer students in the high range (>90%) than in previous years. It is possible that the energies of the better students were diverted away from their own study of details and toward helping their team mates learn basic concepts, although there was no indication from students' feedback that this was the case. It is a phenomenon that will have to be monitored over the long term.

One of the basic tenets of cooperative learning methods, such as TBL, is that groups will perform better than individuals. This was born out in the IRAT-GRAT correlation. GRAT scores were on average 16% higher than the teams' mean IRAT scores. Students frequently commented that they were impressed by this phenomenon; when they worked together in a very prepared and focused way, they performed better as a group than the "smartest" one in the group. At the same time, teams whose individuals performed well on the IRAT scored better on the GRAT, demonstrating individual ability driving group performance. This phenomenon was also not lost on the students who quickly appreciated the importance of all members coming to class prepared.

Interestingly, there was not a significant correlation between GAP scores and either IRAT, GRAT, or examination scores. It was somewhat surprising that the teams performing best on the GRAT showed only average ability in solving the GAP problems. The

involved clinical vignettes of the GAP with questions requiring integration of content and multi-step reasoning, seems to require a different skill set than the RATs. Our exams mostly consist of short recall-based questions or simple clinical vignettes and do not evaluate integrative problem solving to the same degree as in the GAPs. By increasing the number and difficulty of problem-solving questions on the exams, consistent with the USMLE's Step I shift to more questions requiring problem-solving and clinical reasoning (Josefowicz et al., 2002), there would likely evolve a better correlation between the GAP and the exam scores.

The institution of TBL in the Human Structure course is part of a larger trial of TBL throughout the basic science curriculum at Wright State University School of Medicine. TBL in some form is now implemented in each course of the hybrid discipline-based/systems-based curriculum of the first two years. We are investigating the value of this learning approach in each course as well as the long term effects of team learning on individual and group problem solving skills.

In conclusion, our first experience with team-based learning in a traditional basic medical science course was very positive. Our faculty felt more engaged with the students than in the former small group instruction and our students considered working with other students an effective way to learn content and practice clinical reasoning skills. Although the class's grade average was similar to previous years' averages, we believe that the team-based learning did help the few academically weaker students to succeed. The TBL method should be considered for broader application in medical basic science education.

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