ARTICLE
The Neuroscience Classroom Remodeled with Team-Based Learning

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As neuroscience faculty we strive to have students be invested in their learning and be engaged in the process. However, these attributes are difficult to promote using a lecture-based format. Flipping the classroom so that students prepare before coming to class obliges them to take responsibility for their learning. This, combined with having them work in Teams with their classmates – across the entire semester – provides incentive and support. This article describes how I applied a method called Team-Based Learning (TBL) to my Neurobiology course. TBL requires that students read the assigned text before class and demonstrate their knowledge through quizzes called Readiness Assurance Tests (RATs) that are completed first individually (iRAT) then by each Team (tRAT). This process uncovers the most challenging material and identifies student misconceptions that the instructor addresses through mini-lectures. In subsequent classes, students work in Teams solving content-specific application questions (ungraded) and complete four written Team assignments (graded) that require critical thinking and collective decisions. Teams represent a safe space for students to share knowledge, ask questions, learn from and teach one another. Placing students in Teams promotes regular attendance and ensures preparation before class. Students report that working in Teams helps them to remember content and how to use the group's knowledge to solve problems. They also note the benefits of hearing multiple perspectives, diverse arguments, and different ways to reason. Scores on hourly exams and course grades show that TBL is an effective means for students to learn Neurobiology.

Key words: TBL; active learning; flipped classroom; group work; collaborative learning; student-centered learning; student engagement; teaching strategies

Prepared. Present. Engaged. When I create a course syllabus, in addition to content, I consider ways in which the class structure promotes students coming to class *prepared,* having read the assigned text, being *present*, arriving on-time, with consistent attendance, and staying *engaged,* participating and actively learning the material. Using a lecture-based format, I have tried different ways to achieve these goals, all with limited success.

In Spring 2015, I participated in a semester-long faculty seminar on my campus geared towards active learning strategies in anticipation of the opening of a Technology-Enabled Active Learning (TEAL) classroom, which was under construction in a new building. The TEAL classroom is spacious with a maximum capacity of 63. It contains seven large round tables, moveable chairs, three computers/screens/keyboards at each table, a central computer and document camera for the instructor, a large screen on one wall, and floor-to-ceiling whiteboards around the room. As a seminar participant, my Neurobiology class would now be held in the newly-opened TEAL classroom. Faced with this prospect, I could not rely on the same lecture style I had used in the past. The physical structure of the TEAL classroom demanded that I adopt a new approach. I decided to try Team-Based Learning (TBL) – a flipped classroom method that I learned about in the faculty seminar (Michaelsen et al., 2004). Amazingly, it was through the transformation of my Neurobiology class to TBL that *I was able to achieve all of my pedagogical goals*: students came to class prepared, had excellent, regular attendance, and were actively learning and applying their knowledge.

There were other, unanticipated benefits of TBL. As an instructor, I could focus class time on the most challenging material. No time was wasted covering basic content. I was also able to add four thought-provoking written assignments, which did not exist in the lecture version of the course. These assignments are completed in class by each Team. Since students were required to work together in Teams - a new experience for them - at the end of the semester, I asked students to describe what they liked about TBL. Their anonymous written responses uniformly extolled the benefits of being part of a Team. With teammates they routinely debated points of view, listened to different perspectives, made collective decisions, and felt comfortable asking questions. Several noted the significance of being able to teach their teammates, which they said demonstrated their own learning. Students reported that they felt responsible to come to class and to be prepared, so as to not let their teammates down. Self-described shy students said that they found a voice and support within Teams. Several students mentioned that they did not 'cram' for hourly exams like they did for other science courses; TBL forced them to keep up with material as they were learning it. By the end of the semester, my experience using TBL was so profoundly positive that I changed the following semester's class to TBL – a course I teach in the Honors College on Addiction, which has a mix of science and non-science majors.

In this article, I describe TBL, outline its structure, and provide details about how I reconfigured my Neurobiology course. The TBL version of this course still includes four hourly exams and a laboratory section (4-credit course) or two written assignments (3-credit course, without laboratory

section). While I decided to dive-in and completely transform my lecture-based courses to TBL, it is my hope that aspects of what I describe using Teams could be applied to non-TBL courses. And, while the TEAL classroom was the impetus to change my teaching, a special classroom is not required. TBL works in traditionally-designed classrooms – as I have done in my Addiction course.

WHAT IS TEAM-BASED LEARNING (TBL)?

TBL is a flipped classroom approach that requires student preparation before class and emphasizes cooperative learning, within Teams, during class (Michaelsen et al., 2004; Michaelsen and Sweet, 2008). There is a cycle to its structure. The beginning of the TBL cycle is called the Readiness Assurance Process (Gullo et al., 2015; Michaelsen et al., 2004; Michaelsen and Sweet, 2008; Sibley and Spiridonoff, 2014). The first step consists of assigning texts that students are required to read before coming to class. This is followed by having students take a closed-book quiz called a Readiness Assurance Test (RAT) about the assigned reading at the beginning of class. Students take the RAT by themselves – called an 'individual RAT' (iRAT), which is handed-in to be graded. Immediately afterward, students join their teammates to complete the 'Team RAT' (tRAT), which is the identical to the iRAT, but is completed, closed-book, by each Team. The tRAT is followed by a mini-lecture by the instructor on the most challenging material from the assigned reading set (Michaelson et al., 2004; Michaelson and Sweet, 2008). Material covered in mini-lectures is a combinaton of anticipating which content or concept the students may find difficult as well as responding to student questions with impromptu explanations. In subsequent class meeting(s), students work in Teams on content-specific application activities (Michaelsen et al., 2004; Michaelsen and Sweet, 2008; Roberson and Franchini, 2014). This TBL cycle – before class preparation > iRAT > tRAT > mini-lecture > content application activities – is repeated for each reading set. The aim is for five to seven TBL cycles per semester with the majority of class meetings focused on content application activities (Michaelsen et al., 2004; Michaelsen and Sweet, 2008). However, I employ twice as many TBL cycles across the semester since each reading set consists of a textbook chapter or portion of chapter (Bear et al., 2016). I feel that the material is too dense and complex to assign more reading per cycle.

FORMATION OF TEAMS & TEAM FOLDERS

Teams are a fundamental component of TBL. They are established at the beginning of the semester and remain in place for the entire semester (Michaelsen et al., 2004). TBL literature recommends that each Team consist of five to seven students, be as equal as possible in terms of the representation of students in the course, and that students who know one another well (i.e., best friends, partners, relatives) should not be placed on the same Team (Michaelsen et al., 2004; Michaelsen and Sweet, 2008). With these guidelines, I create Teams using a multi-step process. With 63 students, I divide my Neurobiology course into nine Teams with seven students per Team.

During the first meeting of the semester, I hand out a short, written questionnaire to students asking them to report their grade in a key prerequisite course, Cell Biology, and to list the names of any best friends/partners/relatives enrolled in the class. Before the semester begins, I have information from my class roster regarding each student's major, school year, and whether that student is in the Honors College. Using all this information, I sort students into categories that I consider equivalent – creating seven 'preliminary Groups' (A - G) with nine students per preliminary Group. In determining categories of equivalent students I take different factors into consideration, for example, students in Honors College, high versus low grades in Cell Biology, students taking Neurobiology without laboratory section, and students whose major is not Biology. It is from these preliminary Groups that the nine Teams will be formed using a public, transparent method. Students who know one another well are placed into the same preliminary Group because this will ensure that they end up on separate Teams, as I describe next.

A week into the semester, once course enrollment is fixed and Add/Drop has ended, I devote an entire class period to creating Teams. On this day, I call students forward by preliminary Group, A - G. Each student places a hand into a cloth bag and pulls out scintillation cap with a number, 1 – 9, written on it. The random number selected by each student indicates that student's Team number. This process is repeated for each preliminary Group in order to create nine Teams with seven students per Team. To this end, each Team contains an equivalent mix of students in the class – members of Honors College, students who earned high and low grades in Cell Biology, students whose major is not Biology, and students who are taking the course without laboratory section. For the remainder of the class period students gather with teammates, learn names, and start to get to know one another by sharing something surprising about themselves.

Each Team is also handed a physical folder labeled by Team number (Michaelsen et al., 2004). Taped to the inside of the Team folder is an attendance sheet and a Team grade sheet. Attached with a paperclip are four index cards labeled A, B, C, D, which Teams will use to display their answer choice during content application questions. Teammates write their names on the folder cover and on the attendance sheet. Each Team chooses a folder 'monitor' and an alternate; these are students who will pick-up/return Team folders at the beginning/end of class and take Team attendance. I discovered that Team folders are an efficient means to receive and return student work – especially in large classes. Before class, all materials that I want to hand out to students (i.e., tRATs, returned graded work, with scores hidden from public view) are placed into Team folders. At the end of class, materials that students want to hand-in to me (i.e., completed tRATs and Team assignments) are placed into Team folders. At the end of each class before leaving the room, I look through Team folders to check attendance and ensure they contain all the correct materials.

READINESS ASSURANCE PROCESS & iRAT/tRAT

The first step in the TBL cycle is student preparation before class. I assign specific reading from the textbook (Bear et al., 2016), a chapter or portion of a chapter, and provide students with my former lecture slides as an outline. Student preparation is assessed at the beginning of the next class by an iRAT. These quizzes are supposed to be a bit challenging since they serve as a springboard for Teams to complete the tRAT (Michaelsen et al., 2004; Michaelsen and Sweet, 2008). My iRATs consist of ten multiple choice questions with four answer choices per question, and cover the essential content from the reading set. The ten questions range in difficulty. I aim for a well-prepared student to answer seven-eight questions correctly. Since students take iRATs at the beginning of class, this promotes punctuality and attendance. Students have to attend class to receive credit for an iRAT; there are no make-ups. I feel comfortable with this policy since I drop the three lowest iRAT scores for each student when calculating the course grades.

Once the students complete the iRAT, they hand it in, and join their Teams to take the tRAT, which is identical to the iRAT and also closed-book. Working on the tRAT, students huddle with teammates to discuss answers, explain content, ask questions, and debate choices. From the TBL literature (Michaelsen et al., 2004; Michaelsen and Sweet, 2008), I learned about the Immediate Feedback Assessment Technique (IF-AT), which employs lottery ticket-like scratch cards (Epstein Educational Enterprises) as a vehicle for completing multiple-choice quizzes. I purchase multiple packs of IF-AT cards (Epstein Educational Enterprises) and use them for the tRATs. This way, Teams get immediate feedback on their answers – a 'star' appears when the correct answer is scratched off while incorrect choices yield blank spaces. If their first answer choice is incorrect, Teams keep working until they find the correct answer. I give partial credit for correct second choice responses on tRATs.

While Teams are working on the tRAT, I walk around listening to discussions. The classroom buzzes with energy! Students are curious, motivated, and really want to understand the material. As Teams complete the tRAT, I ask for their score, which is often higher than any individual iRAT on the Team – an observation reported by others (Michaelsen et al., 2004; Michaelsen and Sweet, 2008). I also ask each Team which RAT questions we should discuss and make a list on the whiteboard; this provides an outline for the remainder of the class period. As we review the difficult RAT questions, I provide mini-lectures and make sure to clear up misunderstandings. Most mini-lectures are done on the spot and in response to student questions. I use my former lecture slides and the whiteboard to provide explanations. Othertimes I can anticipate when I will give a mini-lecture, for example, when a concept is challenging for the students, such as receptive fields in the retina.

TEAM APPLICATION ACTIVITIES

For the class period(s) after an iRAT/tRAT, students work in Teams on ungraded activities that are designed to have them apply newly learned content. TBL literature advises that these activities require more than simple knowledge recall (Michaelsen et al., 2004; Michaelsen and Sweet, 2008; Roberson and Franchini, 2014; Wallace et al., 2014). The idea is to challenge understanding and have students debate with their teammates in order to arrive at answer choices (Michaelsen et al., 2004; Michaelsen and Sweet, 2008; Roberson and Franchini, 2014; Wallace et al., 2014). The model mentioned frequently in the TBL literature is a courtroom jury (Michaelsen et al., 2004; Michaelson and Sweet, 2008; Sibley and Spiridonoff, 2014. A jury has a limited number of choices available for their decision: guilty or not guilty. However, to reach a group decision, jury members must weigh evidence, apply rules of law, and debate using coherent arguments. The answer choice is straightforward, but the process involved in making the choice is complex (Michaelsen et al., 2004).

The first type of Team application activity I use consists of multiple choice questions, presented one at a time, that all Teams work on simultaneously (Michaelsen et al., 2004; Michaelsen and Sweet, 2008). Teams are given a limited amount of time per question to arrive at a single answer choice. This process requires that teammates talk to one another; no notes or textbook used. This type of Team application activity is similar to the courtroom jury model. While Teams are deliberating, I walk around and listen to their discussions. When time is up, I go to the front of the classroom and instruct Teams to hold up an index card from their Team folder – A, B, C, D – to display their answer choice, *all at the same time*. Simultaneous reporting is a key feature of Team application questions; it ensures that answer choices are not influenced by the choices of other Teams (Michaelsen et al., 2004; Michaelsen and Sweet, 2008). The nature of class discussion is determined by the answers selected. If all Teams choose the correct answer, discussion would be limited since the content was understood. More often, Teams choose different answers, and then I ask Teams to explain their choices. The subsequent class discussion uncovers misunderstandings and clarifies the material for everyone. However, instead of answering all questions myself, I encourage students to offer their own explanations to the class (Gullo et al., 2015). I step in to summarize, explain and elaborate.

The second type of Team application activity that I use has a different structure and purpose. I create blank summary charts that, once completed, will organize the material. This helps students place specific content into a framework. I use summary charts at the end of larger content units, such as: the neuronal membrane, neurotransmission, and classes of neurotransmitters. Before class, I assign specific content to each Team to review to help them prepare. The following class period, each Team is given a blank summary chart and instructed to complete only the portions of the chart related to their assigned content. The idea is to have students talking with teammates in order to fill in their portion of the chart. I discourage students from looking through the textbook or notes for answers. When I start to see this happening, I know it is time to switch gears and work as a class to fill in

the entire summary chart. To do this, I ask each Team to report their contributions as I write answers into a blank chart that is projected to screens by the document camera. Class discussion occurs, as needed, while we fill in the chart. After class, I share the blank chart and the completed chart with the students, so they can practice on their own, and check their answers for correctness and completeness.

TEAM WRITTEN ASSIGNMENTS

Working with their teammates during class, students complete four Team written assignments across the semester. These are graded and account for half of the Team grade (see next section for details about Team grade). The Team written assignments are a new addition to my Neurobiology course; they were created once I adopted TBL. Three of the Team written assignments present scenarios that require teammates to think like a research group about specific problems in neuropharmacology. The assignments are structured so that Teams are guided through a series of decisions. Teammates debate options and make choices that must be supported by articulating their reasoning. These three written assignments ask Teams: (1) to evaluate the specificity and selectivity of various sites of action in a synapse where a potential, fictitious drug could affect neurotransmission, (2) to characterize a newly discovered, fictitious neurotransmitter, and (3) to design an experiment that tests how a potential, fictitious drug could affect maze learning in rodents. The fourth Team written assignment requires teammates to work through the circuitry of the basal ganglia in order to understand the role of glutamate, dopamine, and the effects of Parkinson's Disease on motor outflow. Doing the basal ganglia assignment, Teams must consider the consequences of sequential inhibitory synaptic connections in the 'direct' and 'indirect' pathways. To help Teams complete their four written assignments, they are provided with dry-erase markers and scrap paper and encouraged to use classroom whiteboards to outline their thinking and scrap paper to draft their responses. Team written assignments are completed during a single class period; hand-written answers are submitted at the end of class to be graded. Since there are only nine Teams and the written responses are not lengthy, Team written assignments are straightforward to grade. However, these assignments provide students with a profound learning experience – one that probes their understanding and requires that they work as a Team to apply neuroscience content to thought-provoking problems.

TEAM GRADES AND PEER ASSESSMENT

In my Neurobiology class, Teams earn a Team grade from scores on 13 tRATs and four Team assignments. The Team grade accounts for 25% each student's course grade (Michaelsen et al., 2004). If every student on a Team had good attendance, came prepared, and actively participated, then all teammates deserve the Team grade. In theory, this makes sense. In practice, it might not be the case for every Team. TBL literature advises that Team grades be modified for each student through a process of peer assessment (Michaelsen et al., 2004). This allows students to recognize teammates who assumed significant leadership roles, as well as to modify Team grades of teammates who were frequently absent without excuse, were unprepared, or did not participate during deliberations. At the end of the semester, I require that all students provide numerical feedback on each teammate. This is done outside of class, is not shared with teammates, and is delivered directly to me. To do this, each student must apportion 600 points across six teammates. If students feel that all teammates were equally deserving of the Team grade, they give each teammate 100. If students decide to apportion points unevenly across teammates, they make sure the total number of points distributed adds up to 600. Based on six peer assessment scores for each student, I calculate an average score. This number is then divided by 100 to create a multiplier, which is used to adjust each student's Team score. Therefore, the peer assessment process creates a unique *modified Team grade* for every student, which, in turn, accounts for 25% of each student's course grade.

BENEFITS OF TBL

The most remarkable thing about using TBL is how active the classroom becomes. Students no longer sit passively listening to the instructor lecture. The learning is now student-centered and takes place within Teams. Teammates explain, listen, and debate. Teams represent a place for students to work through ideas, share knowledge, learn from, and teach one another. When students are part of a Team, they feel responsible to teammates to attend class regularly and to come prepared. With TBL, every class period is dynamic and challenging. Students are engaged and pay attention because they are either working in Teams or the mini-lectures and class discussions are focused on the most difficult content.

CHALLENGES OF TBL

Teaching with TBL requires considerable thought and preparation in order to execute. Before I transformed my Neurobiology class, I spent several weeks reading about TBL in order to understand its structure and components. I recommend the following edited book (Michaelsen et al., 2004), articles (Gullo et al., 2015; Michaelsen and Sweet, 2008; Roberson and Franchini, 2014; Wallace et al., 2014) and online materials (Sibley and Spiridonoff, 2014; Team-based learning collaborative). Only after I had a sense of how TBL worked did I proceed to map my lecture-based Neurobiology class onto its format.

There are several challenges to making the transformation to TBL. I offer the following observations and advice:

(1) *With TBL, content is no longer delivered to students by lecturing.* One challenge for faculty is how to use the content to construct questions and problems for Teams to solve (Roberson and Franchini, 2014; Wallace et al., 2014). This is how student learning now takes place. Writing RAT and Team applications activities/assignments requires a lot of thought and revision. However, faculty can make use of already available test banks to aid in this process. Several of my colleagues at UMass-Boston who have switched to TBL do this. The instructor also needs to be sensitive to

what is happening in the classroom in order to manage and facilitate TBL activities since each Team has a different style, personality, and speed. This new role for faculty requires practice, focus, and keeping track of time (Gullo et al., 2015).

(2) *The amount of content covered using TBL is less than in a lecture-based course.* Mapping my Neurobiology course onto a TBL format, I could not include as many textbook chapters (Bear et al., 2016) as I had when I lectured. With TBL, each chapter (or topic) now has one class period of iRAT/tRAT/mini-lecture and another class period of Team application activities. Therefore, once I adopted TBL I had to decide which content was essential to my course. Doing so I created six themes: Neurophysiology (Ch 3 & 4), Neurotransmission (Ch 5 & 6), Neuroanatomy (Ch 7 & 15), Sensory Systems (Ch 8 – 12), Motor Systems (Ch 13 & 14) & Neuronal Plasticity (Ch 23, 24 & part of 25). However, with TBL I was able to expand on topics in thought-provoking ways. For example, asking Teams to categorize the effects of different agents that act at the neuromuscular junction – cholinergic agonists, antagonists, long-lasting agonists, cholinesterase inhibitors and Botulinum toxin – by whether they depolarize (or not) and cause muscle contraction (or not). In this way, Team application activities and Team written assignments are excellent venues for students to apply content and for challenging their understanding.

(3) *Explanations, practice and enthusiasm help students understand how TBL works.* All my students were unfamiliar with TBL at the beginning of the semester, and most reported negative experiences with group work in other classes. Therefore, I needed to quell anxieties and explain how TBL was different (Michaelsen et al., 2004; Michaelsen and Sweet, 2008). The first week of the semester, I did this in several ways, always with a positive attitude and enthusiasm. My course syllabus describes the TBL process in detail. In addition, I created a separate handout that we reviewed during the second meeting of the semester, which articulates how class will be conducted and all the elements that contribute to the course grade. During the third meeting of the semester, students did a practice iRAT on Ch 2 (Bear et al., 2016), which was scored, but not graded. We then discussed the iRAT to tRAT process in preparation for the first tRAT. On the day of a tRAT, I always bring extra IF-AT cards in case a Team scratches the wrong row of answer choices. This happens occasionally. When it does the Team reports it right away, shows me their IF-AT card, and I give them a new card so that they can continue working on the tRAT.

(4) *With TBL, course grades include new components*. Each student's course grade now includes iRAT scores and a modified Team grade (Michaelsen et al., 2004). I created two new grade sheets that organize students by Team. One grade sheet is for iRAT scores: I count the highest ten iRAT scores for each student and drop the lowest three scores. The other grade sheet is for Team grades and consists of scores on 13 tRATs and four Team written assignments. Once the Team grade is calculated, it must be modified by peer assessment (a separate grade sheet) to create a unique modified Team grade for each student. The total

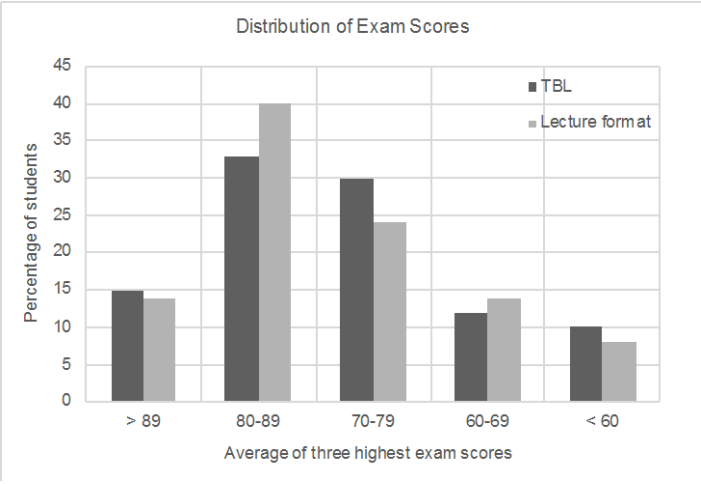

Figure 1. Distribution of exam scores in Neurobiology taught using TBL (N=126 students) or Lecture format (N=156 students). Data reflect percentage of students in TBL or lecture versions of Neurobiology and the average of their three highest exam scores.

iRAT score (10% of course grade) and modified Team grade (25% of course grade) are entered into the main grade sheet, which includes four hourly exam scores (three highest exam scores, 40% of course grade) and a laboratory score (25% of course grade, 4-credit course) or two written assignment scores (25% of course grade, 3-credit course, without laboratory section).

IMPACT OF TBL

In the TBL classroom the instructor shifts from the delivery of content by lecturing to having students work in Teams to answer questions and solve problems (Michaelsen et al., 2004; Michaelsen and Sweet, 2008). For TBL to operate successfully as a teaching method, students must prepare before class and attend class regularly. This requires considerable effort and engagement on their part. Measures of student performance on the three highest hourly exams demonstrate that students can learn neuroscience content effectively with TBL (Figure 1). Hourly exam questions and format were similar in the TBL and lecture versions of the course, although when teaching with TBL, each exam covered fewer textbook chapters. Comparing across two semesters of teaching Neurobiology with TBL (2016 & 2017, N=126 students) and two semesters of using a lecture format (2014 & 2015, N=156 students), averages of the three highest exam scores were similar, 79% (TBL) and 80% (lecture format), as was the distribution of the exams scores (Figure 1). However, looking at course grades, 83% of students in the TBL Neurobiology class earned a grade of "B" or higher compared to 75% of students in the lecture version of the course (Figure 2). This observation is consistent with results from two studies that employed TBL to teach clinical neurobiology (Anwar et al., 2015; Tan et al., 2011). These authors also noted better outcomes with TBL, compared to traditional teaching methods, specifically in students at risk for earning lower grades (Anwar et al., 2015; Tan et al., 2011). Data from my course are consistent with their observations: with TBL only

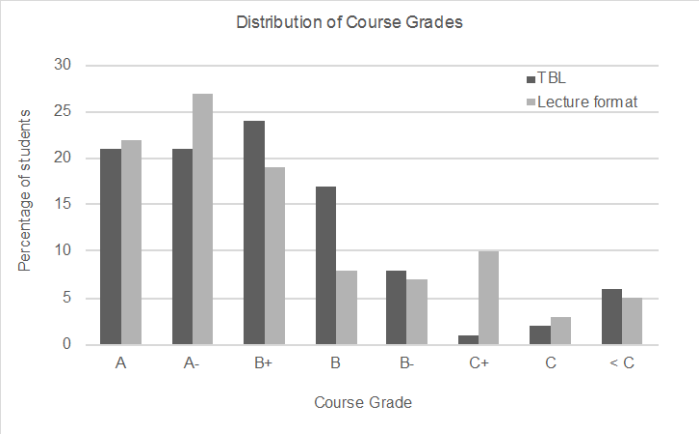

Figure 2. Distribution of course grades in Neurobiology taught using TBL (N=126 students) or Lecture format (N=156 students). Data reflect percentage of students in TBL or lecture versions of Neurobiology and their course grades.

10% of Neurobiology students earned grades of B-/C+/C compared to 20% of students in the lecture format, while a similar percentage of students received grades of C- or lower, 6% (TBL) and 5% (lecture format) (Figure 2). Since the exam score distributions were similar between TBL and lecture versions of Neurobiology (Figure 1), the upward shift of the class grade distribution with TBL was likely due to the inclusion of a Team grade component, which accounts for 25% of the course grade. However, there was still a small number of poor performing students (C- or lower) when Neurobiology was taught using TBL (Figure 2); these students earned low exam scores and sometimes had low peer assessment scores (affecting their modified Team grade) because of frequent absences or minimal participation.

Moveover, teaching with TBL adds considerable value to the classroom beyond exam scores and course grades. When students work in Teams they have the entire semester to practice presenting arguments and making collective decisions with their peers. In order to be a good teammate, students must attend class regularly; attendance sheets in the Team folders show that this is happening. Students also report feeling responsible to teammates to come to class and to be prepared. With Teams in place, the instructor can ask students to work with their teammates on challenging scientific problems. In fact, I added four Team written assignments to my Neurobiology course, which require critical thinking and collective decision making. Within the supportive environment of Teams, students learn how to cooperate, lead, support, and build consensus. In sum, the TBL method not only serves as a vehicle for students to learn neuroscience content, it also gives students the practice and preparation they need to navigate the 21st century scientific workforce in which teamwork is essential (Bennett and Gadlin, 2012).

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