Team Based Learning in STEM and the Health Sciences

"Teaching is leading students into situations in which they can only escape by thinking."
–Spencer Benson

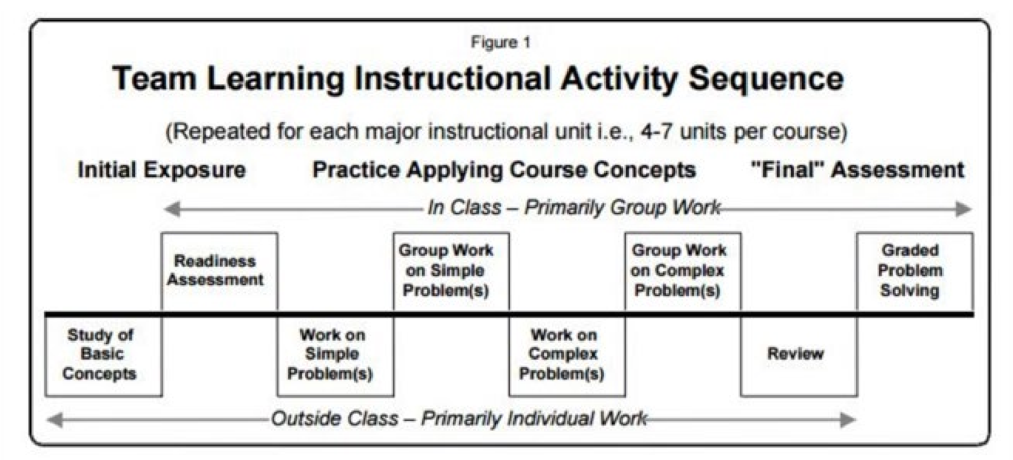
Abstract
Team-Based Learning (TBL) is a collaborative-learning pedagogy in which students work in permanent teams during class time to solve discipline-relevant problems. TBL has been shown to improve scores on measurements of student learning in both professional and undergraduate STEM fields, with the greatest number of studies in the health sciences; more research is needed in undergraduate contexts. In the author's undergraduate physiology classes, students show large conceptual gains across the semester as well as conceptual gains during individual class periods, remember much of what they learned in the first semester of a two-semester sequence over the summer, are enthusiastic about the method and engage in positive out-of-class learning behaviors such as reading the textbook. Ongoing work suggests that the quality of problems and questions given to the students to solve is a critical aspect of success using this approach. Overall, TBL is an example of a pedagogical system that is a straightforward way to implement many of the practices that have been shown to improve student learning: active participation of students, immediate feedback on performance, collaborative learning, and accountability for preparation outside of class and performance in class.

I. Description of TBL. Knowing what we know now about the value of different teaching practices in STEM, if we were to invent a comprehensive teaching strategy, it would be likely to have the following characteristics: a flipped-classroom approach; students working in teams, doing collaborative (not just cooperative) work, in which they did not answer lower-level questions but rather, applied the concepts of the course to real life; and some method to ensure students were prepared for class. In the Dark Ages before modern empirical investigation of teaching techniques, somehow the University of Oklahoma professor Larry Michaelson—who was not even planning to invent a new teaching method, but to somehow deal with his suddenly-doubled class size—intuited all this and invented Team-Based Learning (TBL), a pedagogy with all of the above characteristics, in the 1970s (Michaelson 2002).

TBL is a pedagogical strategy in which teams follow a specific sequence of activities throughout a unit (a semester is typically divided into 5-7 units), beginning with individual preparation and followed by teamwork of increasing complexity. Immediate feedback occurs throughout the process, in such a way that accountability to teammates is built-in. Each unit begins with an individual Readiness Assessment Test (iRAT), a multiple-choice quiz that holds students accountable for having gained specific learning objectives, typically the "basics" of the unit's topic, outside of/before class. Students then immediately re-take the RAT as a team (tRAT) using a form of immediate feedback for each answer, most commonly the Immediate Feedback—Assessment Test (IF-AT) scratch-off forms (Epstein Educational Enterprises, Inc.). Using such a form, teams can immediately see if they chose the correct answer, and if not, choose another for half-credit (second choice) or quarter-credit (third-choice). Thus, at the end of this relatively brief process, all students have learned the material necessary to wrestle with more complex questions. This RAT process might be thought of as simply “fancy reading quizzes,” but practicitioners argue that the process is superior to a standard reading quiz due to two major elements differentiating the readiness assessment process: the immediate feedback and the team discussion.

The next, and major, phase of a TBL unit is the “Applications” phase, in which student teams are given problems to solve that reflect as much as possible the real-word practice of the course topic. The most important aspect of these problems and questions is that teams are asked to make a decision. Indeed, as Sibley and Ostafichuk say in their book (2014) introducing instructors to the pedagogy, “TBL could easily be called decision-based learning.” Sibley and others often use the analogy of a courtroom jury in a criminal case, who must make a specific choice (guilty or not guilty), but that choice is based on complex and sometimes contradictory information.

Figure 1. The “Castle Diagram,” describing the structure of Team-Based Learning, from Michaelson (2002).



To be successful in promoting student learning and preventing social loafing, each application must be too difficult for an individual but addressable by a team. Practioners emphasize the “4Ss” of application design: Significant Problem, Same Problem, Specific Choice, and Simultaneous Report. Two of these have already been mentioned: the problem should be as “real-world” and non-trivial as possible (Significant Problem), and teams should be asked to make a decision (Which is the most likely diagnosis? Which is the most common product of this reaction? What is the best reason for using this construction method?) rather than answer an open-ended question, which often leads to poor quality, time-wasting team discussions. Further, teams should always be working on the same problem (otherwise, among other issues, teams will “tune out” when others report while they wait for their turn), and to avoid a “collapse” toward the apparent right answer, students should report their answers to the application question simultaneously. This can be accomplished any number of ways, from clickers to a simple system of holding up voting cards on the instructor’s signal.

Figure 2. A TBL classroom with voting cards visible. Credit: Woudase Gallo.

After teams report their answers, the instructor facilitates a whole-class discussion of the question, most often by randomly selecting a team or individual (a variety of methods are used to do so) to report the team's reasoning (the team's decision can already be seen by all students); the instructor's aim is to reveal as many argments, good and poor, as are helpful in understanding the problem, and moving on to the next problem or question once this is done. A more complete discussion of TBL facilatation than space allows for can be found elsewhere (e.g. Pelley and McMahon 2008; Sibley and Ostafichuk 2014, Chapter 7). Some instructors assign points to applications and others do not, treating the application process as formative rather than summative, and often finding that there is no loss of student effort or attention due to the motivations provided by the "4S" structure; further, the focus is maintained on learning rather than points.

TBL teams are often large to facilitate the solving of complex problems (5-7); because of the emphasis on accountability, large size is rarely seen as a problem, though some TBL instructors modify teams to make them closer in size to those used by other team learning pedagogies (e.g. Nanes 2014). Teams should be formed by the instructor in such a way as to distribute evenly across the teams the skills and experiences needed to address the problems posed in the course. Some literature specifically supports this practice (e.g. Brickell et al. 1994; Feichtner and Davis 1984), but more recent data are equivocal on the importance of how teams are formed (Harlow et al. 2016; Hodges 2017). Finally, TBL teams are permanent, which, according to both theoretical constructs (including Tuckman's frequently cited stages of team development (forming, norming, storming and performing; Tuckman 1965) as well as the life cycle model of group development (Wheelan 1994)) and empirical data (Michaelson et al 1989) allows teams to proceed from less-functional to more-functional states and spend more total time in the latter state.

A final universal aspect of TBL is the peer evaluation process. A variety of protocols exist within TBL to do this and other instructors create their own, but some form of peer evaluation is critical for individual accountability. Most practicioners advocate including both a midterm and a final peer evaluation, typically with only the final one counting toward the grade. Many sources delineate this process in detail (e.g. Levine 2008; Sibley and Ostafichuk 2014, Chapter 8).

Thus, although TBL is a very specific pedagogical approach, and indeed may strike some readers as *oddly* specific, it actually neatly brings together many of the empirically-supported best practices of student-centered active learning into a single strategy. This is very convenient for TBL adopters, who are often those who have tried “this and that” active-learning and/or cooperative-learning strategies in their teaching and are ready for something more comprehensive.

II. Team-Based Learning in STEM and the Health Sciences: What is the Evidence?

Several reviews have summarized the evidence base for TBL practice broadly (e.g. Sisk 2011, Kubitz 2008, Haidet et al. 2014), but our focus here will be studies conducted in STEM and the health sciences. The health sciences are the area of widest TBL use, particularly in professional schools including medical, nursing, physical therapy and pharmacy. Medical school remains the single most common venue of TBL practice, with more than 100 medical schools worldwide implementing TBL to some extent (Haidet et al. 2014), some of which use TBL exclusively in their courses. There is even a book dedicated to the use of TBL in health professions education (Michaelson et al 2008).

One of the earliest evaluations of TBL in a medical school was in a gross anatomy and embryology course at Wright State University (Nieder et al. 2005). Instructors reported better student preparation and teamwork skills after implementation of TBL; exam scores were not different than before implementation, however, though there was a decreased variability in those scores that suggested the lowest-performing students were helped the most by the method, a theme that reappears in other papers described below. Also at Wright State, a well-designed crossover study by Koles et al (2005) confirmed this overall result, showing no difference in final exam scores overall for TBL versus case-based group discussion parts of a pathology course, but the lowest-scoring students did perform better when taught using TBL. In a later paper, Koles et al. (2010) found significantly higher scores among second-year medical students (5.9%) on comprehensive course examination questions assessing content learned using TBL versus other methods, again with a larger difference in performance among the lowest-performing quartile of students (mean difference in scores between questions on material using TBL and other methods of 3.8% for the highest quartile and 7.9% for the lowest quartile).

Vasan et al. (2011) found significant increases in both departmental exam scores and the National Board of Medical Examiners (NBME) exam scores when moving from lecture to TBL format in preclinical medical courses. Persky (2012) found significantly better achievement on exam questions testing higher-level learning objectives in a pharmacokinetics course in pharmacy school after a switch from “small-group learning” to TBL. In a gross anatomy laboratory in medical school (Huitt et al. 2015), there was a trend toward higher exam scores when they replaced one-third of cadaver dissections with TBL units, despite the fact that students who experienced TBL had less time for actual dissection. Students taught using TBL did better on some individual exams, but there was no difference on others. They also retained more information later, another trend that reappears in mutiple examinations of TBL practice.

A 2013 review of the use of TBL in medical education (Fatmi 2013) found that among the 14 papers meeting the review criteria, 7 showed an improvement in learning with TBL that was statistically supported, 3 showed an improvement but did not provide statistical support, and 4 showed no difference; however, learners did not always prefer TBL (see “reaction” in the figure) (Figure 3).

Figure 3. Summary of outcomes in a review of TBL use in medical education (Table 5 from Fatmi et al. 2013).

			Findings: Any significant difference			
Outcome	Intervention	Comparator	No statement	$p > 0.05$	$p < 0.05$	Study design and number of participants enrolled
Knowledge	TBL	CBGD		No difference		RCT ($n=83$)
					Favours TBL	NCC ($n=$unclear)
		SGL			Favours TBL	NRCT ($n=112$)
					Favours TBL	NRCT ($n=167$)
		Mixed Active Learning			Favours TBL	CC ($n=64$)
		Independent Study	Favours TBL			PC ($n=1417$)
		Traditional Lecture		No difference		NCC ($n=$unclear)
					Favours TBL	RC ($n=186$)
			Favours TBL			NCC ($n=280$*)
					Favours TBL	NCC ($n=306$)
				No difference		NCC ($n=143$)
					Favours TBL	NCC ($n=371$)
			Favours TBL			NCC ($n=$unclear)
				No difference		PC ($n=121$)
Reaction	TBL	CBGD		No difference		RCT ($n=83$)
		SGL		No difference		NRCT ($n=112$)
					Favours SGL	NRCT ($n=167$)
		Mixed Active Learning		No difference		CC ($n=64$)
		Traditional Lecture	Favours TBL			NCC ($n=$unclear)
			Favours lecture			NCC ($n=280$*)
					Favours TBL	NCC ($n=306$)

RCT = randomized controlled trial; NRCT = non-randomized controlled trial; NCC = non-concurrent cohort; CC = concurrent cohort; PC = prospective cohort; RC = retrospective cohort.
*The exact number of participants enrolled in the study was not reported.

The value of TBL during the clinical years of medical training has also been examined. Okubo et al. (2012) found that TBL improved performance on a validated test of clinical reasoning. Thomas and Bowen (2011) used a crossover design to test the effectiveness of TBL in an ambulatory medicine clerkship, and reported significantly higher examination scores on material learned via TBL, versus “small group learning.” Levine et al. (2004) also reported a high value of using TBL in a clerkship study, finding improved performance on the NBME psychiatry subject test after implementing TBL.
Finally, in a neurology clerkship, Alimoglu et al. (2017) found no effect on an end-of-clerkship exam, but students who learned the material via TBL instead of lectures showed increased retention of neurology clerkship knowledge one year after the clerkship ended (Figure 4).

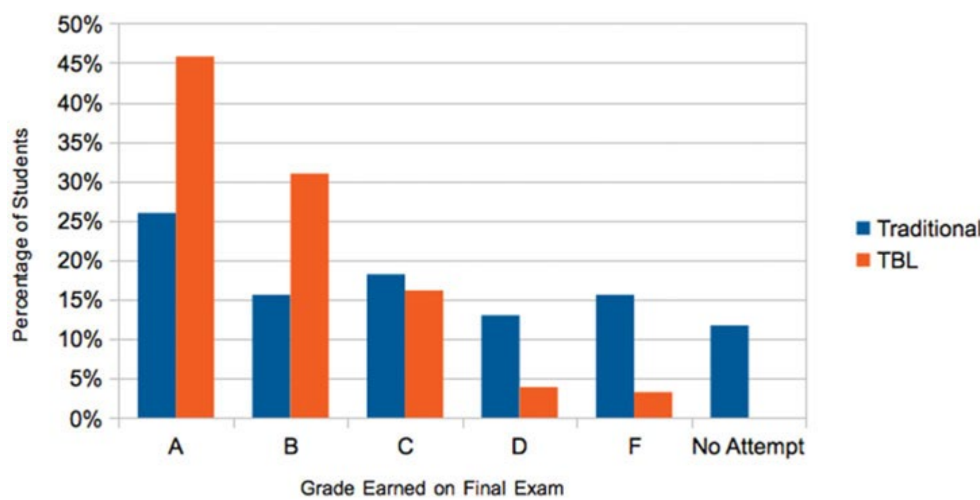
Figure 4. Increased retention, and perception of engagement, in neurology clerskhips taught via TBL in contrast to lecture. From Alimoglu et al. 2017.

	TBL	Lecture	*P* Value*
End-of-clerkship exam†	79.6 ± 4.4	78.9 ± 3.9	0.966
Retention test‡	5.85 ± 1.74	3.28 ± 1.70	<0.001
In-class engagement			
Observation scores			
Instructor§	4.54 ± 0.65	1.33 ± 0.67	<0.001
Student§	4.33 ± 0.91	2.50 ± 0.88	<0.001
No. of questions			
Instructor	3.66 ± 1.50	2.45 ± 1.86	<0.001
Student	3.27 ± 0.45	1.33 ± 0.66	<0.001

*Student's *t*-test; †scores > 100; ‡scores > 10; §scores > 5.

Closest to my own context of undergraduate physiology are a few studies of TBL in undergraduate STEM courses. A study in an undergraduate Microbial Physiology course (McInereney and Fink 2003) found that final exam scores improved after implementation of TBL, though some potentially confounding variables were present. TBL was found to improve performance in a physiology laboratory course (Zimmerman 2006). Positive outcomes were also achieved using TBL in an undergraduate Biochemistry course (Garrett 2008), an undergraduate nursing course (Clark et al. 2008) and an introductory biology course (Carmichael 2009). Two narrative accounts of positive, transformative experience in TBL in undergraduate STEM are Engle's (2008) summary of use of TBL in an undergraduate Genetics course, and Karla Kubitz' (2008) description of her undergraduate sport and exercise psychology courses. In mathematics, little work in this area has been published, but a redesign of a linear algebra course to use TBL (Nanes 2014) resulted in a dramatic improvement in student performance, including on the comprehensive final exam (approximately double the number of As and Bs; Figure 5) and final course grade.

Figure 5. Final exam grades in a traditional (blue) and TBL (orange) linear algebra class (Nanes 2014).



We have included above only those studies in which learning or a purported direct measure of it was the primary outcome. However, in addition, nearly all studies that also, or alternatively, measured student engagement have demonstrated a positive impact of TBL on that engagement, often dramatically so; summaries of these studies can be found elsewhere (Persky 2012, Kubitz 2014, Haidet et al 2014). Given the well-established connection between engagement and learning as described elsewhere in this volume, this is a nontrivial result, and one that anyone who has used TBL can assure you of; my own experience (described below) is strongly in accordance with this.

The above studies represent a good start in investigating the value of TBL pedagogy on student learning, but are relatively few in number, and some work in this area is relatively low-quality, e.g. not including control groups or using validated measurement instruments (these issues are discussed further in Haidet et al. 2014 and Sisk 2011). More, and better, work needs to be done. Despite this, we can be reasonably confident in using this pedagogy because each of its *elements* is so well supported in the literature, as described in other chapters of this volume, especially: collaborative learning; flipped classrooms; motivating student preparation for class; and providing voluminous and instantaneous feedback on student learning.

III. Team-Based Learning in Undergraduate Physiology

I have taught my undergraduate physiology courses using Team-Based Learning every semester since Spring 2011, including the sophomore-level Anatomy and Physiology two-semester sequence (2011-2014) and the upper level courses Human Physiology and Comparative Physiology (2014-present). Each of these classes has an enrollment of approximately 93 students, and is taught in an active learning classroom with 11 large tables, screens and whiteboards accessible to each table, and no “front of the room.” Students are divided into 15 teams who work together during every class day throughout the semester. The semester is divided into 7 units, each of which begins with the “readiness assessment” process described above. For the rest of the unit, class time is designed around short problems or questions, often clinical applications, that specifically probe the most difficult learning goals for the unit. Some problems are open-ended, but most follow the TBL “specific choice” format, in which student teams are asked to make a decision. For examples, see Figure 5. Teams “vote” simultaneously on the answer to each problem or question, using a series of colored, lettered cards (see Figure 2, above), following a verbal countdown by the instructor.

Figure 6. Examples of application questions used by the author in physiology courses.

Unit	Question	Specific Choice?
Nervous System	How will the action potential be different if there were half as much sodium inside the cell membrane as usual?	Y
Nervous System	Mr. Yin is rushed into your ER with dangerous tachycardia… which of the following autonomic nervous system receptor subtypes should be targeted with a receptor antagonist drug?	Y

Senses	How is it possible that humans have, at most, 1000 different olfactory receptors, but can smell 10,000 distinct things?	N
Muscle	You pick up a book, set it down and pick up two books. What change allows you to use more force the second time?	Y
Cardiovascular	Mr. Nguyen has an incompetent mitrial (bicuspid) valve. Which of the following symptoms would you predict in Mr. Nguyen?	Y
Cardiovascular	Ms. Cooper has artherosclerotic plaques from her fast-food diet, partially filling her coronary blood vessels. In what direction and through what mechanism do these plaques affect her blood pressure?	N
Digestion	Would your health and quality of life be worse without a stomach, or without a large intestine?	Y
Reproduction	Which of the following hormones is the best target system for a male contraceptive?	Y
Renal	If you are so dehydrated you might die, should you drink your own urine?	Y
Immune	Aliens with ray guns will destroy your cytotoxic T cells, helper T cells, or regulatory T cells, but allow you to decide. Which will you choose?	Y

Following voting, the instructor selects students at random, using a shuffled stack of cards with student names and photos, to defend their team's choice, until enough students have been chosen that the correct reasoning is clear; volunteers are also accepted after a few cards have been drawn. Not all TBL practitioners use random call, but I have found it greatly increases student investment and decreases texting and other distracted and distracting behaviors. Knight et al. (2016) empirically tested group random call after clicker questions in an introductory biology class and found that students' discussions in the random call condition were of overall higher quality, with more evidence-based reasoning and more requests for feedback and information among student groups.

Facilitation is the most difficult part of TBL practice. If the students know that you are about to tell them the Right Answer, they are less motivated to pursue that target themselves. In my experience, the facilitation aspect should be a whole-class discussion in which the students' voices are dominant, and should involve as many students as needed (no less, but also no more, or students will be bored and time is wasted) to uncover the physiological basis of the question and associated physiological reasoning. Typically, misconceptions valuably arise during this discussion, and allowing them to be aired and debated is the best chance of uprooting them from students' brains, far better than "papering over" these misconceptions via the instructor's immediate statement of the best answer.

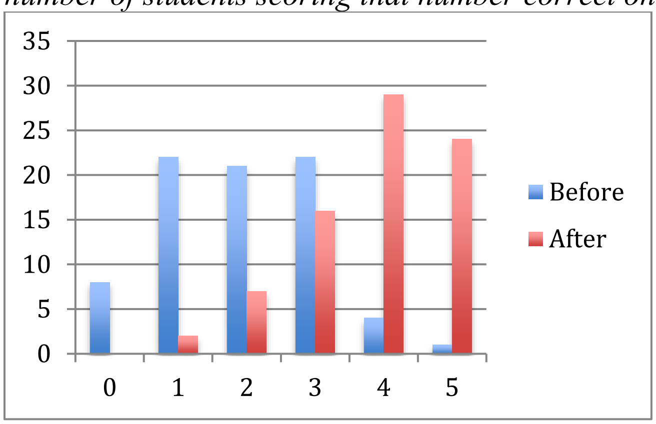
Because I have only taught these classes using TBL, I have no pre- or non-TBL condition to compare to. However, by using pre- and post-tests of conceptual understanding of physiology at the beginning and end of the semester, we can at least say that students gain a significant amount of knowledge and understanding across the semester (Figure 7; $p<.0001$ for both Anatomy and Physiology I and Anatomy and Physiology II).

Figure 7. Performance on a conceptual test of anatomy and physiology on the first and last class days of Anatomy and Physiology I (top) and II (bottom). Values are mean ± SD.

	Pre-Test	Post-Test	P value
A&P 1	43.4 ± 12.5	79.5 ± 12.7	<0.0001
A&P 2	38.3 ± 8.1	82.2 ± 6.3	<0.0001

Similar data were obtained in a pre-post test of conceptual understanding in Human Physiology given in the Fall 2017 semester. Students scored significantly higher on the post-test than the pre-test (75.8± 17.3% versus 37.9±14.4%, p<0.0001). In addition, with the use of pre- and post- concept-based quizzes used across individual class periods, we can say that class time itself is productive, with pre-post concept-based quizzes all showing significant gains from the beginning to end of class time. For example, in September 2017, students scored an average of 1.9/5 on the neurophysiology pre-test and a 3.8/5 on the post-test one hour later (*Figure 7*). Results were similar in October (cardiac physiology) and December (reproductive physiology).

Figure 8. Example of concept gain in neurophysiology across class time (the x axis is number of students scoring that number correct on the 5-question concept quiz).



Adherents of TBL claim, with some evidence as described above, that students will retain information better using this pedagogical approach than using other teaching methods. Although, again, we did not have a control group who did not receive TBL, we were able to show very low "forgetting" from A&P I to A&P 2, that is, from May to September (Leupen 2014).

University administrators are often concerned about the "DFW" rate of the course, or the percentage of students enrolled in a course who receive Ds, Fs, or withdraw from the course. Team-Based-Learning Anatomy and Physiology students had much lower DFW rates, roughly 3-5% from 2011-2014 as compared to historical levels (2000-2010) of 18-25% (Leupen 2014), though there are many possible additional causes for this besides the switch to Team-Based Learning; the size of the class, instructor, classroom, and other factors were all different. However, we have support for the possibility that a reduced DFW rate was in part due to the increased engagement students feel in a Team-Based Learning course. Students in one of these TBL courses reported that they read the textbook more often than in other courses, were more likely to come to class, and felt like they were learning more (Leupen 2012). Although student satisfaction is certainly no guarantee of learning value, given the resistance instructors often receive when implementing active-learning techniques, as discussed elsewhere in this volume, it is worth noting that this instructor has experienced almost no resistance to the teaching method, and these courses have consistently received high student ratings (also experienced in Garrett's (2008) TBL class). Although this is by no means always the case in TBL classes, students are certainly capable of enjoying and preferring TBL courses; at UMBC there were two full-TBL courses taught in the College of Natural and Mathematical Sciences in Spring 2018, for example (one in Math and one in Biology), and these two courses received the highest "overall" course ratings in the College that semester (among courses with more than 10 students who completed the response instrument).

Our current work on TBL undegraduate physiology courses is analyzing transcripts of team discussions among groups in a TBL Physiology class from Fall 2018 (manuscript in preparation). Evaluation of discussion transcripts identified instances of high-level discussion (high Bloom's level explanations) and focused on the conditions associated with this level of discussion. Students appear engage in higher-level explanations when one of two conditions is present: first, the application question posed truly requires higher-level reasoning to answer (that is, the Bloom's level and overall quality of the question are high); second, during the discussion, at least one student provides what was coded as a "reevaluation" (disagreement or questioning of others' conclusions). Students may be more willing to reevaluate after some time spent together as a team, supporting the TBL practice of permanent teams. Finally, while not directly tested here, higher-level discussion is unlikely to occur without preparation (readiness assessment), again supporting TBL practice. End-of-course surveys also showed that teams tended to increasingly value consensus and hearing each team member's voice as the semester went on.

In summary, undergraduate physiology appears to be an appropriate and rewarding venue for team-based learning, and there is no *a priori* reason why these results could not be achieved in other undergraduate STEM courses of appropriate size; indeed, the literature cited above supports that proposition.

IV. Recommendations for Practice and Future Directions

I once overheard a participant at a TBL 101 Workshop at the national Team-Based Learning Conference say to his colleague, "So, have you drunk the Kool Aid yet?" Indeed, TBL enthusiasts are often seen as promulgating this teaching strategy with near-religious fervor, and perhaps some associated closed-mindedness. But the zeal of the convert is forgivable when you realize how overjoyed these instructors are to find themselves suddenly in a classroom full of noisy discussion about their favorite subject!

Most TBL users have had someone tell us, "Well, I tried team-based learning, and it didn't work." Most commonly, this is an issue caused by the generic name of the method (Jim Sibley has suggested that "Decision-Based Learning" could be a more precise name); in these cases, the person is not referring to TBL at all, but rather the use of teams during class, which indeed often fails without individual accountability or team-appropriate tasks given to the students. However, even among those who are familiar with the method, there are some who believe they are using it, but are actually using only Readiness Assessment Tests. While these can indeed improve students' preparation for class, the purpose of that preparation is lost when the instructor continues with class as usual (lecture or other didactic methods) instead of having students use the material they have learned. In these cases, students—and eventually the faculty members, given the response from students and the failure to improve learning—reject the method, without ever having done actual TBL in the first place.

While it *is* possible to choose aspects of TBL to apply to one's classroom without embracing the whole method, tread carefully. As described above, it is a poor choice to use only RATs and not team applications. (And ***never*** go over the RAT point-by-point when it's over. The team RAT has already taken care of that!) The heart of this method is the applications, not the reading quizzes (though the quizzes directly support the success of the applications). Alternatively, following TBL's "4 Ss" is an excellent way to improve group work and in-class questions using *any* pedagogy, and we would recommend you start there. Before implementing TBL (or any other complex pedagogy!), read one of the TBL books—I especially recommend Sibley and Ostafichuk's *Getting Started with Team-Based Learning (*or the TBL in the Health Sciences Book [cite])—or attend one of the day-long workshops offered at the national meeting (held every year in March) or at regional airport hotels around the country. These workshops are run *as* TBL classes, which gives you the experience you need to use the method yourself. Another excellent technique is to request materials (RATs, learning goals, application questions) from someone in your field using the TBL listserv; even if you do not want to use the materials, they will give you great ideas about how to prepare your own.

Here are my "Top 5" takeaways from TBL practice and research:

1. TBL is a straightforward, cleanly "packaged" way to implement many of the specific practices that have been repeatedly shown to improve student learning: active participation of students, immediate feedback on performance, collaborative learning, and accountability for both preparation outside of class and performance in class. So if you feel you are ready to move past the "a little of this, a little of that" toe-dipping method of evidence-based teaching, TBL may be a great fit for you.

2. The key to successful use of TBL is the application questions and how you design them. Most importantly, the question must be one that requires students to practice expert-level thinking (even if simplified) to solve, *never* something they can look up or ask their "smartest" team member to tell them. Questions that apply class content to professional practice will inevitably motivate students to "spend" the cognitive energy to answer. And if you are a "doubter" about specific choice, give it a try. Nothing clarifies a group's thinking and discussion more than having a specific decision to make rather than an open-ended question.

3. Applications, or any complex problem-solving tasks, will simply fail if students are not prepared for class. The Readiness Assessment Tests prepare students with exactly the tools they need to solve your in-class questions (indeed, they should be back-formed from those application questions: what knowledge do students need to be able to think productively about these questions?), and students can immediately see the value of the reading quiz and the reading itself when they are asked to use the information just minutes after the quiz. It is critical to tell students what they need to know from the reading: you *cannot* (in TBL or any other context) just tell students to go read 50 pages of a textbook and "take a quiz on it." They will have no idea how to prioritize the information or at what level it should be learned. Provide them with specific, action-verb-driven learning goals for the entire unit as well as the RAT (in my learning guides, the goals on the RAT are italicized, making it easy for students to identify them and prepare for the RAT).

4. The practice of TBL and other flipped-classroom techniques highlights the critical need, as discussed by other authors in this volume, to think more about what belongs in individual space versus group space: we should all be doing things in our face-to-face class meeting times that can *only* be done there, and moving other activities outside of the classroom. We have precious little time each semester with our students, and must always be asking ourselves: What is the very best use of the very limited time we have together as a class? Next, we must ask: what needs to happen outside of class to allow those in-class times to be successful learning experiences? Getting this balance right is the key to maximizing the degree to which our students' disciplinary thinking can develop in a single semester.

5. Research on TBL in undergraduate contexts especially remains limited. We need to learn more about the optimal size of groups in different contexts, how to increase the cognitive level of the conversation of teams, how to stimulate higher-level discussion and that elusive goal, critical thinking, and learn more about who benefits most from TBL and related pedagogies.

Fundamentally, this is a teaching strategy that is in line with the research literature on effective teaching in many ways, as summarized in the first "takeaway" point above, though it is just one of those methods, and it is still evolving, along with the evidence. Many practitioners can attest to the power of this method to energize their classroom and improve their students' learning, and a commonly heard refrain at TBL events is "I'll never go back to teaching any other way." Team-Based Learning has earned its place among evidence-based pedagogies, works well within the structure of an undergraduate STEM course, and would benefit from being considered by more undergraduate instructors.

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