Investigating Student Success in Team-Based Learning Calculus I and in Subsequent Courses

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With recommendations for active-learning strategies and challenging courses, we applied mixed methods to examine students' success in Calculus I and subsequent courses following instruction using Team-Based Learning (TBL). Overall, TBL students performed better on midterm and final calculus exams, gave more explanations, and completed Calculus I at a higher rate than their peers. These results remained true when students' incoming competencies for calculus were considered. TBL students performed comparably to their peers in Calculus II and Physics.

Keywords: Calculus, Team-Based Learning, Flipped, Active, Large

Research in mathematics education calls for active learning in post-secondary mathematics courses. Freeman et al. (2014) published the findings of a meta-analysis of 225 studies reporting data on exam scores or failure rates for undergraduate STEM students in active learning classrooms versus traditional lecture classrooms. Students in active learning classes consistently performed better. In their nationwide study, Bressoud, Mesa, and Rasmussen (2015), encouraged challenging and engaging courses along with student-centered pedagogies and active-learning strategies as two of seven recommendations leading to successful calculus programs. Active learning also promotes the transfer of knowledge (Billing, 2007). When learning occurs through active engagement while embedding understanding and reflecting upon practices, Billing (2007) says justifications, principles and explanations are socially fostered, generated and contrasted. To identify which active learning strategies benefit learning, Wieman (2014) and Freeman et al. (2014) call for examination of the strategies implemented in classrooms.

Team-Based Learning (TBL) is a specific form of active learning designed to engage students in problem-solving discussions and hold students accountable for their preparation, no matter the size of the class (Sibley & Ostafichuk, 2014). TBL utilizes the flipped classroom model. Many instructors in recent years have investigated the impact of the flipped classroom in Calculus I in both large and small class settings, with the primary benefit to students in flipped sections being higher final exam scores when compared to students in non-flipped sections (Schroeder, McGivney-Burelle, & Xue, 2015, Anderson & Brennan, 2015, Jungic, Kaur, Mulholland, & Xin, 2015, and Maciejewski, 2015). Studies reported mixed performance in students' subsequent performance in Calculus II after having flipped Calculus I, with only one study reporting flipped students performing significantly better (Schroeder, et al., 2015 and Anderson & Brennan, 2015). The study presented here explores the benefits of TBL Calculus I taught to students in large and small class settings both during the semester of engagement and in subsequent courses.

Developed by Michaelsen, Knight, & Fink (2004) to help students learn how to apply concepts, TBL maintains that groups must be formed heterogeneously and remain permanent, students must be made accountable for their individual and group work, group tasks must promote critical thinking and team development, and students must have frequent and timely performance feedback. Aligning to Michaelsen's methods, at the start of the semester instructors assign groups of 5-7 students to teams. A module in TBL covers 2-3 weeks' worth of content and consists of the Readiness Assurance Process (RAP) and application exercises. The RAP holds students accountable for their work completed outside class time and encourages better team functioning. The RAP includes reading and/or viewing videos to gain initial understanding of course information, taking an individual Readiness Assessment Test (iRAT), completing a team Readiness Assessment Test (tRAT), an appeals process, and an instructor mini-lecture. The RATs consist of multiple choice or short answer questions. Students do not receive feedback on the iRATs prior to completing the identical tRATs with their teams. Following the tRATs, instructors give the answers and highlight the main concepts and procedures addressed by the RAP. The RAP positions students to work on the team-based application exercises occurring during subsequent class session(s). The application exercises are rich problem-solving activities designed so each team solves the same significant task, makes a specific choice for an answer, and simultaneously reports an answer. During the tRATs and application exercises, the instructors circulate the classroom to answer questions and nudge students in ways to consider the concepts and solution paths. As done by Nanes (2014) and Prudente (2017) for small linear algebra courses, we modify the TBL process by limiting the length of a module to 2-3 class sessions instead of 8-12 class sessions, and administer the iRATs online outside of class time. At various points throughout the course, students evaluate their team members, further enhancing the team's function and assuring student accountability to the team.

With the emphasis on team communication, interaction, and development of shared understanding, the theoretical framework of social constructivism underlies the foundation and implementation of TBL. Vygotsky highlighted the role of language and social interactions to develop meaning and understanding of a concept (Bigge & Shermis, 1999). The TBL process provides scaffolding for students and situates students in their zones of proximal development. When encountering a new topic, students first engage with material by reading and/or watching instructor-made videos. During the tRATs and application exercises, students engage with other students in interesting, meaningful collaborative problem-solving activities (scaffolding), as they record language and equations and create graphics to communicate their shared understanding (Bigge & Shermis, 1999). The tRATs and application exercises also position students in their zones of proximal development (ZPD) as the designed tasks target skills beyond what students can do independently but can achieve with assistance from both instructors and more knowledgeable peers (Bigge & Shermis, 1999). By design, the heterogeneous teams in TBL offer students different opportunities to serve as the more knowledgeable others to lend assistance in the ZPD (Sibley & Ostafichuk, 2014). Once students in teams complete the application exercises, the students likely will be able to complete future similar tasks individually, thereby raising the ZPD (Shabani, Khatib, & Ebadi, 2010).

Research Questions

Do students in TBL calculus perform better on departmental midterm and final exams when compared with Non-TBL calculus students? How do TBL students perform on both conceptual and procedural problems on the comprehensive final exam? How well do TBL students transfer their calculus knowledge to subsequent courses, for example, to calculus-related questions on their first physics exam? How do TBL students fare in calculus I and subsequently in calculus II and physics when compared to their peers?

Methodology

The population at a large (36,000) Midwestern Research I institution includes 43% women, 11% US minority, and 12.6% international students. In Fall 2016, 1845 students enrolled in Calculus I for science and engineering majors. Students registered for a section of Calculus I not knowing the course-delivery system. Three of the authors taught 366 students using TBL (N = 301 students across two large classes and N = 65 students across two small classes). All Calculus I students completed uniformly graded departmental midterm and final exams. TBL students completed pre- and post-tests of the Calculus Concept Inventory (CCI) and an eight-item semantics differential assessing students' confidence in mathematics. The 1507 Non-TBL Calculus students received primarily traditional instruction. For one subset (N=136) of the Non-TBL students, researchers gathered pre- and post-CCI, pre- and post-confidence surveys, midterm exam scores, final exam scores and students' answers to three of the final exam problems. For a second subset (N=108) of Non-TBL students, researchers collected pre- and post-confidence surveys and midterm and final exam scores. During Spring 2017, 232 students consented to the release of information regarding their first exam in calculus-based physics. For 771 students, the Registrar's office provided demographic information and Calculus I, II, and Physics course grades for consenting TBL and Non-TBL Calculus I students and Physics students.

For TBL students, a subset of Non-TBL Calculus students, and students who consented after the drop date to provide physics exam information (i.e., survivors in physics), researchers calculated "incoming competency scores" by averaging students' ALEKs placement score (of 100), students' pretest CCI score (of 22), and the number of high school calculus units (of 6). If students did not take the CCI, the incoming competency score was the average of the number of high school calculus units and the ALEKs placement score. Table 1 displays the averages of the scores for the three groups.

Table 1. This table shows the incoming calculus competency averages.

TBL Calc			Non-TBL Calc			Non-Calc I Physics		
Mean	SD	N	Mean	SD	N	Mean	SD	N
.477	.113	298	.478	.116	354	.583*	.141	116

Note. *p < 0.001. The Non-Calc I Physics completed Physics in Spring 2017 but not Calculus I in Fall 2016.

Researchers determined the quintiles of the incoming competency scores for 744 students. For each quintile, researchers analyzed students' performance in Calculus I, II, and Physics. Additionally, for both TBL and Non-TBL Calculus I students for whom researchers possessed pre- and post CCI scores, final exam scores, including scores on three problems of the final exam, researchers partitioned the final exam scores into quintiles. Based on the final exam, researchers selected exams from a subset of each quintile and of each instruction type. For quintiles one through five, researchers randomly selected 14, 24, 24, 24, and 14 exams[1], respectively and performed qualitative analysis on three of the eight final exam questions. Applying a detailed scoring rubric, two of the authors blindly evaluated students' solutions from the 200 final exams. Of the three questions selected, a conceptual question provided the graph of a derivative (f') and asked students to graph the second derivative (f''), identify where f

[1] Researchers sought to oversample the middle quintiles but the Non-TBL group had exactly 24 exams in quintile 3.

increases, decreases, is concave up and concave down, and where *f* has critical points and inflection points. A procedural question asked students to evaluate a definite integral whose integrand involved the sum of three parts: a simple polynomial, a function for which substitution was required, and a third requiring interpretation of an integral as an area. The third question required optimizing an area given a function containing a parameter. This problem required students to consider multiple techniques including integrating, calculating derivatives, and verifying an optimal value. Each of these three problems was worth 15 points.

Two graders applied the rubric for the conceptual, procedural, and complex procedural problems having inter-rater reliability calculated using percent agreement of 93.79, 86.75, and 96.18, respectively. The two raters and another researcher discussed and resolved all differences.

Results

When considering the final exam scores for all students in Calculus I, Table 2 shows TBL students outperformed Non-TBL students on the uniformly graded departmental exam. Additionally, Table 3 displays the rate at which students earned D, F, or withdrew (DFW) from the course, demonstrating a significantly lower DWF rate for TBL students when compared to Non-TBL students.

Table 2. This table gives Fall 2016 departmental final exam scores.

TBL			Non-TBL		
Mean	SD	N	Mean	SD	N
55.52*	21.88	325	50.05	21.89	851

Note. *p < 0.001.

Table 3. This table gives DFW Rates for Calculus I.

Fall 2016	TBL	Non-TBL
Overall	**19.1** (70/366)*	32.0 (473/1479)
Female only	**24.7** (18/73)	30.1 (85/282)
Ethnic Underrepresented only	**34.8** (8/23)	45.5 (61/134)
International Only	50.0 (5/10)	**37.1** (65/175)

Note. *p < 0.01. Boldface type indicates lower DFW rate.

For students categorized based on incoming competency scores, researchers analyzed student success on the departmental midterm and final calculus exams, on the first physics exam, and the DFW or DF rates for Calculus II and calculus-based physics course. As shown in Table 4, for students with comparable incoming competency, for all but the first quintile, students in TBL Calculus outperformed their Non-TBL peers on the midterm exam. For the final exam, TBL students performed better than Non-TBL students significantly so for quintiles 4 and 5.

For students who took Calculus II or Physics during Spring 2017, very few differences occurred in performance on the first Physics exam or when considering the rates at which students completed Calculus II. TBL students in the top four quintiles completed Physics at a higher rate than Non-TBL students, but never significantly different.

Qualitative analysis performed on three of eight of the final exam problems for 100 TBL and 100 Non-TBL students partitioned by quintiles showed TBL students outperformed Non-TBL students on the conceptual problem, with significance for quintiles two and four. Differences in the numbers of explanations and correct explanations arose as shown in Table 5. TBL students sometimes gave three times as many correct explanations as their peers. For the procedural and complex procedural questions, TBL students and Non-TBL students performed comparatively.

Table 4. This table shows students' success on Calculus I exams depending on an incoming competency score.

	Calculus 1 Midterm Exam						Calculus 1 Final Exam					
	TBL			Non-TBL			TBL			Non-TBL		
	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
Q1	54.8	20.8	63	57.2	19.4	64	37.4	21.1	57	36.9	20.3	62
Q2	72.9*	13.9	52	66.11	17.5	63	51.6	16.5	52	44.4	20.6	58
Q3	78.2*	13.8	80	72.5	17.3	49	58.15	18.3	80	53.2	20.6	47
Q4	83.1*	9.57	51	72.8	16.8	35	62.2*	18.9	50	53.2	21.7	34
Q5	89.3*	8.7	41	80	12.8	29	74.3*	17.6	40	60.3	24.4	29

Note. $^*p < 0.05$.

Table 5. This table shows the number of explanations given for the conceptual question of the final exam.

	TBL		Non-TBL	
	Explanations	Correct Explanations	Explanations	Correct Explanations
f increases/decreases	72**	61	56	47
f critical points	73**	59	55	21
f' concave up/down	64*	44	52	34
f' inflection points	72**	29	55	15

Note. Numbers are based on 100 TBL exams and 100 Non-TBL exams. $^*p < 0.05$. $^{**}p < 0.01$.

Discussion

Similar to the studies examining flipped calculus, (Schroeder, et al., 2015, Anderson & Brennan, 2015, Jungic, et al., 2015, and Maciejewski, 2015), this study demonstrates that when compared to their peers, TBL students performed higher on calculus midterm and final exams, gave more explanations and correct explanations on a conceptual question, and performed comparatively in downstream courses relying on calculus knowledge. This study adds to the literature in that we explored students' performance based on their competencies brought to calculus. The few distinctions in performance of TBL students with Non-TBL students in downstream courses could be due to a mismatch of assessments. TBL students were frequently assessed in their conceptual understanding during Calculus I while assessments in downstream courses likely targeted more procedural understanding.

Noteworthy in this study are the smaller DFW rates in Calculus I for TBL students compared to Non-TBL students. The higher DFW rates for female and ethnic underrepresented students show significant work yet remains by mathematics departments to better serve all students. In addition, the emphasis on communication in TBL likely challenges international students beyond what occurs in Non-TBL courses.

Questions

What additional aspects of the data should be investigated? Does the incoming competency calculation fairly assess a student's position at the start of Calculus I? What are effective ways to measure students' performance in downstream courses and to capture students' transfer of calculus knowledge?

References

Anderson, L., & Brennan, J. (2015). An experiment in “flipped” teaching in freshman calculus. *PRIMUS*, *25(9-10)*, 861–875.

Bigge, M., & Shermis, S. (1999). *Learning theories for teachers* (6th ed.). New York: Longman.

Billing, D. (2007). Teaching for transfer of core/key skills in higher education: Cognitive skills. *Higher Education, 53(4),* 453-516.

Bressoud, D., Mesa, V., Rasmussen, C. (2015). *Insights and Recommendations from the MAA National Study of College Calculus.* Washington, DC: MAA Press.

Freeman, S., Eddy, S., McDonough, M., Smith, M., Okoroafor, N., Jordt, H., and Wenderoth, M. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences, 111(23)*, 8410–8415.

Jungic, V., Kaur, H., Mulholland, J., and Xin, C. (2015). On flipping the classroom in large first year calculus courses. *International Journal of Mathematical Education in Science and Technology. 46(4),* 508–520.

Maciejewski, W. (2015). Flipping the calculus classroom: an evaluative study. *Teaching Mathematics and Its Applications. 35,* 187–201.

Michaelsen, L. K., Knight, A., and Fink, L. (2004). *Team-based learning: A transformative use of small groups in college teaching.* Sterling, VA: Stylus.

Nanes, K. (2014). A modified approach to team-based learning in linear algebra courses. *International Journal of Mathematical Education in Science and Technology. 45(8),* 1208–1219.

Prudente, M. (2017, July). *A team-based learning approach to linear algebra.* Paper presented to MathFest meeting of the Mathematical Association of America, Chicago, IL.

Schroeder, L., McGivney-Burelle, J., and Xue, F. (2015). To flip or not to flip? An exploratory study comparing student performance in Calculus I. *PRIMUS. 25(9-10),* 876–885.

Shabani, K., Khatib, M., & Ebadi, S. (2010). Vygotsky’s zone of proximal development: Instructional implications and teachers’ professional development. *English Language Teaching, 3(4),* 237-248.

Sibley, J., & Ostafichuk, P. (2014). *Getting started with team-based learning*. Sterling, VA: Stylus Publishing.

Wieman, C. E. (2014). Large-scale comparison of science teaching methods sends clear message. *Proceedings of the National Academy of Sciences*, *111(23),* 8319–8320.

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