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Implementing Team Based Learning in a First Year Introduction to Engineering Course

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Abstract

Optimizing student learning has been the goal of many active learning techniques. This paper will discuss in particular the experience, evaluation and lessons learned from implementing Team Based Learning (TBL) in a freshman introduction to engineering course. Unlike in a traditional lecture style class, students of a TBL class are held accountable for coming to class prepared. Instead of passively sitting in a classroom taking notes, students of a TBL class spend most of the lecture time actively engaging in team-based problem solving activities. The responsibility of learning shifts from instructor to students. Benefits of TBL include a more interactive and engaged classroom, student practice of problem solving, teamwork, and life-long learning skills. Assessment results showed that over 86% of students surveyed had favorable experience with TBL. In addition, similar positive experience was reported from students in different gender and race, in different academic levels and with different academic performances. These results show that TBL is a teaching pedagogy that can benefit a wide range of students.

Introduction

Team Based Learning (TBL) has been shown to be an effective collaborative learning tool in healthcare professional schools such as medical, pharmacy and nursing schools, and its use in undergraduate programs in engineering, sciences and humanities has been growing[1-3]. Unlike other active learning strategies, TBL involves a prescribed sequence of individual work, group work, immediate feedback and applications. This paper will discuss in particular the experience, evaluation and lessons learned from implementing team-based learning in a freshman introduction to engineering course at Arizona State University. The introduction to engineering course is a 15-week 2-credit hour course structured as a 50-minute lecture and 2-hour and 50-minute lab per week. The course introduces students to engineering design process, engineering model and drawing, MATLAB, teamwork, technical communication and project management. Basic disciplinary knowledge is also covered to help students with their half semester long multi-disciplinary design project.

There were many challenges implementing TBL in this particular course: short lecture time, small group size and compact learning schedule. Despite these difficulties, TBL was implemented in the lecture portion of the course in three sections of introduction to engineering course with approximately 40 students each in the Fall semester of 2014. The effectiveness of the TBL approach was evaluated using the Team-Based Learning Student Assessment Instrument (TBL-SAI) survey[4] at the end of semester. TBL-SAI measures the student responses in three categories: student accountability, preference for lecture or team-based learning and student's satisfaction with TBL. With the same course materials but delivered in a different format, the score of a comprehensive exam was also used to compare if there is any difference in student's competency in mastering the course materials between the students of Fall of 2014 with the adoption of TBL and the students of Fall of 2013 without. In addition, the anonymous end of term student course evaluation was used to show if there was any change in student perception in

both the course and the instructor between the two cohorts of students with and without the use of TBL.

The rest of the paper is organized as follows. First, the team based learning teaching pedagogy is briefly introduced in the background section. Its implementation in the freshman introduction to engineering course is described next, followed by the assessment and results. Lessons learned and recommendation for future improvement is presented next, followed by conclusion.

Background

Team-based learning is a flipped classroom teaching methodology that is different from other forms of collaborative or cooperative learning. There are four essential elements of TBL[5]:

1. Teams must be properly formed and managed. Diverse and permanent teams of five to seven students are required.
2. Students are held accountable for pre-class preparation and contributing to teamwork during class.
3. Students are given frequent and timely feedback.
4. Students make complex decision on course concepts during class that are reported in simple form.

In a team-based learning course, it is recommended that large (five to seven students per team) diverse teams are formed by the instructor at the beginning of the course, and stay consistent for the duration of the course. To motivate every student to contribute and hold them accountable for in-class teamwork, peer evaluations are used. Either a fixed percentage grade or a scale factor for team portion of the total grade is often incorporated in the grading scheme based on the result of peer evaluations.

In a TBL class, course materials are divided into modules. A typical module spans several class periods. Every module follows the same prescribed sequence. First, pre-module preparatory materials are assigned to students such as textbook readings, PowerPoint slides, videos and etc. The students should come to the first class of each module having completed the assigned preparatory materials. To ensure students coming to class prepared, a readiness assurance test is used, which is a multiple-choice test based on the assigned materials. Students first complete the test individually, known as the Individual Readiness Assurance Test, or iRAT. Then they retake the same test with their teammates (Team Readiness Assurance Test or tRAT). A special kind of scoring sheet, known as an Immediate Feedback Assessment Technique (IF-AT) form[6] is typically used during the tRAT. They are “scratch and win”-style card as shown in Figure 1. On the IF-AT form, each question has a row of boxes that can be scratched like a lottery ticket. Students must scratch off the opaque coating to reveal the correct answer, which is indicated by a small star. Depending on how many scratches reveal the correct answer, students are awarded with different points. Using IF-AT forms is essential to provide instant feedback to students. It also forces discussion in the team to come to a consensus before choosing which box to scratch. The discussion is continued until the correct answer is revealed. Following the team test, students are encouraged to appeal any questions that they disagree with due to ambiguity either in the reading or in the question using a written appeal. Then the instructor can give a short mini-lecture to clear up any remaining confusion regarding the test.

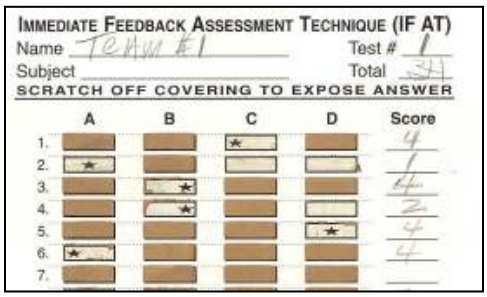

Figure 1. IF-AT form for tRAT

Once the readiness assurance process is completed, the rest of the lecture time scheduled for the same module is devoted to application activities. The application activities are built upon the students' individual pre-lecture preparation and their subsequent learning during the readiness assurance process. The application activities are designed to follow the 4-S's rule: Significant problem, Same problem, Specific choice and Simultaneous report. Specifically, students work in teams to solve the same problem that is significant to them. The problem requires a specific choice, and all teams report their choices simultaneously. The answers are then discussed as a whole class and teams are asked to defend their answers.

In a TBL classroom, students spend most of the class time working in teams and applying course concepts to solve relevant, interesting and significant problems. The responsibility for learning shifts from instructor to students. During this process, students develop problem solving, teamwork, and life-long learning skills. Instead of passing on information to a passive audience, the role of the instructor shifts from a lecturer to a facilitator of a livelier and more interactive classroom.

Team-based learning is gaining popularity in engineering education with quite a few recent developments[7-9]. The most relevant work to this study is the TBL implementation in the Introduction to Engineering course at University of Alaska Anchorage[9], which is a one credit, student success oriented course. Unlike their course, the Introduction to Engineering course in this study focuses more on engineering design process, tools and models, and hands-on design project.

Implementation

The introduction to engineering course at Arizona State University is a 2-credit lecture and lab course with a 50-minute lecture and a 2-hour 50-minute lab scheduled each week for 15 weeks. As the first course in engineering, the course introduces students to engineering design process, engineering model and drawing, MATLAB, teamwork, technical communication and project management. Besides learning these basic engineering concepts, students also work on a multidisciplinary design project and build a functional prototype. To help them with the design project, basic disciplinary knowledge is also introduced. The course is set up in the following format: during the first half of the semester, the lectures are used to introduce core course concepts; for the second half, they are exploratory in nature and cover different applications of engineering. The labs are used to reinforce lecture concepts through hands-on exercise for the

first half of the semester and students are working on their design project for the second half. Feedback from the students towards this course has been positive. Student liked the hands-on experience during the lab but many thought the lectures were unnecessary and didn't contribute much to their learning. To provide students with a better learning experience, team-based learning was implemented in the 50-minute lecture portion of three sections of the Introduction to Engineering course in the Fall semester of 2014. The lab portion was left intact.

Students already worked in teams in the lab (but not in lecture) before converting to team-based learning. Students formed teams of four at the beginning of the semester and stayed in the same team for the rest of the semester. CATME[10-13], a web-based team management tool, was used to form teams. A team-maker survey was created to survey students in different categories such as major, schedule, English skills, writing skills, shop skills and etc. Team forming criteria in CATME were set such that teams were formed to have members with similar schedule but diverse in all other categories. As mentioned earlier, the ideal team size in a team-based learning class is five to seven students. This is because the intellectual horse power of a large team is needed for complex problem solving. The team size was kept at four in this course due to the lab space seating arrangement and it was considered better for students to work in the same team for both lecture and lab.

Before converting to team-based learning, the format of lectures usually began with instructor delivering the course content followed by student exercise and/or group work. To convert the course to use team-based learning, nine modules were created, with each module covering one core course concept. Pre-lecture reading was assigned along with a reading guide. Ten multiple choice questions were developed as the iRAT/tRAT test for each module. The student exercises used in the old lectures were modified to follow the 4-S's principle and used as application problems.

During the first seven weeks of the semester, the lectures and labs were coupled before the conversion. The seven core course concepts were introduced one per week, including design process, engineering models and drawing, MATLAB, electrical and mechanical fundamentals, project management and technical communication. These core concepts were introduced early in the semester so that students could apply them in their project. As described earlier, a typical TBL module often takes place over several class sessions so that students have sufficient time to work on multiple application problems. However, making it happen in this course would require restructure the whole class including both lectures and labs. During this first trial implementation, it was decided to change only the lectures, not the labs. The easiest conversion was to develop the seven core concepts into seven modules with one module per week. The lecture portion of these seven weeks followed the same prescribed TBL sequence. Before the lecture, pre-lecture readings along with a reading guide were assigned from the textbook[14] and supplemental readings were provided for topics not covered in the textbook. During the 50-minute lecture, a 10-question multiple-choice readiness assurance test iRAT/tRAT was given first. The appeal process and a mini-lecture followed. Students then went on to work on one or more application problems depending on how much time was left. The application problems were all multiple choice questions. The students were given voting cards labeled A through D during the application activities. They discussed the problem within their team to reach a

consensus. Once time was up, all teams had to raise their answer card simultaneously. The instructor then moderated discussion regarding why teams chose their answers.

During the second half of the semester, students worked on their multi-disciplinary engineering design project building their prototypes in labs. The lecture schedule was not as tight as the first half. Lectures were divided into two modules, one on engineering profession and the other on engineering grand challenges[15]. Each module spanned two or three lecture periods. The first lecture of each module follows the same sequence as one of the first seven modules. More application problems were worked on during the subsequent lectures. Instead of using multiple choice type application problems, these two modules used an application technique called gallery walk. For example, one application problem was to let students develop a water purification plan for a backpack camping trip. Each team was given a poster paper which they could present their ideas. They were given a set time period to work on their poster. When time was up, they put up their poster around the room at the same time. Each team was given a chance to briefly describe their poster. Then each team was given two sticky notes and was asked to choose the top two designs. A representative from each team was sent to put the sticky notes on the posters of their choice simultaneously.

The grading scheme for the course was shown in Table 1.

Table 1. Grading Scheme

Individual	
Individual Readiness Assurance Test (iRAT)	10%
Quizzes and Exam	20%
Journal Reflection	20%
Team	
Team Readiness Assurance Test (tRAT)	5%
Design Project	45%
Total	100%

Two peer evaluations were conducted using CATME. One was around week 9 into the semester and the other was at the end. The peer evaluation let the students evaluate both themselves and other members on the team in different categories such as contributing to work, interacting with teammates, keeping team on track and etc. The resulting adjustment factor from the last peer evaluation was used to scale the team grade portion of the student grade.

Assessment and Results

The effectiveness of the implementation of team-based learning in the Introduction to Engineering course was assessed using a proven instrument called Team-Based Learning Student Assessment Instrument (TBL-SAI)[4] across three sections in the Fall of 2014. In addition, the average exam score and teaching evaluations were compared between the Fall 2014 cohort implementing team-based learning and the Fall 2013 cohort of four sections without using TBL.

Student Acceptance

Among the students from three sections of Introduction to Engineering in the Fall of 2014, a total of 87 students consented to participate in the TBL-SAI survey approved by the Institutional Review Board (IRB). The TBL-SAI survey was given to the students at the end of the semester. The instrument has 33 questions using a 5-option symmetric disagree-agree scale. A score from one to five is assigned to each point on the disagree-agree scale with one being "strongly disagree" and five being "strongly agree". For example, for the question "Team-based learning activities are fun", the student answer "strongly agree" gets five points and the answer "strongly disagree" gets one point. Depending on the wording of the questions, some questions requires a reverse score from five to one being assigned to the disagree-agree scale. For example, the question "Team-based learning activities are a waste of time" uses a reverse score with five points assigned to "strongly disagree" answer and one point assigned to "strongly agree" answer.

The TBL-SAI surveys student's experience with team-based learning in three subscales: accountability, preference for lecture or team-based learning, and satisfaction. The accountability subscale has eight questions and is used to assess student preparation for class and contribution to team. The preference for lecture or team-based learning subscale consists of 16 questions and is used to assess student ability to recall material and student attention level in lecture and team-based learning. The last subscale is satisfaction, which consists of nine questions. It is used to assess student satisfaction with team-based learning.

The TBL-SAI survey results based on the 87 student responses for the three subscales and the overall score are shown in Table 2.

Table 2: TBL-SAI Survey Result

Subscale	Possible Range	Neutral Point	Mean	STD
Accountability	8-40	24	30.7	4.23
TBL vs. lecture	16-80	48	48.6	7.84
Satisfaction	9-45	27	33.3	5.34
Overall	33-165	99	112.6	13.76

The possible range represents the range from the lowest total score to the highest total score in each subscale after inversion, i.e., it corresponds to the student response with scores of all ones (lowest) and the response with scores of all fives (highest) for all questions in each subscale. The neutral point corresponds to the response with scores of all threes, i.e., "neither disagree nor agree" for all questions in the subscale. Table 2 shows that the mean scores of all subscales are above the neutral point. For all scales, the higher the score, the more preference or positive attitude is shown towards team-based learning.

Figure 2 shows the response distribution across the different ranges of the overall score, i.e., the sum of scores across all three subscales. It shows that over 86% of the students' total score are above the neutral point, which is 99 indicated by the dashed line in the figure. In other words, the majority of the students have positive experience with team-based learning overall. However, Table 2 indicates students don't have much preference for TBL over lecture, as shown by the close to neutral mean score for the TBL vs. lecture subscale.

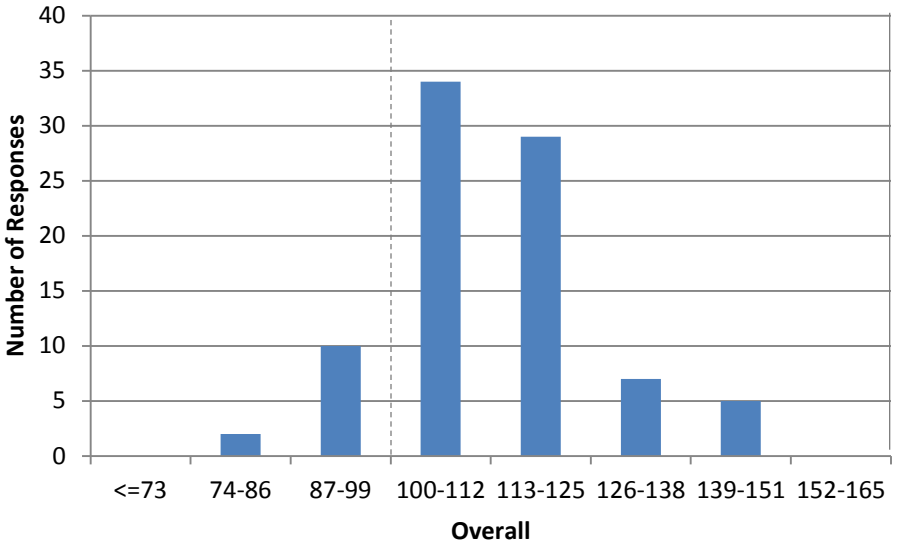

Figure 2. Response distribution for the TBL-SAI overall score

To investigate the reason why students showed positive experience with TBL, but showed no preference for team-based learning over lecture, the score for each of the 33 survey questions is averaged individually and is sorted from highest to lowest. The three highest average score and the three lowest average score are shown in Table 3.

Table 3. Three lowest and three highest score TBL-SAI survey questions

Overall Ranking (33 questions)	Question	Subscale	Score
1	I enjoy team-based learning activities.	Satisfaction	4.24
2	I think team-based learning activities are an effective approach to learning.	Satisfaction	4.21
3	I contribute to my team members' learning.	Accountability	4.08
3	I am proud of my ability to assist my team in their learning.	Accountability	4.08
-3	I remember material better when the instructor lectures about it.	Preference	2 (Reverse)
-2	I can easily remember material from lecture.	Preference	1.85 (Reverse)
-1	It is easier to study for tests when the instructor has lectured over the material.	Preference	1.55 (Reverse)

Table 3 shows that students do enjoy team-based learning activities, think it is an effective way of learning, and they are accountable to their teams, as shown by the top three scores in the satisfaction and accountability subscales. However, they find it difficult to "remember" course materials and to study for tests in team-based learning. This is because in a team-based learning lecture there is no instructor presenting course materials by writing notes on the board or through PowerPoint slides, i.e., students don't have a clear set of notes to study from. This generates

anxiety for students before quizzes and exams. Strategies to alleviate this anxiety will be discussed in the Lessons Learned and Future Work section below.

Student Demographics

To see if a particular student population favors team-based learning, the TBL-SAI total score is averaged across different student population based on the following criteria: gender, race and academic levels. Table 4 shows the number of responses and the average TBL-SAI total score from male and female participants respectively. It shows both male and female students have similar positive attitude towards team-based learning. Team-based learning does not benefit more for a particular gender than the other.

Table 4. Average TBL-SAI Total Score for Different Gender

Gender	Number of Responses	Average TBL-SAI Total Score
Male	77	112.8
Female	10	110.4

Table 5 shows the number of responses and the average TBL-SAI total score from white and nonwhite participants respectively. It shows both white and non-white students have similar positive experience with team-based learning. Team-based learning again does not favor white students over minority students.

Table 5. Average TBL-SAI Total Score for Different Race

Race	Number of Responses	Average TBL-SAI Total Score
White	46	113.6
Non-white	41	111.4

Table 6 shows the number of responses and the average TBL-SAI total score from students at different academic levels. It shows students have similar positive attitude towards team-based learning no matter how many college credits they have taken. Once more, team-based learning does not favor a particular population than others.

Table 6. Average TBL-SAI Total Score for Different Academic Levels

Academic Level	Number of Responses	Average TBL-SAI Total Score
Freshman	58	113.0
Sophomore	21	110.8
Junior	4	114.0
Senior	3	113.7
Post-Bacc Undergrad	1	114.0

Exam Score

The test score of a comprehensive exam was also used to assess the implementation of team-based learning. The exam was a 40-question multiple choice test. The same exam was given in Fall 2013 and in Fall 2014. However, the exam was administered differently. In Fall 2013, the test was given near the end of the term, while in Fall 2014, the test was given around week 10 of

the semester. The average exam score and how the two exams were administered differently are shown in Table 7.

Table 7. Average Exam Score and Exam Rules for Fall 2013 and Fall 2014 Cohorts

	Average Exam Score	Exam Rule
Fall 2013	83.88	Online Quiz. Open-book and open notes. Time limit is one hour and thirty minutes.
Fall 2014	83.02	In-lecture quiz. Closed-book and closed notes, one 8.5x11 cheat sheet allowed. Time limit is 50 minutes.

Table 7 shows under the much stricter exam rules, the Fall 2014 cohort performed almost identical as the Fall 2013 cohort, which had a much relaxed exam rule. The exam score shows the effectiveness of team-based learning in helping students master course materials.

To investigate if there is any correlation between the exam score and how students rated team-based learning, the exam grades are plotted against the TBL-SAI total score in Figure 3.

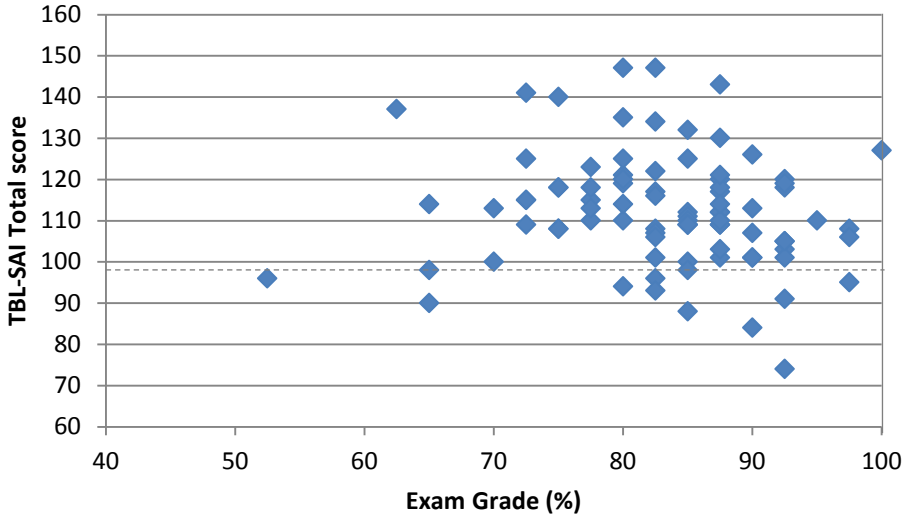

Figure 3. TBL-SAI Total score vs. Exam Grade

Figure 3 shows that there is no correlation between the TBL-SAI score and exam grade. This is consistent with the previous finding[9] from the implementation at University of Alaska Anchorage. Students rated team-based learning independent of their grades. In other words, students from all grade levels can have positive experience with team-based learning and benefit from it.

Teaching Evaluation

Table 8 shows the result of anonymous teaching evaluation administered by the engineering school. The result shows that adopting team-based learning did not negatively affect the students' evaluation of the course or the instructor. On the contrary, the average evaluation score for the course and the instructor increases by 0.3 and 0.2 respectively.

Table 8. Comparison of Teaching Evaluation

Student Evaluation	Fall 2013 (no TBL, 68 responses)	Fall 2014 (TBL, 78 responses)
Course	4.1 out of 5	4.4 out of 5
Instructor	4.2 out of 5	4.4 out of 5

Example comments from the anonymous teaching evaluation and the comment section of the TBL-SAL survey are listed below:

- "The team-based learning activities were a much better way to learn."
- "Team (based) learning really did assist my learning in this class."
- "I enjoyed team-based learning."
- "I love group work it makes everything easier to understand."
- "The group work really stimulated the learning process. Group work also made the course a lot more interesting and fun."
- "I like most about this course is learning how to work as a team."

Lessons Learned and Future Work

The results from the first trial implementation of team-based learning in the introduction to engineering course look promising. However, there is still a lot to be desired. The followings are some areas that could be improved upon.

Study Materials and Summary

In a TBL class, without a huge pile of lecture notes as a written record of their "learning", students were often not clear what exactly they had learned and were concern about what they would need to study for exams. One student commented in the TBL-SAI survey: "I enjoyed most of it but I would have liked more lecture notes." This complaint is consistent with the low scores to the survey questions in the Preference subscale in Table 3. A couple of strategies could be implemented.

First, provide students with more study materials. In the trial implementation, answers to pre-lecture reading guide were not collected. The readiness assurance tests were closed-book and closed-note. In future offering of the course, the questions in the pre-lecture reading guides could be assigned as homework problems and collected. The students can also use the homework as cheat sheet for the readiness assurance test. There are two advantages to this change. On one hand it gives students incentives to actually complete the pre-lecture readings, because they earn points for completing the homework assignment and at the same time the homework will help them do well on the readiness assurance tests. On the other hand, the homework answers can help students review reading materials before tests. In addition, it is helpful to provide well-defined learning objectives for each module such as a fact and skill sheet so that students have a clear picture of what they will be responsible for in tests. Furthermore, additional practice problems can be assigned after the in-lecture application activities. They can reinforce the concepts and skills that students have learned during lectures and can also serve as practice problems before tests.

Second, offer effective closure. At the end of any learning experience, it is important to remind the learners what they have learned, and it is especially true with team-based learning[16]. Closures can be used at the end of an activity, module and the entire course. An effective closure can provide a summary of all that has been learned. It can help students see the value in what they have learned and how they can apply them in the future. It is also important to integrate what students have learned to the big picture and the context of the whole course.

Course Structure

There are a lot of course materials covered in the first seven weeks of the course. The one 50-minute module per week model is not optimal. Students didn't get chance to work on many application problems due to the time constraint and it led to complaints such as "too many quizzes", "The lectures weren't actually lectures. All we did was taking tests/quizzes." One potential solution is to overflow the lecture materials to the lab, i.e., use about 30 minutes of time at the beginning of the lab to do more team-based application exercises. Another solution is to restructure the entire course so that the modules are more spread out. The nine modules seem to be too many, seven modules would be more reasonable.

Team Dynamics

In a typical team-based learning course, students are only required to work in teams during lecture. With a large diverse team of five to seven students and the proper accountability structure in place, team dynamics is usually not a complaint from students. However, this lecture-lab course has a much more substantial teamwork component because the students have to work with the same team in both lectures and labs. With a relative small team size of four students, if two or more students don't actively contribute to the team, the team-based learning experience can be substantially compromised. Here are some student comments: "Your experience in team-based learning heavily depends on the other members of your team." "This all relies on me liking my team members. If I had had a less enjoyable group I would probably not like TBL as much." "Lack of teammate participation may be stressful." For a course with mostly freshman who just enter college, it is important to teach them how to work well in a team and how to give constructive feedback[17]. Teacher intervention might be required to help resolve team conflicts and put dysfunctional teams back on track.

Conclusion

Team-based learning was implemented in a freshman Introduction to Engineering course. The implementation was assessed using TBL-SAI survey, exam score and anonymous teaching evaluation. The assessment showed over 86% of students reported positive experience with TBL. Survey results also showed the TBL teaching pedagogy does not favor students in terms of gender, race and academic levels. In addition, no correlation was found between exam grade and TBL-SAI score. These results showed that team-based learning can be used to benefit a wide range of students. Future improvements include provide students with more study materials, offer effective closure, improve course structure and provide students with more guidance on team dynamics.

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