Adapting Team-Based Learning to Facilitate Development of Competencies and Skills Needed for Global Engineering Competitiveness

O'Connell, R. M.
Professor
University of Missouri
Columbia, MO, USA

Conference Topic: The global engineer, curriculum development, active learning

INTRODUCTION

Industry and accrediting agencies tell us that when many of today's engineering students enter the work force, they will find themselves on multi-disciplinary and diverse international teams solving global-scale problems. The skills needed to be successful in that setting include superior technical competence and excellent transferable professional skills. Research shows [e.g., 1, 2] that student-centered active learning tends to produce better conceptual understanding than does traditional passive lecture-based learning, and that when active learning is conducted in an extensively group-based environment, students can also develop various professional skills, such as self-directed independent learning, problem-solving, and interpersonal team skills. Team-based learning (TBL) is a form of group-based student-centered learning in which students independently study new conceptual material before it is treated in the classroom, and then subsequently spend considerable classroom time working in teams on increasingly challenging applications of that new material [3]. Experience during a recent two-year (four semester) initiative to develop TBL as the principal teaching and learning strategy in the second-year electric circuit theory sequence has led to several changes or revisions to the basic TBL process, which optimize the effectiveness of the strategy at teaching both technical content and certain professional skills in the two courses that comprise the circuit theory sequence. TBL has been previously used in some engineering courses, e.g. [4, 5], but not with the changes described here.

The purpose of this paper is to describe the changes and the resulting revised version of TBL that is being used in the electric circuit theory sequence. Due to the theme of educating engineers for global competitiveness, emphasis is on the impact of the changes on professional skills development. The basic, or textbook, TBL process is described in Section 1, and the revisions that evolved while attempting to apply it in the circuit theory sequence are described in Section 2. The revisions that impact professional skills development are assessed using several continuous assessment instruments, which are described in Section 3. Finally, evaluative measures that illustrate the effectiveness of the revised TBL strategy at teaching professional skills in the TBL-taught courses are discussed in Section 4.

1 BASIC TEAM-BASED LEARNING

At the outset of a TBL-taught course [3], permanent (i.e., for the entire semester) teams of five-to-seven students each are formed carefully by the instructor, making the groups as diverse or heterogeneous as possible with respect to talent, ethnicity, gender, and any other factors deemed relevant. Permanency is necessary to allow team members time to develop the confidence and trust needed to develop into an effective learning unit. Specific roles such as leader and recorder are not assigned. Diversity ensures a wide range of ideas and experience, but it also provides group dynamics challenges that students are likely to encounter in the workplace. Also, an approximately uniform distribution of talent among teams usually minimizes the practical problems caused by some teams finishing assignments much earlier or later than the others. The group size of five-to-seven is suggested as needed to provide sufficient intellectual resources needed for successful completion of group assignments. Next, the course or module is defined into approximately six major content segments or units, each of which consumes approximately two-to-three weeks of semester time. Then, for each of those content segments, a three-phase sequence of activities takes place. They are the preparation phase, the application phase, and the assessment phase.

In the preparation phase, students first do the readings for the entire two-to-three week content unit. The idea is that they must independently obtain "a good introduction to the information and ideas on the topic," not "an in-depth mastery or full comprehension" [3]. This is done outside of class and before the material is formally addressed in the classroom. The phase culminates with a readiness test, i.e., a short objective test on the assigned reading. The test is taken by each student individually, submitted, and then taken again by each of the student teams working together. Scores from both tests are recorded and eventually contribute toward final grades. After the readiness test, the instructor may do some brief summary lecturing, especially over items on which the students had trouble on the readiness test. The requirement to independently study new material before addressing it in the classroom encourages development of the professional skill associated with self-directed independent learning.

During the application phase, which lasts for the remainder of the two-to-three week period allotted to that content unit, the student teams work on increasingly challenging assignments related to the material studied independently in the preparation phase. The purposes of the phase are to facilitate learning of both technical content at the requisite depth of understanding, and to facilitate problem-solving and interpersonal team skills.

Creating effective assignments can be "the single biggest challenge for teachers wanting to use TBL…" [3]. In order to foster effective group work, assignments must be challenging enough that they can't easily be solved by one student working alone, and yet they must be focused enough that they can't be subdivided into smaller tasks and distributed among team members, again resulting in individuals working alone. (Sub-dividing work into subtasks is encouraged and even required in problem-based learning (PBL), an alternative group-based learning strategy [6 – 9], but it is strongly discouraged in TBL.) In the electric circuit theory sequence in question, textbook problems have fortunately proven to constitute excellent group work assignments, thereby greatly simplifying the task of creating effective assignments.

While working on group assignments, TBL requires student teams to follow a prescribed scheme of group work that includes coming to class prepared, using good interpersonal team skills, and successfully completing the assignment. By "good interpersonal team skills" is meant contributing to the group discussion by speaking and listening respectfully and appropriately, and by providing individual peer instruction when appropriate and necessary. The instructor's role during group work is to provide frequent feedback related to both understanding of the technical course content and to the development of team skills. This phase clearly encourages development of transferable team skills.

The final phase in the TBL sequence is the unit assessment phase, which consists of a summative exam over the material covered during the two-to-three week content segment in question. The scores on this exam determine the students' grades for that portion of the course. Thus, each content segment is basically a self-contained mini-course.

2 REVISIONS THAT IMPROVE LEARNING IN ELECTRIC CIRCUITS

While using TBL in the second-year electric circuit theory sequence over a period of four semesters, the following five beneficial revisions to the textbook process described above evolved [10, 11].

- Use of intended learning outcomes (ILO), including one for the TBL process.
- Use of formative and summative assessments.
- Teams of four (rather than five to seven) students each.
- A shorter readiness cycle.
- A specific problem-solving scheme for group work.

2.1 Intended learning outcomes

Consistent with the modern pedagogical practice of expressing course content in terms of intended learning outcomes, or ILOs [2], i.e., statements of what students should know and be able to do at the end of the course, the technical content of each of the two courses in the electric circuit theory sequence is expressed in terms of six ILOs. Achievement of the technical ILOs is assessed using formative and summative examinations, as described in Section 2.2 below.

In addition to the technical ILOs, both courses have the following seventh ILO: “At the end of the course, students should be able to produce a record of successfully preparing for and participating in good group work.” This outcome addresses student engagement with and learning of the TBL process, which essentially defines all the important non-technical professional skills that TBL teaches. It enables the instructor to include learning of the TBL process in students’ grades, which serves to motivate them to engage in the process and thus better learn those skills. Achievement of this ILO is assessed using a number of continuous assessment instruments, which are described in Section 3 below.

2.2 Formative and summative examinations

Another change that was derived from good modern practice was to make the unit assessment exams of the assessment phase of TBL formative, rather than summative, and to add a summative comprehensive final exam at the end of the course [2]. The principal purpose of the formative unit assessment exams is to provide feedback to help improve learning of technical content in anticipation of the grade-determining summative final exam. This change is consistent with the pedagogical concept, implied in ILO statements, that students should be both held accountable for, and rewarded for, demonstrating what they know and can do at the end of the course. Summative exams throughout the course, wherein those scores contribute toward the final grade, are inconsistent with this.

2.3 Size of teams

The third change to the basic TBL process concerns the number of students in each team or learning group. While the basic process recommends a team size of five-to-seven, it was determined soon after the start of the two-year TBL initiative that at the second year (sophomore) level, in a team of five or more, unprepared or unwilling-to-participate students can contribute very little in group work without being noticed, i.e., they can “hide” relatively easily. Instead, a team size of four was found to both provide sufficient intellectual resources to solve the problems at that level, and to better prevent “hiding.” A team size of four has the additional practical advantage that four students can easily arrange their classroom desks in the shape of a tidy square, enabling easy communication among all team members. This change helps to maximize participation in group work and thus maximize development of all the professional skills associated with working in teams.

2.4 Length of readiness cycle

Next, it was observed early in the initiative that most second-year electric circuit theory students are unable to obtain “a good introduction to the information and ideas on the topic,” when the required reading material in the preparation phase consists of approximately one-sixth of the course content, or typically one or two complete chapters from the textbook, as is required in textbook TBL. This is probably because electric circuit theory (and most engineering course content) tends to be hierarchical, i.e., most topics build on previous ones, so that in order to understand a given topic it is

essential to understand (master) most of what came before it. It is very difficult for most second-year engineering students, working independently, to proceed very far into a body of new hierarchical technical content before becoming unable to obtain even an introductory level of comprehension. To overcome this difficulty, the readiness cycle in the preparation phase of the revised version of TBL has been shortened considerably. Now, preparation assignments consist of readings and relatively simple illustrative problems related to new technical content to be applied in group work in the following class session or two, rather than the following two or three weeks; thus, a typical preparation reading assignment covers only a section or two of a chapter in the textbook, rather than an entire chapter or two. As before, each preparation assignment culminates in a short readiness test, but now those tests, or quizzes, are given optionally at the instructor's discretion, and unannounced, to avoid burdening the instructor with excessive grading work. This change helps to maximize development of the professional skill related to self-directed independent learning.

2.5 Problem-solving scheme

The final change to the textbook TBL process relates to what student teams are required to do during group work in the application phase. As stated above, one of the purposes of the application phase of TBL is to help students develop problem-solving and interpersonal team skills, but the strategy neglects explicitly to specify a problem-solving scheme, which would further help students develop the professional skills associated with group work. Thus, in the revised TBL strategy, student teams are required to use good interpersonal team skills while following a simple problem solving scheme consisting of three sequential steps: brief individual reflection on the problem in question; team brainstorming, consideration of alternate solution approaches, and agreeing on a solution approach; and interdependent and iterative work on the agreed-upon solution approach. Occasionally, work done during the third step leads to the decision to attempt an alternate solution approach.

As mentioned above, in the electric circuit theory sequence, textbook problems make excellent group work assignments, to which student teams can apply the specified problem-solving scheme. The only challenge for the instructor is carefully to select problems that are of increasing difficulty, so that, by the end of the time allotted to a specific ILO, students are able to solve problems at the requisite challenge level.

3 CONTINUOUS ASSESSMENT OF PROFESSIONAL SKILL DEVELOPMENT

Assessment of learning in the two electric circuit theory courses, taught using the revised TBL strategy, consists of assessing how well students have achieved, by the end of the respective courses, the six technical-content-related ILOs and the professional-skills-related TBL-process ILO. The technical content outcomes are assessed using formative and summative examinations, as described briefly in Section 2.2. The TBL-process outcome, defined in Section 2.1 above, is assessed using a series of continuous assessment instruments, which are described in this section. They evolved over the course of the four-semester initiative [12], due in part to the results of student course evaluation surveys that are conducted at the end of each course. The instruments that are currently used to assess achievement of the TBL-process ILO include:

- Class attendance records;
- Readiness quizzes;
- Preparation notebooks;
- Instructor observation; and
- Peer assessment.

3.1 Attendance

Because team members depend on each other to be prepared for and contribute productively to the discussions during the group work exercises, attendance is mandatory in the revised-TBL-based circuit theory sequence, and attendance records are included in the grade for the TBL-process ILO.

3.2 Readiness quizzes

Readiness quizzes and preparation notebooks serve to both motivate students to engage in the preparation phase of the revised TBL strategy and to provide objective evidence of their having done so. They assess learning of the professional skill associated with self-directed independent learning.

Because the principal purpose of the readiness quiz is motivational, it is assessed for effort with a typical grading rubric consisting of the question "Did the student do the readiness assignment, and, if so, with how much effort?" and three possible answers: i) A, yes, and appropriate effort is evidenced by responses to quiz questions; ii) C, yes, but marginal effort is evidenced by responses to quiz questions; F, no evidence shown of any significant effort. End-of-course evaluation surveys reveal that students generally feel that, to be most effective, readiness quizzes should be given at least bi-weekly.

3.3 Preparation notebooks

Use of preparation notebooks is an extension of the notion of the reflective journal that is common to courses in history, literature, education, etc. [2]. In the revised TBL-taught courses in question, each student is required to summarize preparation-phase readings and do any other assigned preparation work in a so-called preparation notebook. The notebooks are occasionally collected and, like the readiness quizzes, assessed for effort. A typical grading rubric for the preparation notebooks consists of the question "How much effort did the student put into summarizing readiness readings and completing other assigned preparation work?" and five possible answers: i) A, readings are thoroughly summarized, and most assigned work is completed; ii) B, most readings are summarized, and much of the assigned work is completed; iii) C, some readings are summarized, and some assigned work is completed. (minimum passing effort; iv) D, little, if any summary work, and very little assigned work is completed; v) F, essentially no evidence of doing any preparation work. End-of-course course evaluation surveys reveal that students generally feel that, to be most effective, preparation notebooks should be collected and assessed approximately monthly.

3.4 Instructor observation

The other two continuous assessment instruments, instructor observation and peer assessment, provide subjective evidence of student engagement in both preparation for group work and appropriate participation in it. Instructor observation occurs during group work, while the instructor acts as tutor, facilitating learning of both the technical content and the requisite team skills. To do this, he/she moves around the room from group to group, unobtrusively observing the discussion and interactions among group members, and observing progress toward successful completion of the assignment or learning activity. When necessary, he/she provides formative feedback for learning of technical content either by asking guiding questions (within a single group) or by doing some brief "just-in-time" lecturing to the entire class on a point of common difficulty. Successful completion of the assignment is assessed qualitatively via instructor observation during group work.

Instructor observation during group work also allows the instructor to determine, by their level of involvement in the discussion, whether individual students have prepared adequately for class. It is also easy to observe how well the group, both individually and collectively, follow the prescribed problem-solving scheme and use good interpersonal team skills, and to provide appropriate formative feedback. Based on these observations, occasionally it becomes necessary to disband a dysfunctional team and distribute the members of that team among other, more successful teams.

3.5 Peer assessment

The peer assessment instrument is administered toward the end of the course. The instrument begins with brief descriptions of the TBL-process ILO's expectations regarding attendance, preparation for group work, and appropriate participation in group work, followed by the following statement:

Please write a brief narrative to evaluate each of your group mates' contribution to group work, giving consideration to attendance, preparation, and participation. At the end of your narrative, write the grade that you think the person deserves for his/her contribution. Their grade in the learning outcome for group work will be affected by your responses, as will your own for the quality of your participation in this exercise. Only the instructor will see this sheet that you complete. Your responses will remain confidential.

A narrative format for the peer assessment was found to be much more effective than a Likert-type instrument, which was used at the beginning of the initiative, but quickly discarded when it was observed that most students rated each of their teammates at the high end of the scale in all areas, without having to justify their ratings, thereby essentially nullifying the exercise. While the results of the peer assessment usually support the results of the instructor's observations, they occasionally identify students who had, previously unbeknownst to the instructor, either demonstrated outstanding group leadership, or had been either frequently unprepared for class or who had overly dominated group discussions.

3.6 Grade determination

At the completion of either course, average scores from these continuous assessment instruments are weighted approximately equally and combined to determine students' grades for the TBL-process ILO, which typically constitutes 20 percent of the overall grade for the course. To simplify the process, attendance records and instructor observation are not quantitatively included, since attendance is considered qualitatively in both the peer assessment and instructor observation, and instructor observation is used qualitatively to adjust peer assessment scores when the two differ significantly. *Table 1* shows the data for the two electric circuit theory courses for two recent semesters each. For example, in Fall 2013 the Circuit Theory 2 course contained 51 students who took eight readiness quizzes, had two preparation notebook checks, and did one peer assessment. The average scores for the three items, including adjustment for instructor observation, were, respectively, 0.54, 0.91, and 0.88. The equally weighted average of those three numbers was 0.78, a B-range overall score.

Each student's final grade for either course is determined using 20 percent of his/her individual average score for the just-described TBL-process ILO, 20 percent of the independently determined laboratory score, and 60 percent of his/her final score for the six content-related ILOs, which is determined by the summative final examination, as explained in Section 2.2 above.

Table 1. Recent Continuous Assessment Data for both Electric Circuit Theory Courses

Semester	Course Number	No. of Students	Readiness Quizzes		Notebook Checks		Peer Assessment	Combined Average	ILO Grade
			no.	avg.	no.	avg.			
Fall 2012	1	54	6	0.52	3	0.79	0.83	0.71	B-
	2	39	5	0.42	1	0.71	0.88	0.67	B-
Fall 2013	1	49	5	0.54	3	0.90	0.84	0.76	B-
	2	51	8	0.54	2	0.91	0.88	0.78	B-

4 EVALUATIVE MEASURES

In this section, evaluative measures that illustrate the effectiveness of the revised TBL strategy at teaching professional skills (self-directed independent learning, problem-solving, and interpersonal team skills) in the electric circuit theory sequence are discussed. Measures to be discussed include:

- The continuous assessment data given in *Table 1*;
- Results from an exit survey of graduating seniors (*Table 2)*;
- Results from exit interviews with graduating seniors;

The quantitative data in *Table 1* show that the TBL-process ILO, i.e., the one that addresses learning of transferable professional skills, has been consistently achieved in both courses in recent semesters. Also, while the peer assessment data are an overall assessment of the professional skills associated with both preparation and participation, the readiness quiz and preparation notebook check data address only the skill associated with preparation, i.e., self-directed independent learning, and their averages are, in all cases, lower than the peer assessment data. This suggests that students are developing problem-solving and interpersonal team skills better than self-directed independent learning, which, in turn, suggests an area for improvement efforts.

A recent survey of graduating seniors included several perception-of-learning of professional skills questions. Among a class of 49 graduates, 44 of them had taken at least one of the TBL-taught electric circuit theory courses during their undergraduate program, and 20 of those responded to the professional skills questions. The results are summarized in *Table 2.*

Questions 1 through 3 in the table address self-directed independent learning skills; Questions 4 and 5 address teamwork skills, and Question 6 addresses professional skills in general. Questions 1 and 2 show that 85% and 65% of the respondents, respectively, felt that readiness quizzes and preparation notebook collections had at least some effect in motivating them to do preparation phase work.

Question 3 addresses self-directed independent learning generally, and it shows that only 10% of the respondents felt that they would have learned those skills better in a traditional setting. These three questions illustrate the effectiveness of the "shorter readiness cycle" revision to the basic TBL

Table 2. Results on perception-of-learning questions from graduating senior exit surveys

	Question		Percent of 20 respondents
1.	Did the unannounced readiness quizzes motivate you to prepare for class?	very little some a lot	20% 60% 20%
2.	Did the preparation notebook collections motivate you to prepare for class?	very little some a lot	35% 40% 25%
3.	Compared to a traditional approach, how much did TBL help you develop the self-directed independent learning skill?	very little some a lot	10% 40% 50%
4.	How much did TBL help you develop problem-solving skills?	very little some a lot	10% 55% 35%
5.	How much did TBL help you develop interpersonal team skills?	very little some a lot	15% 60% 25%
6.	Compared to a traditional approach, how much did TBL help you develop transferable professional skills?	very little some a lot	0% 35% 65%

process discussed in Section 2.4. Before the revision, students were learning very little in the preparation phase, and thus they were not learning how to learn independently.

Questions 4 and 5 in *Table 2* address learning of problem-solving and interpersonal team skills that characterize teamwork. As the results show, only 10% and 15% of the respondents, respectively, felt that the TBL-taught course(s) did not significantly help them develop problem-solving and interpersonal team skills. The results for Question 4 illustrate the effectiveness of "a specific problem-solving scheme for group work" revision to the basic TBL process discussed in Section 2.5. Textbook TBL emphasizes interpersonal team skills, but does not emphasize or specify an actual problem-solving routine.

Finally, Question 6 summarizes the entire table, and it shows that virtually none of the graduating TBL alumni felt that their professional skills development would have been better in a traditionally taught course(s) than in the TBL-based course(s) they took. All the results in *Table 2* validate the effectiveness of "including one (an ILO) for the TBL process" in the revisions to the basic TBL process, discussed in Section 2.1.

One final measure of the effectiveness of the revised TBL strategy is a recent series of exit interviews with 17 of the above-mentioned 44 seniors who had previously taken at least one of the TBL-taught circuit theory courses. Besides verbally verifying the information provided in *Table 2*, the students were unanimous in agreeing with the early determination, mentioned in Section 2.3, that the group size of four for participation phase group work is optimum. A typical comment was as follows:

The group size of four was just the right size. There was still a group to work with when someone didn't show up, so I think three would be too small. It also wasn't too big that people got lost in the crowd. All of the members had to participate and couldn't just sit back and let the others do the work, because it was easy to tell when someone wasn't trying. I think five might be okay, but there's a greater risk of people not inputting to the discussion.

This comment and others like it illustrate the effectiveness of the *teams of four (rather than five to seven) students each* revision to the basic TBL process: it optimizes students' opportunities to develop problem-solving and interpersonal team skills.

5 SUMMARY

The revised version of TBL described here was developed over two years in order to improve the effectiveness of the strategy at teaching both technical content and certain professional skills in the two courses that comprise the circuit theory sequence. Emphasis here has been on professional skills development as a way of contributing to the education of engineers for global competitiveness. Five changes to the textbook TBL strategy were described, four of which directly impact and improve professional skills development. Expressing the TBL process as a specific graded ILO motivates students to buy into the process, i.e., do pre-class preparation work and participate appropriately in group work. Using a one or two day readiness cycle makes it possible for students to obtain an introductory level of understanding of new content before encountering it in the classroom. A team size of four was found to optimize participation by all teammates in group work, and specifying a problem-solving scheme to be used in group work enhanced students' learning of team skills. Success of the revisions at facilitating development of team skills was evidenced by scores in the continuous assessment instruments, and by graduating seniors' responses on an exit survey and in an exit interview.

REFERENCES

[1] Prince, M. J., (2004), Does Active Learning Work? A Review of the Research, *Journal of Engineering Education*, Vol. 93, No. 3, pp. 223-231.

[2] Biggs, J. and Tang, C., (2007), Teaching for Quality Learning at University, 2nd ed., SRHE and Open University Press, Berkshire, U.K.

[3] Michaelsen, L. K., Knight, A. B., and Fink, L. D., eds., (2004), Team-Based Learning: A Transformative Use of Small Groups in College Teaching, Stylus Publishing, Sterling, VA.

[4] Demetry, C., (2010), An Innovation Merging Classroom Flip and Team-Based Learning, Proc. 40th ASEE/IEEE Frontiers in Education Conference, Washington, DC.

[5] Olson, B. W., (2011), A Practical Application of Team-Based Learning to Undergraduate Coursework, Proc. Midwest Section ASEE Conference, Russellville, AR.

[6] Boud, J. D. and Feletti, G., eds., (1997), The Challenge of Problem-Based Learning, 2nd ed., Kogan, London, U.K.

[7] Savin-Baden, M., (2000), Problem Based Learning in Higher Education: Untold Stories, SRHE and Open University Press, Buckingham, U. K.

[8] DeGraff, E. and Kolmos, A., (2003), Characteristics of Problem-Based Learning, *International Journal of Engineering Education*, Vol. 19. No. 5, pp. 657-662.

[9] Perrenet, J. C., Bouhuijs, P. A. J., and Smits, J. G. M. M., (2000), The Suitability of Problem-

Based Learning for Engineering Education: Theory and Practice, *Teaching in Higher Education,* vol. 5, no. 3, pp. 345-358.

[10] O'Connell, R. M., (2011), Adapting Team-Based Learning to the First Circuit Theory Course, Proc. 41st ASEE/IEEE Frontiers in Education Conference, Rapid City, SD.

[11] O'Connell, R. M. and On, P. W., (2012) Teaching Circuit Theory Courses Using Team-Based Learning, Proc. ASEE Annual Conference and Exhibition, San Antonio, TX.

[12] O'Connell, R. M. (2012), Assessment Practices for Team-Based Learning in Sophomore-Level courses, Proc. Midwest Section ASEE Conference, Rolla, MO.