AC 2012-4057: TEACHING CIRCUIT THEORY COURSES USING TEAM-BASED LEARNING

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Abstract

The purpose of this paper is to report progress made in adapting the learning strategy known as team-based learning for use in the required sophomore-level electric circuit theory sequence. The project is motivated by the desire to introduce students to self-directed independent learning and to learning in groups early in their programs. Team-based learning provides both of these features. Learning groups provide students with the opportunity to teach each other, which has been shown to produce deeper conceptual learning than listening to a traditional lecture. Also, while observing the group learning, the instructor can identify and correct learning difficulties on the spot, which is usually not possible with the standard traditional lecturing method. Despite the potential benefits, several practical challenges have been encountered while attempting to implement the strategy. These include motivating students to study and learn new material outside of class and before encountering it in the classroom; motivating them to engage appropriately in the specified group work process; and motivating them to engage in the formative/summative assessment examination processes used. The paper describes progress made over three semesters in overcoming these challenges.

Introduction

Educational research has shown that student-centered active learning can produce much deeper conceptual learning than can traditional lecturing[1], and that when active learning is conducted in an extensively group-based learning environment, such as problem-based learning, project-based learning[2], or team-based learning[3], students also develop various professional functioning knowledge skills, such as problem-solving, written and oral communication, independent learning, team work, etc[4].

In our undergraduate electrical and computer engineering programs, students complete a two-course senior design sequence using project-based learning, where, in addition to solving challenging design problems, they develop several of the professional skills. They also work in teams in the laboratory components of several earlier courses, but there is little formal instruction therein on how to conduct good team work. If some of those ideas were learned early in the program, they could be used in any number of courses throughout the program, thereby enabling students to enter the senior design sequence with strong team skills and thus able to focus on the technical aspects of the design projects. Also, they would graduate with much stronger professional skills than at present.

In order to develop self-directed independent learning and professional team work skills early in the curriculum, we are using an adaptation of the learning strategy known as team-based learning in both courses in the required two-course electric circuit theory sequence, which is usually taken in the sophomore year. In the following sections of the paper we describe basic or textbook team-based learning and explain why it was chosen over problem-based learning for this initiative. We then describe how the strategy has been implemented, evaluated, and subsequently revised in the two courses over three semesters.

Textbook Team-Based Learning[3]

Team-based learning is a teaching and learning strategy that requires students to study new material independently before coming to class, and to spend most of their time in class working in groups on challenging problems and assignments aimed at deepening their understanding of the subject matter[3]. Thus, it basically reverses or "flips" the processes that traditionally occur inside and outside the classroom[5,6]. In team-based learning as defined and described by Michaelsen et. al.[3], course content is subdivided into approximately six major units, each of which consumes approximately two-to-three weeks of class time. For each of those major content units, the following three-phase sequence of activities occurs.

Phase 1 is the Preparation phase, in which students complete the reading assignments for the entire two-to-three week unit. The purpose of the first phase is for students to obtain "a good introduction to the information and ideas on the topic," and not "an in-depth mastery or full comprehension." The Preparation phase is conducted outside of class and before the material is formally addressed in the classroom. In the first class session following the allotted preparation time, the Preparation phase culminates in the Readiness Assurance Process, which consists of a short objective readiness test on the assigned reading. The test is taken by each student individually, submitted to the instructor, and then taken again by each of the student teams. Scores from both tests are recorded and contribute toward final grades. Finally, the instructor may lecture briefly on material that the students had trouble with on the readiness test.

The idea behind the Preparation phase is that students can learn the basic ideas on their own, and thus the instructor need lecture only on the more challenging ideas that students had trouble with in the reading, as determined by the readiness test. Also, students should be motivated to focus on the brief lecture, because it specifically addresses points of difficulty they had in the reading.

Phase 2 is the Application phase, which lasts for the remainder of the two-to-three week period allotted to that unit. During this phase students work in teams on increasingly challenging applications and problems related to the material read in Phase 1. The Application phase has two purposes: to help students achieve the depth of conceptual understanding (declarative knowledge) required by the instructor, and to help students develop teamwork and problem-solving skills (functioning knowledge). While working on these group assignments, student teams follow a prescribed scheme of group work that stresses individual accountability to the process.

Phase 3 is the unit Assessment phase, which is just a summative exam over the material covered during the two-to-three week period in question. Thus, each two-to-three week unit is basically a self-contained mini-course.

Choosing team-based learning over problem-based learning

Before describing how basic team-based learning was adapted for use in our circuit theory sequence, it will be explained why it was chosen over problem-based learning, another group-based learning strategy. In problem-based learning[7,8] teams of students are confronted with open-ended realistic problems and required to develop solutions by following a prescribed multi-

step problem-solving scheme, and in which instructors function as tutors who also follow a prescribed scheme of tutorial behavior. It is important to understand that the problems to be solved are assigned without any prior instruction by the instructor, so that the problems themselves dictate what declarative content knowledge has to be learned (independently and interdependently by the students) in order to solve the problem. The phrase "The problem drives the learning" is often used in descriptions of problem-based learning[4,9]. Because the problems themselves, and not any prior instruction, hint at and ultimately determine what content knowledge is to be learned (in order to solve the problems), the problems must be designed with extreme care, in order to make sure that the course learning outcomes and content are all adequately addressed. However, even when problems are designed with such care, student teams often find ways of solving them without having to learn and use the intended content knowledge. Thus, there is a danger, when using problem-based learning, that some items of course content will not be learned. Avoiding these so-called knowledge gaps is one of the biggest challenges to properly using problem-based learning[10,11].

In team-based learning, on the other hand, in the Preparation phase, students are told exactly what specific content material needs to be learned in order to be successful in the subsequent Application phase. They take a readiness test and are given a subsequent brief corrective lecture over the important content before beginning the Application phase. Thus, there is much less risk of creating knowledge gaps when using team-based learning, which is the principal reason why team-based learning and not problem-based learning, was chosen for our initiative.

Adaptation and Implementation: Fall 2010

In our adaptation of team-based learning for use in the two-course electric circuit theory sequence in the Fall 2010 semester, each of the six declarative content-based intended learning outcomes of each course was identified as a major team-based learning unit. A seventh learning outcome was specified, which required students to produce a record of preparation for class and participation in learning activities, particularly group work during class. Associating both the Preparation and Application phases of the process with an assessed learning outcome, which would contribute toward the final grade, helped motivate students to both prepare for and participate appropriately in the group work.

In Fall 2010, Circuit Theory 1 had 42 students and Circuit Theory 2 had 20 students. The lecture portion of each course was conducted in three 50-minute sessions per week. The only learning facilitator in the room was the instructor (author R. O.). At the beginning of the semester, the students in each course were formed, randomly (using the Blackboard platform), into teams of approximately four students each. A group size of four was used (rather than five to seven) to encourage participation in group work by all students and for the convenience of rearranging classroom desks into tidy squares for group work. Both classes were given instruction, during a full class period at the beginning of the semester (with regular reminders throughout the semester), on what was expected of them during group work. Those expectations included: 1- following a simple problem-solving scheme, which included brief individual reflection, brief group brainstorming to decide a solution approach, and then interactive work with discussion until the problem is solved; and 2- using good interpersonal team skills, which included speaking, listening, and peer instructing, both respectfully and appropriately.

For the Preparation phase, the predominant source of reading material was the textbook (Electric Circuits by Nilsson and Riedel), although instructor-written summaries were occasionally provided as well. Initially, Preparation phase reading assignments were of the material for the entire two-to-three week unit, as specified in the description of basic team-based learning. Typically, that would consist of an entire chapter or even two from the textbook. It was rapidly observed, however, that, as circuit theory is hierarchical and rapidly increases in difficulty the further one proceeds into a chapter, the material became too difficult for most students after only a few pages, so that most of them were unable to obtain even "a good introduction to the information and ideas on the topic".[3] Thus, Preparation phase reading assignments and associated readiness tests were given every two or three days instead of every two or three weeks. Readiness test scores were used as one of several assessment instruments for the seventh learning outcome, the one associated with preparation and participation.

For the Application phase, assignments were taken principally from the textbook, which was usually found to be an adequate source of increasingly challenging problems for group work. During group work, the instructor acted as tutor, performing two principal tasks: observing, assessing, and facilitating (reminding teams about) use of the prescribed process of group work; and facilitating technical content learning, which involves providing formative feedback, teaching by asking guiding questions, and occasionally interrupting the process to do brief 'just-in-time" lecturing to the whole class on some point of common difficulty. Occasionally the groups were required to submit their work as a report, one report per team, for formative assessment.

The Assessment phase at the end of each two-to-three week unit consisted of a strictly formative assessment exam, and not a summative assessment, as specified in basic team-based learning theory. The formative assessment exam had no numerical impact on the students' final grades. Instead, it was used to provide feedback for improved student learning in anticipation of the grade-determining summative final exam to be taken at the end of the semester. This change to the basic team-based learning process was made in order to both allow and require students to demonstrate achievement of course learning outcomes at the end of the semester, consistent with the learning outcome statements, i.e., of what students should know and be able to do by the end of the course. Thus, the six declarative content-based learning outcomes were assessed by summative final examination.

The seventh learning outcome, which was associated with preparation for class during the Preparation phase and participation in group work during the Application phase, was assessed continuously via readiness tests, daily instructor observation of attendance and behavior during group work, submitted group work, and a peer assessment survey given at approximately mid-semester. In the peer assessment the members of each group anonymously assessed each other's contributions to the group work process.

Evaluation: Fall 2010

In order to gather feedback information that could be used for improvement, evaluation of the adapted team-based learning strategy, as implemented in Fall 2010, was done using two instruments: continuous observation by the instructor throughout the semester, and a Student

Evaluation Survey taken (with student permission) at the end of the semester to examine students' perceptions of the strategy. There were two positive results and two negative results from the instructor-based observations. The positive results concerned the group work. First, as the semester progressed and after several reminders about the group work process, most teams eventually did, as promised by the basic team-based learning theory[3], evolve into engaged learning units in which students discuss the problem in question and alternate solution approaches, and instruct each other when necessary. And second, while observing and tutoring group work, it was very easy for the instructor to see exactly what the conceptual learning difficulties were, and to take appropriate and immediate actions to correct them. Often, the observed difficulties were very different from the instructor's expectations.

The two negative results from the instructor-based observations, which suggested changes to be made in the way we were using the strategy, concerned motivating students to prepare for class on a regular basis, and students' discomfort with the formative/summative assessment grading scheme being used. These concerns were echoed in the Student Evaluation Surveys, taken of 62 students in both courses at the end of the semester. A summary of the principal results of the survey follows:

- Perception of learning: 45 students (73%) felt that they learned more with team-based learning (as implemented) than they would have if a traditional lecture approach had been used. Most of the students emphasized the benefits of working on problems in groups in class with tutor (instructor) assistance. No attempt was made to determine quantitatively whether the students actually had learned more with team-based learning than they would have otherwise, but the final mean grade point average (GPA) was 2.75 in Circuit Theory 1 and 2.60 in Circuit Theory 2. Criterion-referenced grading was used to assign those grades.

- Satisfaction with group members: 58 students (94%) were pleased with their group. Many noted that they became better at working as a team as the semester progressed, just as promised in the basic theory. Those students who expressed dissatisfaction stated that it was because their group had at least one student who was frequently either absent, late, or unprepared.

- Preparation and readiness testing: 48 students (77%) favored the readiness test concept, although several of them commented that some of the readiness tests were unfairly difficult, and 57 students (92%) agreed that readiness assignments, over assigned readings, should used as an alternative way to test readiness.

- Strictly formative assessment exams: 43 students (69%) took them at least moderately seriously, i.e., prepared for them; the others did not, mainly because the scores didn't contribute to the final grade. A frequent comment was that a graded assignment or test in another course always took priority.

- Summative assessment and final grades: Only 20 students (32%) were comfortable with such heavy emphasis on the final exam. Many objected to the anxiety caused by such a system. This is reflective on our local (American) educational culture, in which it is common for tests given throughout the semester to contribute significantly toward the final grade.

Changes for Spring 2011 and Results

For Spring 2011, Circuit Theory 1 had 33 students and Circuit Theory 2 had 41 students. As in Fall 2010, the lecture portion of each course was conducted in three 50-minute sessions per week, and the only learning facilitator in the room was the instructor (author R. O.).

Based on the Fall 2010 Evaluation process, and in order to improve the team-based learning strategy as implemented in the two electric circuits courses for the Spring 2011 semester, several changes were made. First, even though 94% of the students were satisfied with their randomly formed groups in the Fall, for the Spring it was decided to form the groups more carefully, as suggested by the basic theory[3], by making the groups as diverse as possible with respect to talent, ethnicity, and gender. Second, in response to student input concerning preparation and readiness, readiness tests were supplemented with readiness assignments, which consisted of assigned problems from the textbook. However, when it was realized that many students were copying and submitting solutions from the solutions manual, the practice was discontinued. And finally, in order to both increase engagement in the formative assessment process and to alleviate anxiety caused by the heavily weighted summative final examination, a so-called 50-50 compromise was instituted, in which, if a student's score on the final exam for a specific learning outcome was lower than the corresponding score on the earlier formative exam, the final grade for that learning outcome would be determined by the average of the two scores[12]. Otherwise, the score on the final exam alone would be used to determine the grade.

As at the end of the Fall 2010 semester, a Student Evaluation Survey of students' perceptions was taken at the end of the Spring 2011 semester (with student permission), with emphasis on evaluating the effects of the changes made for the Spring semester. The principal results of the survey, taken by 61 of the students in the two courses, are as follows:

- Perception of learning: 56 students (92%) felt that they learned more with team-based learning than they would have if a traditional lecture approach had been used. This is an improvement from 73% in the Fall. As in the Fall, no attempt was made to determine quantitatively whether the students actually had learned more with team-based learning than they would have otherwise, but the final mean GPAs in the two courses were 2.92 in Circuit Theory 1 and 3.13 in Circuit Theory 2 (using criterion-referenced grading). It might be noted that the group of students whose GPA was 3.13 in Circuit Theory 2 in the Spring was virtually the same group that had earned a GPA of 2.75 in Circuit Theory 1 the previous semester.

- Satisfaction with group members: 58 students (95%) were pleased with their group. This is virtually the same result as in the Fall (94%), and student comments echoed those in the Fall.

- Preparation and readiness testing: 38 students (62%) favored the readiness test concept, which is less than the 77% who favored it in the Fall. As mentioned, the attempt to assign textbook problems as readiness work was unsuccessful due to the ready availability of the solutions manual. Despite this problem, students echoed the sentiment from the Fall that readiness assignments are desirable. Several students made the suggestion that if readiness tests are to be used, they should be in the form of short quizzes, and be given frequently.

- Revised formative and summative assessment exam schemes: 56 students (92%) treated the formative assessment exams at least moderately seriously, as compared to only 69% in the Fall, and 55 students (90%) were comfortable with the scheme used to determine their final grades, as compared to only 32% in the Fall. These large improvements are the results of the above-mentioned 50-50 compromise made for the spring, which essentially turns the formative assessments into a back-up in case of a poor performance on the summative final exam.

Changes for Fall 2011 and Results

For the Fall 2011 semester, two final changes were made to the team-based learning strategy as implemented here. First, following suggestions from the Spring 2011 Student Evaluation Survey, occasional, unannounced readiness quizzes were used to motivate and assess student preparation for class[12]. And second, at the suggestion of a colleague[13], students were required to keep a preparation notebook, in which they were required to summarize and outline Preparation phase readings and work on any problems assigned as part of the preparation assignment.

As at the end of the Fall 2010 and Spring 2011 semesters, a Student Evaluation Survey of students' perceptions was taken at the end of the Fall 2011 semester (with student permission), with emphasis on evaluating the effects of the two changes made for the Fall 2011 semester. The principal results of the survey, taken by 44 of the 74 students in the two courses, are as follows:

- Unannounced readiness quizzes: 33 students (75%) agreed that the concept motivated them to prepare for class, i.e., complete the Preparation phase assignments, and 26 of them (59%) agreed that they should be given more often than was the case in the Fall 2011 semester (six readiness quizzes were given in circuit theory 1 and three were given in circuit theory 2). The most common suggestions for quiz frequency were one per one or two weeks.

- Preparation notebook: 25 students (57%) agreed that the concept motivated them to prepare for class, and 22 of them (50%) agreed that they should be

collected for grading more often than once (the case in both courses in Fall 2011). The most common suggestions for notebook collection frequency was once per three or four weeks.

Conclusions

After three semesters, two of the three challenges that were encountered initially have been resolved reasonably satisfactorily. Instructor observation and Student Evaluation Survey results suggest that it is a gradual process throughout the semester, but most students gradually become comfortable with the specified group work process, and most students feel that they learn more using team-based learning than they would have in a more traditional lecture-based setting. Although not scientific, class average GPA values tend to support this conclusion. Instructor observation and Student Evaluation Survey results also suggest that the formative/summative assessment scheme being used works reasonably well when the described 50-50 compromise is included.

Concerning the challenge to motivate students to study and learn new material outside of class and before encountering it in the classroom, it still remains to find an optimum way to motivate them to engage in the Preparation phase of the strategy. Based on suggestions from the Student Evaluation Survey for Fall 2011, the use of both readiness quizzes and preparation notebooks are good ideas, but the quizzes need to be administered more often, and the preparation notebooks need to be collected and graded more often.

Finally, although the adaptation and implementation of team-based learning as described here has been done specifically for the two-course electric circuit theory sequence in electrical and computer engineering, there is no apparent reason why the results cannot be applied to any engineering course, particularly those at the sophomore level. To assist instructors who are unfamiliar with the strategy, but interested in using it, we have conducted training seminars throughout the past three semesters. We are also preparing an on-line training course for instructors wishing to learn how to use team-based learning. This is the subject of a separate paper from another session at this conference[14].

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