Session 1793

Learning by Teaching in Engineering Technology Education

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Abstract

Engineering technology professors usually receive little or no training in effective teaching methods. Most of them teach the same, ineffective way they were taught—by lecturing. This paper examines a method that can be used to actively engage students in their own learning: "learning by teaching." A sophomore-level electronics engineering technology course was conducted so that most of the material was taught by the students themselves. They presented the material and evaluated each other's mastery of it. This transfer of control from the professor to the students had several benefits: (1) more motivation to learn, (2) better understanding of the material, (3) development of important non-technical skills, and (4) surprising creativity that taught the professor as much as the students.

Introduction

The clock shows 9:00 a.m. and the class lecture begins. You draw two block diagrams on the board and start comparing an open-loop control system to a closed-loop one. Tom and Jack are in the back row whispering to each other about last night's date. Bill is more interested in his Egg McMuffin than in what you have to say. Emily's head seems glued to the desk. Are her eyes even open? After a few minutes, even those who were paying attention at first seem to be thinking about almost anything else.

Nearly every college professor has been through this at one time or another—probably frequently. Some blame themselves for this failure to engage students in class. Others accuse the students as being irresponsible and apathetic. But what is really going on here, and how can it be remedied?

Engineering technology professors usually receive little or no training in effective teaching methods. Most of them teach the same way they were taught—by lecturing. According to McKeachie, "Effective lecturers combine the talents of scholar, writer, producer, comedian, entertainer, and teacher in ways that contribute to student learning." [1] He goes on to explain that few teachers can combine all of these things successfully. Even those that do, find it impossible to accomplish every single day.

Lecturing certainly has its uses: conveying large amounts of information, covering material that is too new to be in textbooks, and sharing the professor's personal experiences and enthusiasm for the material.[2] It has been an important tool in the university professor's toolbox for decades. But, as Abraham Maslow insightfully explained, "If the only tool you have is a hammer, you tend to see every problem as a nail." Some teachers use the lecture as their only teaching tool, treating all classroom situations as "nails." Lecturing is not always the best way to teach a class. Nilson states that one significant disadvantage of the lecture is that most students begin to lose interest after about fifteen minutes.[3] Another weakness, according to Felder, Woods, Stice, and Rugarcia, is that students learn passively, which limits long-term retention and hinders the development of problem-solving and thinking skills.[4]

Can these problems be overcome? Some widely-used techniques encourage active learning by involving students more completely in the learning process. These include group discussions, group activities, and group projects.

Feiman-Nemser and Parker suggests the idea of "teaching as a form of inquiry."[5] Most educators are aware that one of the best ways to clarify and organize ideas is to teach them to someone else. If teachers are also learners, could this concept be exploited in the classroom to help students learn by actively teaching each other?

The objective of developing "learning by teaching" into an effective classroom technique is to enhance engineering technology education in two ways: (1) Students would be more self-directed, motivated, and successful at learning the material than in traditional lecture-based courses. (2) They would also increase their skills in communication, teamwork, and life-long learning.

Method

To discover if these goals would be met and the classroom experience would be enhanced by giving students the opportunity to learn by teaching each other, the format of an Electronics Engineering Technology (EET) class was changed to incorporate the technique for three semesters. At first, there was little formality to this study. The approach was, "Let's give it a try and see if it works." The idea was to divide up the course material, assign each piece to a group of students, give them some basic direction, and turn the teaching over to them. The results were encouraging, so the process was refined and better documentation was kept during the third semester. Even more data was gathered afterwards.

Over a period of three semesters, a total of 37 students participated in the study. As is typical of EET courses, only three of them were females. Students ranged in age from 19 to 25. All of them were from North America. Their GPAs were between 2.6 and 3.5. Every student had been in at least one of the instructor's classes before. For most of them, this was their third experience with him.

EET 251 was the class selected for testing this idea. It is a course in basic control theory that is taken by students in their third semester of the two-year Electronics Engineering Technology program at Brigham Young University-Idaho. This is not a calculus-based course, and students are not expected to actually design control systems. It only gives them a basic understanding of how these systems work and where they are used. Prerequisites include courses in DC and AC circuits, digital electronics, and semiconductors.

The goal was to turn as much control of the class as possible over to the students. There were, however, a few objectives that had to be met to satisfy program accreditation requirements and the expectations of the students' potential employers. Each student was given a short list of course goals that could not be compromised. The first three were similar to those in previous semester offerings of this course. Two new objectives, mirroring the new course format, were added.

At the end of the course, each student would have to demonstrate the ability to
1. Explain the operation of open-loop and closed-loop control systems.
2. Show how process control systems differ from servomechanisms.
3. Identify control system components and explain their operation.
4. Learn technical material from books and other sources outside of class.
5. Explain technical material to a group of peers.

Some reasons for conducting this course differently were explained to the students. They were told that the last two objectives of the course (learning and presenting technical material) were important skills for engineering technicians to possess because they would be expected to do that frequently on the job. They were also skills that were inadequately developed in other courses that used traditional teaching methods.

To accomplish objective number four without overwhelming the students, a text on the simpler end of the difficulty spectrum was needed. *Modern Control Technology: Components and Systems* by Kilian [6] was selected. A second edition of the text was published in 2001 and was used for the last two semesters of the experiment. This book is targeted at technology programs, and specifies minimal prerequisite knowledge. It is also easy reading—for a technical book—which was an important consideration. It would be the primary source of information for the students. They would have to dig the material out themselves without the luxury of having it explained to them.

EET 251 is a three credit course that meets for two hours semiweekly. The 56 hours of semester class time were divided into one block of six hours and five blocks of ten hours. Each of the blocks, except the first, was assigned about 100 pages of material from the text:

Block 1. Course introduction, group formation, block assignments, introduction to control systems, and overview of op amp applications.
Block 2. Introduction to microprocessor-based control, feedback control principles.
Block 3. Switches, relays, and power-control semiconductors, mechanical systems.
Block 4. Sensors, electric, hydraulic, and pneumatic actuators.
Block 5. DC motors, stepper motors, AC motors.
Block 6. Relay logic and PLCs.

The instructor conducted the first six hours of class time (Block 1) himself for several reasons: (1) The groups needed to be established and the first one was given one a week to prepare. (2) The standard of technical depth expected by the presenters was modeled. (3) It was important to establish a framework for the subsequent material that would be covered during the course by the students. The remaining 50 hours (Blocks 2 through 6) were handled completely by the students.

On the first day, it was explained that this course would be different than other courses the students had taken, even those they had taken from the instructor. They would be formed into five groups, each of which would be assigned topics from the textbook to teach the rest of the class. They would have nine hours of class time to help their classmates learn the material using class presentations, discussion groups, lab exercises, homework, field trips, games, etc. They were completely free to determine how this would be done. The other students and the instructor would evaluate them on their effectiveness. The scores they earned as *teacher* in these evaluations would comprise 50% of their course grades. Each group member would be evaluated individually. (Evaluating on an individual basis may not have been the best thing to do. See the Discussion section.) The tenth hour of the block was to be spent testing the level of mastery achieved by the other students. The test (or other evaluation method) would have to be approved by the instructor in advance to ensure some degree of fairness and consistency across the blocks. Scores earned as *learner* in the other blocks would be the other 50% of the course grade.

After the introduction, students formed five groups of their own choosing. In the first semester, all of the groups had 3 or 4 members. This group-size is reported by Felder and Brent to be ideal for teams like this. [7] During the next two semesters, however, the classes were smaller and the normal group size was only two. Once a group formed, it could select the 10-hour block of material it wished to teach. The order of block selection was determined by the speed at which a group could form itself: "first come, first served."

Results

Three questions about the teaching to learn method needed answers: (1) Would students be more motivated than in other courses? (2) Would students learn the material? (3) Would students develop more skill in communication, teamwork, and life-long learning than in other courses? Course grades, various evaluations, and the instructor's observations were used to answer these questions.

During the first two semesters, only instructor observations and comments by students were used to determine whether they were motivated. The results seemed positive, but were anecdotal. In an effort to collect more data on the fall 2002 course, a course evaluation was developed for EET 251 that asked students to answer questions using the Likert response scale. It was completed about two months after the fall 2002 course by seven of the original ten students who had taken the class. They were asked about their level of motivation with the following question:

"You put more effort into learning than in other courses."

Strongly disagree:	0
Disagree:	2
Not sure:	0
Agree:	3
Strongly agree:	2

As the responses in the course evaluation show, most of the students put more effort into this course than they usually do in other courses.

One way to evaluate how well students mastered the concepts in this course is to consider the scores earned by students for the blocks they did not teach. These scores combine the block test with other assignment scores for that block. While some variation from semester to semester exists, all of the average block scores are at the "B" to "B+" level. These are the average block scores earned in each of the three semesters:

Fall 2000: 83.7%
Fall 2001: 88.5%
Fall 2002: 89.6%

To determine if students were proficient in the concepts they actually taught, the peer and instructor evaluations of the presentations were examined. The class and instructor evaluated each presenter on several criteria, including his or her level of preparation and ability to present the topics clearly. The average presentation scores from the peer evaluations and the instructor evaluations in each of the three semesters are shown below:

Fall 2000: 88.4%
Fall 2001: 86.8%
Fall 2002: 90.1%

Additional evidence that students learned the material well is found in the student evaluations of EET 251 administered by the University. These evaluations are not done every semester, and data only exists for the fall 2002 course. Seven of the ten students in the course returned the evaluation. One of the questions on this evaluation dealt with how well the material was learned:

"Compared to other college courses you have taken, would you say you had learned:"

A great deal less:	0
A little less:	0
About the same:	2
A little more:	2
A great deal more:	3

Everyone claimed to learn at least as much as in courses that used more traditional teaching methods. Over three-fourths (77.4%) of the students thought they had learned more.

A question in the course evaluation that students were asked to complete two months later was similar to the one shown above. It produced comparable results:

"The subject matter was understood better than in other EET courses."

Strongly disagree:	0
Disagree:	2
Not sure:	1
Agree:	3
Strongly agree:	1

While less positive than they had been two months earlier, during the course, less than one third disagreed.

Did the students learn to communicate better? Because this was part of the final score for the course, grades are one way to measure this. The validating final grade averages are shown below:

Fall 2000: 87.8%
Fall 2001: 80.9%
Fall 2002: 88.0%

Another indication that this goal was met is found in the course evaluation passed out two months later. Here are the responses to the two questions about communication skills:

(1) "Your written communication skills increased more than in other EET courses."

Strongly disagree:	0
Disagree:	2
Not sure:	1
Agree:	4
Strongly agree:	0

(2) "Your oral communication skills increased more than in other EET courses."

Strongly disagree:	0
Disagree:	0
Not sure:	0
Agree:	7
Strongly agree:	0

One question remained to be answered: Would this experience prepare students better for life-long learning? No quick method to evaluate this question is readily available. The course evaluation did attempt to address it, however:

"Your capacity to learn technical material on your own increased more than in other EET courses."

Strongly disagree:	0
Disagree:	0
Not sure:	0
Agree:	6
Strongly agree:	1

While the results of this question are not proof of increased life-long learning ability, they appear to supportive. Because the ability to learn on one's own was part of the final score for the course, grades may also be a positive indicator. The final grade averages are shown below:

Fall 2000: 87.8%
Fall 2001: 80.9%
Fall 2002: 88.0%

Whether the ability and desire for life-long learning is actually enhanced requires more investigation.

Discussion

Although more data is necessary to make these findings absolutely convincing, the amount gathered to this point seems to support the original hypothesis: learning by teaching is effective, and it should be studied and developed because it can be used to enhance engineering technology education. The students are more motivated and they learn the material better than in courses based mostly on lecturing by the professor. They also increase their skills in communication, teamwork, and possibly life-long learning as well.

The success of this study in a university classroom is partially explained by Eduard Lindeman's philosophy of adult education. As summarized by Knowles, Holton, and Swanson, he promoted the idea that teachers of adults should be fellow "searchers after wisdom" and not profess to be the oracles of it. Adult learners have a need to control their own experiences, and that must be respected. Lindeman continued with, "In conventional education the pupils adapt themselves to the curriculum offered, but in adult education the pupils aid in formulating the curricula." Joint learning (with both teachers and students participating in the process), he further explained, allows the sharing of authority to direct the curriculum. [8] These principles were verified many times by the instructors own observations. Some of the most noteworthy ones follow.

Many of the students were highly motivated and creative. These students often taught the instructor more than he probably would have taught them if he had been conducting the class in the traditional way. The demonstrations, lab exercises and projects, and field trips that the students planned and carried out were outstanding. One student had been an automobile mechanic. He showed the class various sensors and actuators typically found on cars and demonstrated how they worked. One of the labs was about building electric motors out of common materials found around the house. One project culminated with a tournament of battle robots. (No, the instructor did not win.) Team-built electric cars were raced up and down the hallway. They built a miniature fire truck that actually pumped water from an external tank and squirted it out a "water cannon" that had X-Y control. And there were more field trips than in any other class in the curriculum. The city engineer showed the students how the intelligent traffic light on the corner worked. The bowling alley manager took them behind the lanes to see all of the sensors and actuators that set up the pins and returned the ball. They visited the computer-controlled, coal-fired heating plant for the campus. A potato farmer showed them the control technology required to harvest, store, and ship a successful crop. Even the telephone switching facility got visited. All of this was arranged by the students themselves.

Even within the classroom, successful alternatives to lecturing were used.

Dividing the class into teams and playing variations of common games were very popular – both in the initial learning and later to review for the test. Tic-tac-toe, hangman, concentration, and several forms of bean bag throwing kept interest and provided motivation. The general theme for all the learning games was the same. Each team would work a problem or answer a question correctly to earn points, either directly or by having a chance to move a game piece, throw a bean bag, guess a letter, or attempt to match some cards. The competition was fierce. It was more fun and interesting than simply asking questions and calling on people.

Some presentation groups sent everyone to the board, either individually or as teams, to work problems. Others formed buzz groups. Lecturing was not entirely eliminated, however. It was used by nearly every group at least some of the time – usually accompanied by visual aids.

There was one imaginative "learning activity" that seemed to be a waste of time at first, but actually helped reinforce the topic. Using graham crackers as circuit boards, frosting as solder, licorice strings as wires, and various types of candy as electronic components, students were asked to design and build a simple control circuit. After each student explained his or her design, the class voted on the most original creation and a prize was awarded. Of course the "circuits" did not actually work, but the students remembered the functional parts of such a system.

Not every group went beyond the required level. Some of them even did a lackluster job, doing little or nothing extra to enhance everyone's experience. When someone had only skimmed the assigned section in the text and simply lectured, even read to the class aloud from the book, it was reflected in their peer and instructor evaluations. It was evident that most students, however, felt some pressure from their classmates to do more than the minimum. It would have been interesting to know why two of them reported that they were less motivated than in other courses.

It may have been a mistake to score everyone independently. Competition among group members for the highest peer and instructor rating was sometimes evident. Occasionally one of them would really shine while his or her team mates struggled. Felder and Brent suggests that promoting "positive interdependence" is the solution to this. By giving everyone on the team the same score, the stronger ones are encouraged to help the weak ones. If a person thinks he can look better if everyone else performs poorly, there is little incentive to lift the others up to a higher level. [7]

It is also important to keep in mind that this was a third semester class. Giving first semester students this much autonomy may not be as successful. They have spent twelve years under a different philosophy, being told what, when, and how to learn. Adapting to college life is already a struggle for some. Perhaps more research should be done to find the "right" balance between instructor direction and student autonomy.

Conclusion

This technique is clearly not appropriate in every case. Some courses contain completely new material, for which the students have very little background or experience. In others, the topics are complicated and difficult to master without careful explanation from someone who has already learned it well. Learning by teaching, however, can be a powerful tool to have in the teaching toolbox when used under the right circumstances.

Follow the advice given by Harold Fields: "Lectures must be replaced by class exercises in which there is a large share of student participation. 'Let the class do the work' should be adopted as a motto." [8] Turn some control over to the students. Amazing things can happen.

[1] McKeachie, W., *McKeachie's Teaching Tips: Strategies, Research, and Theory for College and University Teachers*, Houghton Mifflin Company, Boston, 2002.
[2] Cashin, W., "Improving Lectures", In Weimer, M. and Neff, R. (Eds.), *Teaching College: Collected Readings for the New Instructor*, Magna Publications, Madison, WI, 1993, pp. 59-63.
[3] Nilson, L., *Teaching At Its Best: A Research-based Resource for College Instructors*, Anker Publishing Company, Bolton, MA, 1998.
[4] R. Felder, D. Woods, J. Stice, and A. Rugarcia, "The Future of Engineering Education: II. Teaching Methods That Work", *Chemical Engineering Education, 34*(1), 2000, pp. 26-39.
[5] S. Feiman-Nemser and M. Parker, "Mentoring in Context: A comparison of Two U.S. Programs for Beginning Teachers", *International Journal of Educational Research*, *1993, pp. 699-718.*
[6] Kilian, C., *Modern Control Theory: Components and Systems (2nd ed.)*, Delmar, Albany, NY, 2001.
[7] R. Felder and R. Brent, "Cooperative Learning in Technical Courses: Procedures, Pitfalls, and Payoffs", *ERIC Document Reproduction Service (ED 377038)*, 1994.
[8] Knowles, M., Holton, E., & Swanson, R. (Eds.), *The adult learner (5th ed.)*, Butterworth-Heinemann, Woburn, MA, 1998.

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