Analysis of Student Performance After Implementing Active Teaching Methods in an Engineering Classroom

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Abstract

There is an abundance of data that suggest that implementing active teaching methods in the classroom produces a deeper, longer lasting understanding and increased enjoyment of course material. However, most engineering educators do not employ these techniques. This study implemented a few basic active teaching methods in two electrical engineering courses for 3 consecutive semesters. The objective of the study was to address three typical concerns engineering educators have about implementing active teaching methods: 1. "I don't have enough time to change my course material," 2. "It is difficult to employ active teaching techniques with my course material so it won't be effective," and 3. "I won't be able to cover all my material if I allow time for the activities in class."

The first part of the study compared three aspects; (1) the amount of course preparation time between an active teaching course and a traditionally taught course; (2) the amount of material covered using active teaching versus the material traditionally covered; (3) student performance as compared to the same group of students' performance in previous courses with the same instructor when material was traditionally taught. The second part of the study, presented here, compared a new group of students in the same two courses; comparisons where made against historical performance and against a number of control questions developed during the first part of the study. Student performance was compared against the amount of exposure to these active teaching methods over an extend period of time. Student retention of course material was also compared.

Results continue to show that students were more engaged and scored higher on topics covered using simple active teaching methods as opposed to traditional lectures. Students in the second part of this study scored comparatively the same on control questions based on topics taught with active teaching methods as compared to the students in the first part of the study. However, students taught with traditional methods in the first part of the study, but taught with active teaching in the second part of the study scored significantly higher on control questions for both methods. Students who learned material from active teaching methods scored significantly higher in long term retention as well. Results also suggest that while some students start off resistant to active methods of teaching, they quickly adapt and appraise those methods positively; however, extended exposure to the same techniques appear to desensitize the students and become less effective over time.

Introduction

There has been a significant amount of research on Active Teaching (AT) and its effectiveness in all aspects of education and there is an abundance of data that suggests AT methods are more effective methods of teaching than traditional lecturing[1,2,3,4]. However, as proven of a technique as it is, many technical educators still are resistant to implementing AT in their classrooms for a variety of reasons; these can include: "the notion that students must first master the underlying principles and theories of a discipline before being asked to solve substantive problems in that discipline[3], it requires too much effort to change existing course notes, and the class-time it takes to implement will reduce the amount of material that can be covered.

A study was performed to investigate the effects of implementing three easy to perform, easy to prepare active teaching methods. Initially, four outcomes were analyzed in this study, including:

1. Time spent on lesson planning will not increase by a significant amount.
2. The amount of course material covered will not decrease.
3. Student mastery of the course material will increase.
4. Student enthusiasm for course material will be greater during Active Teaching classes.

The first part of this study, performed in Spring 2014, demonstrated that no significant increase in effort was required to prepare lectures that included these methods[5]; this included preparing lectures for a new course or for modifying a course which the instructor had previously taught using traditional methods. It was also shown that student enthusiasm for course material was significantly greater during lectures that included AT methods than lectures that were delivered using Traditional Lectures (TL) [5]. This study also showed that more course material could be covered in a semester and that the suggested that students' mastery of that material increased[5].

The second part of this study, performed in Fall 2014 and Spring 2015, continued to investigate outcome 3, with two additional outcomes. The new outcomes were:

5. Student knowledge retention of course material will increase.
6. Student enthusiasm for course material will increase and will result in reduced enrollment attrition.

Background and Motivation

This paper reports on the findings of one instructor's attempt to implement active teaching in his classes with the goal of improving upon his students' performance without significantly changing his workload. Throughout the course of the Spring 2014 semester, the previously mentioned outcomes 1 – 4 were assessed to verify the change in teaching style was having a positive effect. The initial findings during that semester were extremely positive. However, the study did have some limitations:

1. The first part of this study was only conducted in two courses (one sophomore and one junior course); an argument could be made that the sophomore and junior classes of Spring 2014 were exceptional classes and that the improvement in grades was due more to the quality of student than the methods.
2. One method of assessment was to cover a few topics throughout the semester using strictly TL and then including at least one test question on these topics on each semester test. Then, a comparison was made between student performance on skills taught using AT vs. on skills taught using TL. Although every attempt was made to verify the question sets were equitable in both duration and difficulty, it could be argued that the instructor inadvertently made the test questions on skills taught using TL harder than the skills taught using AT.
3. One important aspect of 'student performance' is retention of knowledge. While student performance increased according to all criterion used to assess outcome 3 in Spring 2014, there was no way to assess the students' retention of knowledge.
4. Student enthusiasm during AT lectures increased according to all three criterion used in part one. However, the most important criterion to assess this outcome is "enrollment attrition will decrease". This was not possible to assess this after a single semester.

The term Active Teaching (AT) can be loosely defined by "any teaching method that does not include disseminating course material by traditional lecturing methods." Traditional Lecturing (TL) is characterized, for purpose of this study, by the instructor lecturing for the majority of the class period. The defining difference between AT and TL is the opportunity for student engagement. Details of these differences and examples of specific AT methods are included in the first part of this study[5]. The specific methods of AT used in this study include Thinking Aloud Peer Problem Solving (TAPPS), Small Group Discussion (SGD), and Individual Sketch (IS); details of how these were implemented were discussed in the first part of the study [5].

The study has now been performed during three semesters in four courses by one instructor. This instructor has more than 10 years of teaching experience and has taught the sophomore courses included in this study multiple times using both AT and TL. This instructor's experience teaching the junior courses is limited to 2 course offerings each. Table 1 lists the courses used in this study and compares the amount of times the instructor had taught each class and the style which was used (AT or TL).

Table 1. Courses used to assess the effectiveness of Active Teaching in this study

	Trad. Lecture (Fall 2013)	Active Teaching (Spring 2014)	Active Teaching (Fall 2014)	Active Teaching (Spring 2015)
Sophomore-level	EE220: Circuits I	EE222: Circuits and Machines	EE220: Circuits 1	EE222: Circuits and Machines
Semesters Prev Taught	9 (TL) | 0 (AT)	3 (TL) | 0 (AT)	10 (TL) | 0 (AT)	3 (TL) | 1 (AT)
Junior-level	EE320: Electronics I	EE321: Electronics II	EE320: Electronics I	EE321: Electronics II
Semesters Prev Taught	0 (TL) | 0 (AT)	0 (TL) | 0 (AT)	1 (TL) | 0 (AT)	0 (TL) | 1 (AT)

Methods

During Spring 2014 semester, AT was implemented in the majority of the lectures for both EE222 and EE321. However, a handful of intentionally chosen lectures were still taught with TL in both courses. This was done to compare students' mastery of course material when taught using the two different methods. In the lectures where AT was implemented, three primary methods of AT were used: TAPPS, SGD, IS. The first two were group activities, and the third required individual effort.

Outcomes 1, 2, and 4 were fully assessed during the first part of this study and are not reported on here. Assessment methods for outcomes 3, 5, and 6 are discussed in detail here.

Outcome #3: Initially, student mastery of the course material was assessed by analyzing student grades in two ways. First, on the three semester tests in both classes, questions were posed where the skill being assessed was specifically taught using an AT method and questions were posed where the skill being assessed was specifically taught using TL. In both classes, scores on the AT questions were significantly better [stat] than the TL questions. Second, class averages in EE222 and EE321 during Spring 2014 were compared to the same students' class averages in EE220 and EE320 during Fall 2013; in both cases data supported the criterion for successful implementation of outcome 3.

Analysis of this outcome continued during the second part of the study. First, Fall 2014 class averages of EE220 and EE320 were compared to previous course offerings; the mean and median of the previous five EE220 course grades were used to compare results of Fall2014-EE220, but the instructor only had one previous course offering of EE320 with which to compare results of Fall2014-EE320. Second, the remaining TL lectures from Spring 2014 were modified to include AT methods. At least 1 AT and 1 TL question from Spring 2014 were repeated in Spring 2015 on all three semester tests in both EE222 and EE321; both the Spring 2014 and 2015 classes were told exactly the type of questions to expect on tests and these questions were modified enough so that, while similar to the questions posed in Spring 2014, simply studying the previous tests would not be a significant advantage to the Spring 2015 classes.

The first criterion for successful implementation of AT methods for this outcome was that the Fall 2014 class averages of EE220 and EE320 were higher than previous course offerings. The second criterion for successful implementation of AT was that student performance on skills previously presented using TL in Spring 2014 and presenting by AT in Spring 2015 increased significantly more than performance on skills presented in both spring semesters using AT.

Outcome #5: Student retention of course material, an important subset of outcome 3, was assessed using pre-requisite exams in the spring courses. A list of learning objectives from previous courses that applied to the current course was provided to the students at the onset of the spring semester. Students were given one week to study those outcomes from their previous course notes and informed that they were not allowed to continue with the current course until

they passed the exam. The exams consisted of a randomly selected set of questions based on those outcomes that assess both rote memorization and application; all but one question on each test was taken from test questions previously presented to the students. This directly assessed an improvement of the students' material retention because the Spring 2014 EE222 and EE321 students had taken EE220 and EE320, respectively, using TL whereas the Spring 2015 students had taken the fall courses using AT methods.

The criterion for successful implementation of AT methods for this outcome was simply that the Spring 2015 pre-requisite exam scores were higher than the Spring 2014 scores.

Outcome #6: One of the main objectives of developing AT methods is to increase student enthusiasm for course material and therefore reduce enrollment attrition. In the first part of this study, the goal was simply to show that students' enthusiasm increased during lectures which were presented using AT methods and the results were extremely convincing. The hope was that this increased enthusiasm would extrapolate to overall increased enthusiasm and reduce enrollment attrition, but it was clear from the onset of part one that there would not be enough data to support such claims at that time. However, attrition data has been tracked for many years by the investigating instructor and now, after two consecutive years, a preliminary hypothesis can be made. Final conclusions will be drawn by comparing five years of attrition before the instructor switched to active teaching and the following five years.

The criterion for successful implementation of AT methods for this outcome is that enrollment attrition between EE220 and EE222 and also between EE222 and EE320 will decrease. Not all students enrolled in these courses will be used to quantify this criterion for two reasons.

1. A few non-EE majors often enroll in EE220 and rarely enroll in EE222. These students will be removed from the tally of EE220 students regardless of whether they choose to continue pass EE220.
2. Students who choose to take an internship and therefore delay enrolling in EE320 will be removed from the tally of EE222 students.

Data Analysis and Results

The assessments of the three outcomes addressed in this part of the study are as follows:

Outcome #3: The first criterion used to assess outcome 3 was an improvement to the semester grades of EE220 and EE320. Table 2 shows a comparison of semester grades. The semester grades of both EE220 and EE320 improved significantly ($t = 31.054$, $p < .05$) using AT methods in the Fall 2014 as opposed to previous semesters when those courses were delivered using TL. Semester grades in EE222 also improved and, although they were not considered in outcome 3's criterion, they are included here for completeness. A comparison of grades in EE321 was not possible since the instructor had never taught EE321 using TL.

Table 2. Comparison of semester grades using AT vs. TL.

Class	Mean TL semester average	Median TL semester mean	AT semester average	Significance
EE220*	86.0%	85.3%	90.8%	$p < .05$
EE222**	76.9%	76.8%	84.3%	$P < .05$
EE320***	72.8%	72.8%	81.6%	$P < .05$

* data from previous 5 semesters
** data from previous 3 semesters
*** data from previous 1 semester (only semester taught using TL by current instructor)

The second method of assessment for outcome 3 was to analyze student performance on skills taught in Spring 2014 using TL which were now taught using AT methods. Table 3 shows the students' averages for all test questions based on skills taught using the two methods. There was a 10.2% improvement on questions that where originally taught with TL in 2014, but taught with AT in 2015; a significance test on this data showed that the change was significant ($\sigma = 14.3\%$, $p < 0.05$). There was only a 2.6% change in the student scores on questions that were taught using AT in both semesters; the significance testing shows that this change was statistically insignificant ($\sigma = 10.4\%$, $p > 0.05$). These were the expected results. There was an insignificant change in student scores when the teaching method remained constant, yet when the teaching style changed, the improvement was significant.

Table 3. Student scores on test questions taught using AT vs TL

	2015	2014	Improvement	Significance
Question Set 1	84.4%	81.8%	2.6%	$\sigma = 10.4\%$, $p > 0.05$
Question Set 2	75.9%	65.6%	10.2%	$\sigma = 14.3\%$, $p < 0.05$

Table 3 shows that overall the students' scores improved. However, it should be noticed that the results at the end of the year were less successful than at the beginning of the year. Table 4 displays the scores of the individual test questions used in Table 3. The improvement in the sophomore level course was significant during test 1 and test 2. However, there was little difference in improvement on test 3. This is likely due to the fact that the score on the TL problem from Spring 2014 was already 90%; it is difficult to expect a class average to improve much above that. The junior level course exhibited the expected improvement on test 1, but performance on test 2 remained consistent and performance on test 3 was dismal at best. There are a number of possible explanations for this that will be discussed in detail in the Limitations section of this paper.

Table 4. Student scores on test questions taught using AT vs TL

(when different, problem numbers of 2015 tests are provided)

EE222					EE321				
Test 1	Method	2015	2014	improvement	Test 1	Method	2015	2014	improvement
Prob 1a/b	AT	82.3%	83.1%	-0.96%	Prob 2	AT	73.3%	76.1%	-3.68%
Prob 1c	TL	65.2%	38.2%	70.80%	Prob 3	TL	82.3%	71.7%	14.78%
Test 2	Method	2015	2014	improvement	Test 2	Method	2015	2014	improvement
Prob 2a	AT	83.9%	72.0%	16.59%					
Prob 2b	TL	85.3%	68.0%	25.39%	Prob 1	AT	94.1%	92.8%	1.40%
Prob 3a	AT	90.0%	85.3%	5.47%	Prob 2	TL	72.9%	71.8%	1.53%
Prob 3b	TL	80.8%	64.7%	24.93%					
Test 3	Method	2015	2014	improvement	Test 3	Method	2015	2014	improvement
Prob 1a	AT	97.5%	96.4%	1.14%	Prob 1	AT	69.3%	66.7%	3.90%
Prob 1b	TL	93.8%	90.0%	4.17%	Prob 3	TL	50.8%	55.0%	-7.64%

Outcome #5: In order to assess students' knowledge retention, a pre-requisite test was given at the onset of the spring semester in 2014 and 2015. The student who took the 2014 pre-requisite test took the preceding fall course in a traditional format and the students who took the 2015 pre-requisite test took the preceding fall course in an active format.

Table 5 shows the test results of the four pre-requisite tests. In both cases, students were required to pass the test before continuing with the course and may have taken the test multiple times; however, what is presented here are the initial scores on all four tests. In both courses, three problems were similar to the previous test and three problems covered different topics. As expected, results show that students retained material significantly better when they were forced to engage the material though an activity rather than a traditional lecture.

Table 5. Comparison of Pre-requisite Test Grades

Course	2015	2014	**Improvement**
EE222	78.0%	54.7%	**42.6%**
EE321	85.7%	55.7%	**53.9%**

Outcome #6: The enrollment attrition rates were compiled for the previous three years before active teaching started in EE220 and EE222. Table 6 displays the attrition rates between EE220/EE222 and between EE222/EE320. The high attrition rates the three years before AT started in EE220 and EE222 were typical of many previous years. It is difficult to say that AT was completely responsible for such a stark difference in these rates. It is also possible that AT and/or the improved grades simply delayed the attrition problem and similar number of students will eventually drop out of future classes. This is only a preliminary result;however, it looks very promising.

Table 6. Comparison of attrition rates

Year	EE220	EE222	Attrition	Year	EE222	EE320	Attrition
2014/2015	35	32	8.57%	2015	32	31	3.13%
				2014	18	18	0.00%
2013/2014	28	18	35.71%	2013	23	17	26.09%
2012/2013	32	23	28.13%	2012	27	25	22.22%
2011/2012	35	27	22.86%	2011	30	25	16.67%

Study Limitations

This study included a number of limitations that should be addressed.

First, while outcome 3 looks to have been successfully achieved by both criterions, the second criterion does leave some room for debate. The sophomore class's performance on skills previous taught using TL did improve and the skills taught in both semesters by AT mostly remained constant. However, the results were not significant on test 3. Likewise, the junior course improved as expected on test 1, but did not perform as expected on Test 2 and 3. A new theory was developed while compiling this data: The active teaching methods chosen were effective to start with, but became less effective with continual exposure. The junior class had three consecutive semesters (EE222/EE320/EE321) of the same active teaching methods and the sophomore class had 2 consecrate semesters (EE220/EE222). One of the reasons active teaching works is that the activity removes boredom and forces students to engage in something new and different. Since the active teaching methods (TAPPS, SGD, and IS) never changed, they became the routine and therefore did not have the desired ability to remove the students from their comfort zones. Perhaps it is necessary to include different AT methods as the students become accustomed to the original three.

Another issue encountered with the junior class data was the character of this particular class. The class was perhaps a slightly difficult class to work with in their sophomore year, but did not appear to be anything abnormal. However, the class became more difficult and outright defiant as the junior year progressed. In multiple junior courses, this class refused to complete assignments, complete assigned readings, or submit daily work. Three of the five faculty members who taught junior courses in Spring 2015 had significant issues like this and both of the remaining two faculty members recognized an increased difficultly with the class. This, of course, impacted negatively on their grades and likely impacted the data collected for this study.

Regardless of the possibility of particular active teaching methods losing some effectiveness and regardless of other possible distractions, it was clear that both the studious sophomore class and the difficult junior class had improved semester grades and, since they both performed similarly

to the previous classes on skill taught using AT methods, that improvement was primarily due to an improvement on skills previously taught using TL.

The obvious limitation to outcome 6 is limited to the amount of data that has been collected so far. It appears that AT has the ability to affect enrollment in a positive manner. However, with only 3 data points and two of those data points being taken from the same group of students, it is difficult to draw significant conclusions. This trend will continue to be tracked over the next few semesters.

Conclusions

The initial conclusions from the first part of this study were:

1. Implementing active teaching did not increase instructor work load
2. Implementing active teaching does not reduce the amount of material covered in a course, and could actually increase the amount.
3. Implementing active teaching clearly increases student participation and enthusiasm during a specific lecture.
4. Implementing active teaching appears to improve student performance.

The second part of this study strengthens conclusion 4. The fact that student performance remained consistent on skills presented using AT methods and, for the most part despite the aforementioned limitations, improved on the skills previously presented using TL, dispels one of the more troublesome limitations mentioned in the first part of the study: That the instructor inadvertently biased the test questions either by making the Spring 2014 TL questions too difficult or by making the Spring 2015 tests too easy. If the TL questions were made too difficult, they would still have been difficult on 2015 tests, and had the 2015 tests been made easier, then student performance on all test questions would have improved. These results also remove the suspicion that 2015 students having access to previous tests would provide them with an advantage; if there had been an advantage, then all test questions would have improved.

Possibly the most important result of the study was that students' knowledge retention clearly improved when taught material using AT methods. The fact that students scored approximately twice as high on pre-requisite tests can leave no doubt that, on average, students recalled previous material much better than previous classes had.

While a concrete conclusion cannot be made regarding enrollment attrition at this time, it is fair to deduce a tentative conclusion that active teaching methods have a positive effect on this extremely important statistic. The first part of this study definitively showed that students were more engaged and more enthusiastic during active teaching lectures. Active teaching methods also improved grades meaning fewer students failed courses. Together this means that fewer students dropped or transferred out of the program due to poor grades, boredom, or frustration.

Overall, this study has been a definitive success. Every outcome in both parts of the study either were successfully implemented or, at least, appear to be so according to the data collected thus far. With no increased workload or loss of material coverage, and with such positive results, this instructor will continue to implement active teaching methods whenever possible.

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