The Re-Design of an Introductory Circuits Course Based Upon Student Demographics

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***Abstract* - This paper presents a comparative study for an introductory circuits theory course at Tennessee State University College of Engineering, Technology, and Computer Science. DC Circuit Analysis is a course required by all engineering majors including civil, architectural, mechanical, and electrical. This course is the gateway to all future engineering courses and an integral part of the student's introduction to engineering problem solving, analysis, and critical thinking. The introductory circuits course was re-designed in Fall 2003 to include collaborative learning teams, in-class activities, partial lecture notes, and a more facilitative student-centered learning environment. In Fall 2004, the course was revised yet again to include cooperative learning teams, team assignments, and concept questions. In this analysis, statistics for the course from Fall 2000 to Spring 2003 will be compared to the revised course to identify any statistical difference. Finally, the results of the comparison will be used to identify any additional course modifications necessary to improve student success.**

Index Terms - Active Learning, Collaborative Learning, Cooperative Learning, Retention

INTRODUCTION

This paper explores the performance of engineering students at Tennessee State University's (TSU) College of Engineering, Technology and Computer Science (CETCS). TSU is a historically black university in Nashville, TN with an approximate enrollment of 9000 students and 500 full- and part-time faculty. The CETCS has an approximate enrollment of 1000 students with 8 majors. The introductory DC circuits course and associated laboratory is a 6 hour engineering science requirement for all engineering majors including architectural, civil, electrical, and mechanical. This course is the gateway to all future engineering courses and an integral part of the student's introduction to engineering problem solving, analysis, and critical thinking.

Studies indicate that student success in an engineering program including persistence to graduation is directly influenced by their performance, experience and attitude in the first- and second-year courses [1]. This comparative study attempts to identify factors that may influence student success in the DC Circuit Analysis course and exploit those to reduce attrition in the course and increase retention in engineering. The results of this analysis may be used by other physics or engineering faculty members to improve student academic performance and reduce student attrition in their respective courses.

The motivation for changes to this course was an observation by the author that the student success rate in this vital engineering course was not acceptable. Another motivation for this work was that the rate of failure and attrition of African American and Latino students must be addressed in order to produce a diverse population of engineers. In this analysis, the success of the students is measured by academic performance and the number of times the course was taken before successful completion. The author found that the course had an attrition rate of 33% and a mean grade point of 2.1. The hope is that the work presented here will provide more evidence that active learning activities in the classroom will not only engage students in the learning process, but improve the academic performance of underrepresented minorities. Previous work has indicated that promoting academic excellence, peer interaction and group work can directly affect student performance in technical majors [2, 3]. Ultimately, the circuit course changes detailed here may increase student confidence and therefore retain the engineering student until graduation.

The hypothesis is that the modifications to the circuits course will increase student success in the course as measured by retention and mean final grade point average. The remainder of this document will present background literature on student retention, active and cooperative learning. The literature will also address techniques to improve retention and academic success as it applies to underrepresented minorities in mathematics and science. Additionally, the course details, method of evaluation and results will be presented. Finally, conclusions will be drawn on the results of the statistical analysis of the course.

BACKGROUND

Smith et al. [4] provide a brief review of some of the classroom-based practices that engage students in the learning process including active learning, cooperative learning, and team projects. These researchers show how some studies indicate that students learn better when they interact regularly with faculty and their own peers. In fact, interaction with peer and faculty appears to have more influence on students' attitude toward engineering and academic achievement than the curriculum itself.

Cooperative learning is the use of student groups to increase the learning of the individual as well as the team. The primary difference between collaborative (active) learning and cooperative learning is the team formation and format. In collaborative learning, the team may be formed temporarily for an in-class activity or short-term project. Furthermore, in the collaborative learning team format there may not be the presence of any or all of the five cooperative tenets (positive mutual interdependence, individual accountability, promotive face-to-face interaction, teams skills development, regular group processing). One of the main advantages of cooperative learning is that academic success is shown to improve as compared to traditional lectures or competitive or individual learning class formats. With respect to student retention, Smith et al. also indicates students are more likely to persist to graduation who developed a peer network during their matriculation. The cooperative learning student should also develop teamwork skills in addition to the critical thinking and problem-solving skills. In conclusion, teaching methods that engage students in the learning process have been shown to increase student satisfaction, retention, and performance.

Prince [5] also examines the effectiveness of active learning activities in the classroom. Prince's primary description of active learning is that it will include student activity and engagement. An extension of collaborative learning as described by Smith et al., is that it involves a small group working toward a common goal. Research shows that introducing active learning activities into the classroom can also improve student recall of information. Studies also indicate that student collaboration can also improve retention of traditionally underrepresented groups [2, 3]. The teamwork skills developed are also a major selling point of cooperative learning teams since employers state that teamwork skills are a competency gap among recent graduates.

Terenzini et al. [6] and Felder et al. [7] present comparisons between undergraduate engineering students in lecture-style classrooms versus active learning classrooms. These comparisons indicate that student learning is enhanced when the classroom incorporates student active participation in well-defined challenging assignments. The results of these types of activities will improve students engineering skills as it applies to effective communication, teamwork and solving unstructured problems. The students reported improved design skills, communication skills and group skills when enrolled in the active classroom format.

Felder et al. [7] state that studies have shown that students who are retained in engineering typically do not perform any better academically than those who leave. The primary factors in retaining students in engineering are the students' attitudes toward engineering, self-confidence levels, and the interaction between peers and faculty along with aptitude. Additionally, the students' attitudes and confidence levels are directly related to their classroom experiences. The results of their study indicated that students in the experimental group generally earned higher course grades than those in the comparison group. The comparison group students were also twice as likely to leave engineering and three times more likely to drop out of college. Furthermore, the attitudes of the students in the experimental group were different than those in the comparison group. The experimental group students gave higher ratings to their course instruction, the student-friendliness of the academic environment, the level of peer support, and the quality of their investment in their degree. More of these students also expressed an intention to pursue graduate degrees.

Bonsangue [2] and Treisman [3] explore factors that affect minority student success in calculus courses. This work states that the underrepresented students' perceptions of their own academic worth are influenced by the institutional structure, department practices, and faculty attitudes. These same factors may also affect the students' process of learning. Bonsangue discussed the calculus workshop model which invited all minority students to meet twice a week outside of class and work collaboratively on calculus problems. The results indicated that minority students enrolled in the workshop performed academically better than non-workshop minority students. Additionally, more of the minority workshop students were retained in mathematics-based majors after three years. Also, it was found that non-workshop minority students required one full quarter more to complete the calculus sequence. This study found that promoting academic excellence and peer interaction can directly affect student performance. These non-lecture methods and group learning may have a significant impact on some students' performance and involvement. Tresisman [3] found that African American students typically worked alone and never studied with their classmates. Additionally, the remedial courses had very high minority enrollments and did not appear to prepare the students for subsequent courses. The evidence was also overwhelming that students in remedial course never complete science degrees. The workshop program evaluated by Treisman emphasized group learning. This workshop program was able to convince the students that success in college requires them to work with peers and to create a community of scholars based on shared intellectual interests and common professional interests. In summary, the best practice for engaging students in the learning process may include a combination of individual, collaborative and cooperative activities.

COURSE DETAILS

The introductory DC circuit analysis course covers topics such as Ohm's Law, Kirchhoff's Laws, Thevenin's and Norton's Theorems, Operational Amplifiers, and First- and Second-Order Circuits. The prerequisites for the course include Physics II, Calculus IV and a programming course. The co-requisites for the course are the circuits laboratory and differential equations. In this course, the students are required to complete two PSpice projects and one computer design project. PSpice is circuit simulation software used to analyze circuits using DC bias point detail, DC sweeps, AC sweeps or transient analysis. The computer design project typically involves using Visual Basic, C++, or JAVA to write a program to create an algorithm to solve a higher-level circuit analysis problem. In previous semesters, these projects along with homework and exams were individual assignments. The modifications to the course included a more active classroom with students working in collaborative teams to solve concept questions, that is, questions that typically do not have a numerical answer but that are based upon theory presented in class [11, 12]. The concept question is used to gauge the student's understanding of concepts versus their ability to simply memorize facts. This type of question may involve determining which of two configurations of a circuit would produce a brighter light bulb. In the second phase of the course, students were assigned to cooperative learning teams based upon student preference, student self assessment, concept inventory, pre-requisite grades and Solamon and Felder's Index of Learning Styles Questionnaire [8]. Brickell et al. and Trytten et al. indicate that groups function best when they are assigned instead of self-selected, homogenous with respect to interests and heterogeneous with respect to academic performance [9, 10]. In contrast with the collaborative learning team, the cooperative learning team was required to meet both in and out of class to work on more complex tasks. Teams were also required to work problems and concept questions in class and to teach their solution to the class. The students would also submit minute papers to gauge the student's recognition of key lecture concepts. These cooperative teams had to meet for a minimum of one hour per week outside of class and submit meeting minutes. Examples of meeting activities included studying for exams and quizzes, completing homework and planning for the projects. As part of the plan for the end of semester project, the students had to submit periodic memorandums that mimicked the Bloom's problem solving methodology. The progress memorandums were created as a tool to advance the student toward the computer design project due on the last day of class. The students were required to write a team contract, meeting minutes, memorandums and peer evaluations. The course website contained samples of the team contract, minutes, and memorandums [13]. Also, the course website included the following online forms: course evaluation, peer evaluation, concept inventory, student self-assessment, and learning styles questionnaire [8]. The website also had documents on teams, lectures, assignments, projects and old exams. The entire class was also given a lecture on cooperative learning teams and the 5 cooperative tenets. Finally, the students completed self- and peer-evaluations several times throughout the semester.

METHOD OF EVALUATION

In order to evaluate the hypothesis that active learning techniques will improve student success in the circuits course, data was collected from the Fall 2000 through Spring 2003 semesters as a comparison group. It should be noted that the author did not begin teaching the course until Fall 2003. During this period the course was taught by at least four different instructors. The data collected included final course grades, number of repeats, pre-requisite grades and student demographics such as race, gender, class, and major. The same set of data was collected for the Fall 2003 through Spring 2005 courses after the modification of the course. The students were then categorized and the circuits final grade before and after the changes were evaluated using SPSS 12.0.1 for Windows. Due to the small sample size (approximately 400 students) and the abnormal distribution of the data, non-parametric tests were used to identify significant differences. Mann-Whitney U and Kruskal-Wallis H comparison tests were used for the analysis. With respect to the evaluation results, a significance of 5% may indicate that some change in the course had a significant negative or positive influence on student performance.

RESULTS

Initially, the descriptive statistics will be presented for all of the student groups. Then, the comparative statistics will be presented to determine if there is any difference between the groups.

I. Statistics (Comparison group)

Overall, there were 324 different student records evaluated for the Fall 2000 through Spring 2003 sessions. However, the number of records included 28 students who withdrew from the course without receiving a grade. Also, there were 42 students who appeared in more than one semester after not successfully completing the course on the first attempt. There were actually 4 students who took the course 3 or more times. There were 117 female and 207 male records included in the analysis. The allowable letter grades for the course were A, B, C, D, F, with quality points of 4, 3, 2, 1, 0, respectively. The mean grade point average for males and females were 2.04 and 2.11, respectively. The overall grade point average for all students was 2.06. The results indicated that although females typically performed better in the course than males, it was not significant at the 5% level.

Table I presents the grade distribution based upon race. The results indicate that Hispanic and Caucasian students appeared to perform better in the course and that this performance was significant at the 5% level. However, with such a small sampling this result may indicate an outlier.

TABLE I
COMPARISON COURSE GRADE POINT BASED UPON RACE

Race	Asian	African American	Hispanic	White
Number of students	6	293	2	23
Mean Grade Point	2.17	1.99	4.00	2.76

The classifications of the students taking the course included sophomores, juniors, seniors, and graduate students. The results indicate that the majority of the students taking the course were juniors. It should be noted that the course appears in the sophomore year of the curriculum, however, students who did not meet the math and science pre-requisites were delayed in taking the course by at least one semester. The results indicate that graduate students performed the best in the course; however it was not significant at the 5% level.

The mean grade point average was also evaluated based upon student major. The majors included architectural (AE) civil (CE), electrical (EE), mechanical (ME), computer and information systems engineering (CISE) (masters degree program) and other. The results indicated that majority of the students taking the course were enrolled in electrical engineering. The CISE students performed the best in the course; however it was not significant at the 5% level. Table II illustrates the student grade point based upon major.

TABLE II
COMPARISON COURSE GRADE POINT BASED UPON MAJOR

Major	AE	CE	EE	ME	CISE	OTHER
Number of students	61	23	157	73	3	7
Mean grade point	1.83	2.05	2.12	2.03	4.00	2.67

With respect to the number of times the course was attempted, the results show that the majority of the students pass the course on the first attempt (215 out of 296). Of the remaining 81 students, 1 took the course 4 times and 1 took the course 5 times without success. The attrition rate for this course was determined by finding all students who withdrew or received a non-passing grade (D, F) divided by the total enrollment. The overall attrition rate was found to be 33% for the course.

The pre-requisite course grades were also evaluated to determine if they were an indicator of student performance in the circuits course. The mean grade point for all students who completed these courses was 3.12, 2.91, and 3.00 for Calculus IV, Physics II and programming, respectively. At a level of 5%, there does appear to be a positive correlation between prerequisite grade in all three courses and the final circuits grade.

In summary, the comparison circuits course was pre-dominantly male and African American. Females and non-African American students performed the best in the course. There were more electrical engineering majors and after graduate students they performed the best. Most students reached their junior year before their first attempt at completing the course. On average the students took 1.35 attempts to successfully complete the course. The analysis also demonstrated that overall one-third of the students did not successfully complete the course on the first attempt. The mean course grade for all students evaluated was 2.06. Finally, student performance in pre-requisites was shown to have a significant effect on the circuits course performance.

II. Statistics (Fall 2003 – Spring 2004)

There were 58 student records evaluated during the Fall 2003 and Spring 2004 semesters. This set of records included 23 females and 35 males. In this data set, there was one Hispanic male student who took the course both semesters. The mean final grade point in the circuits course for the males and females in the course was 2.17. These results indicate that both genders performed about the same in the course and therefore there was no statistical difference. Once again, the results indicated that Caucasian students performed the best in the course, although there was a small sample size. The results of this analysis are given in Table III.

TABLE III
COLLABORATIVE COURSE GRADE POINT BASED UPON RACE

Race	African American	Hispanic	White
Number of students	51	2	6
Mean Grade Point	2.16	1.50	2.50

Table IV shows the mean final grade point based upon the student major. The results indicate that civil engineering students performed the best followed by electrical engineering majors. The difference in final grades was found to be significant at the 5% level. The attrition rate for the collaborative learning course was calculated by summing the number of withdrawals and non-passing grades divided by the total enrollment. The percent attrition was found to be 26%.

TABLE IV
COLLABORATIVE COURSE GRADE POINT BASED UPON MAJOR

Major	AE	CE	EE	ME	CISE	OTHER
Number of students	3	9	29	14	3	1
Mean grade point	2.00	2.44	2.38	1.86	1.00	2.00

III. Statistics (Fall 2004 – Spring 2005)

There were thirteen cooperative learning teams formed during the Fall 2004 and Spring 2005 semesters. These formations were based upon student preference, learning styles, prerequisite grades, major, race, and gender. The teams were originally designed to have 3 to 4 members per team, however due to student attrition there were some teams of two. The learning style for each student was denoted by a four-letter sequence. The first letter indicated whether the student was an Active (A) or Reflective (R) learner. The second letter indicated whether the student was a Sensing (S) or Intuitive (I) Learner. The third letter combination indicated whether the student was a Visual (I) or Verbal (R) learner. Finally, the fourth letter indicated whether the student was a Sequential (S) or Global (G) learner. All students were given a four-letter learning style even if there was only a slight preference for one style versus another. In order to evenly distribute prerequisite skills, the teams were also formed by evaluating their grades in the prerequisite course. It should be noted that for the masters' degree or transfer students, the prerequisite grades may not have been available.

The cooperative learning courses included 32 males and 21 females with a mean grade point of 2.8. Thus, there was no statistical difference between the grades for the males and females in the course. The percent attrition based upon the aforementioned criteria was 17%. It should be noted that the student records included one African American male student who took the course in both semesters.

Table V presents the grade distribution for the cooperative learning circuits course based upon race. These results indicate that Caucasian students performed the best in the course and this difference was significant at the 5% level (p =

.029). Table VI presents the grade distribution for the cooperative learning course based upon major. These results indicate that electrical engineering majors appeared to perform the best in the course. The difference in the course grade based upon major was not significant at the 5% level.

TABLE V
COOPERATIVE COURSE GRADE POINT BASED UPON RACE

Race	African American	White
Number of students	41	5
Mean grade point	2.70	3.60

TABLE VI
COOPERATIVE COURSE GRADE POINT BASED UPON MAJOR

Major	AE	CE	EE	ME	CISE	OTHER
Number of students	11	7	45	5	1	1
Mean grade point	2.45	2.57	3.14	2.80	2.00	2.00

III. Comparisons

In order to determine if the comparison and experimental students were academically comparable, the SAT verbal and math and ACT math and science reasoning scores were evaluated. It should be noted that all of these scores were not available for all students. Table VII illustrates the scores tabulated for the student records. The fourth column contains the p-value for the comparison and experimental groups. The boldface type denotes a 5% level of significance. The results indicate that there is a significant difference in the ACT-math scores between the groups and it is actually higher for the comparison group.

TABLE VII
STUDENT SAT AND ACT SCORES

	comparison	collaborative	cooperative	p
ACT-MATH	22.1 (n=234)	21.2 (n=42)	20.6 (n=30)	**.047**
ACT-SCRS	21.0 (n=234)	21.4 (n=42)	20.1 N=29)	.515
SAT-VERB	470.1 (n=108)	488.7 (n=15)	480.6 (n=18)	.822
SAT-MATH	506.1 (n=108)	497.3 (n=15)	526.1 (n=18)	.542

The collaborative and cooperative courses were compared to the comparison course to determine if the active learning activities actually improved student performance. The primary data that was compared was student academic performance based upon gender, race, and major. The data was evaluated in SPSS and a level of significance of 5% is shown in boldface type on the data table. Table VIII shows that male and female students had an improved final course grade. Table IX illustrates the only significant improvement in the final course grade was for African American students. This may be attributed to the course modifications as well as the fact that all the courses were predominantly African American. Table X indicates that the only improved course performance was for the electrical engineering majors. This may also be attributed to the course modifications as well as the fact that electrical engineering majors compose the majority of the student records.

TABLE VIII
STUDENT GENDER COMPARISON

	comparison	collaborative	cooperative	p
Male	2.04 (n=192)	2.17 (n=35)	2.80 (n=26)	**.004**
Female	2.11 (n=104)	2.17 (n=23)	2.80 (n=20)	**.009**
Overall	2.06 (n=296)	2.17 (n=58)	2.80 (n=46)	**.000**

TABLE IX
STUDENT RACE COMPARISON

	comparison	collaborative	cooperative	p
African American	1.99 (n=267)	2.16 (n=50)	2.70 (n=41)	**.000**
White	2.76 (n=21)	2.50 (n=6)	3.60 (n=5)	.157
Hispanic	4.00 (n=3)	1.50 (n=2)	*	.076
Asian	2.17 (n=5)	*	*	*

* no data available

TABLE X
STUDENT MAJOR COMPARISON

	comparison	collaborative	cooperative	p
AE	1.83 (n=59)	2.00 (n=3)	2.45 (n=11)	.086
CE	2.05 (n=20)	2.44 (n=9)	2.57 (n=7)	.521
EE	2.12 (n=144)	2.38 (n=29)	3.14 (n=21)	**.000**
ME	2.03 (n=65)	1.86 (n=14)	2.80 (n=5)	.202
CISE	4.00 (n=2)	1.00 (n=1)	2.00 (n=1)	.223
OTHER	2.67 (n=6)	2.00 (n=1)	2.00 (n=1)	.317

CONCLUSIONS

This paper has presented the re-design and comparative study of an introductory circuits course based upon student demographics. This study has been an analysis of the quantitative data extracted from the course over a 4 year period. The comparison group for the study included student statistics over a three year period. During this period, the course format was primarily a lecture format with individual or competitive grading. In Fall 2003 and Spring 2004, active learning activities were introduced into the course format. In Fall 2004, cooperative learning activities were introduced into the course format. The statistical analysis indicated that at the 5% level, there was a significant improvement in the students' overall mean grade between the cooperative learning course and the control course. There was also a significant difference between the collaborative course and the cooperative course. An improvement in course performance based upon gender as well as for African American students and electrical engineering majors was also significant at the 5% level. All other changes based upon demographics indicated an improvement but were not significant. Although student success in the course was improved based upon attrition, it is still relatively high at 17%.

Future work in the modification of this course would include qualitative as well as quantitative assessments of student success in the course. The qualitative assessments may include a survey of students' attitudes toward engineering before and after the completion of the course. Another quantitative assessment would be a key concept inventory taken before and after the course. The students already complete university and department faculty evaluations and student course outcome assessment surveys and these could also be compared for the different formats of the course. Some other possible sources of information would be to track all students completing the circuits course to graduation to determine the rate and persistence based upon the different course formats and student performance.

The results indicate that there is still work to be done in improving student attrition and success in the DC circuit analysis course; however the introduction of active learning activities did appear to improve student success. For faculty interested in implementing active learning techniques in their course, it is hoped that these results may serve as a justification to make the efforts to do so. The author's website provides additional publications and information that may be helpful in this implementation (http://www.tnstate.edu/cberry). Finally, this work has shown that underrepresented minorities in science and engineering (African Americans and females) did demonstrate some improvement in performance based upon course changes. The final step would be to explore the success of these students in attaining the degree.

REFERENCES

[1] Besterfield-Sacre, M., Atman, C.J., and Shuman, L.J., "Characteristics of Freshman Engineering Students: Models for Determining Student Attrition in Engineering", *Journal of Engineering Education,* Vol. 86, No. 2, April 1997, pp. 139-149.

[2] Bonsangue, M. "An efficacy study of the calculus workshop model," *CBMS Issues in Collegiate Mathematics Education*, Vol. 4, American Mathematical Society, Providence, RI, 1994, pp. 117-137.

[3] Treisman, U., "Studying Students Studying Calculus: A Look at the lives of minority mathematics students in college", *The College Mathematics JournalI,* Vol. 23, No. 5, pp. 362-372.

[4] Smith, K.A., Sheppard, S.D., Johnson, D.W., and Johnson, R.T., "Pedagogies of Engagement: Classroom-based Practices", *Journal of Engineering Education,* Vol. 94, No. 1, January 2005, pp. 87 – 101.

[5] Prince, M., "Does Active Learning Work? A Review of the Research", *Journal of Engineering Education,* Vol. 93, No. 3, July 2004, pp. 1 – 9.

[6] Terenzini, P.T., Cabrera, A.F., Colbeck C.L., Parente, J.M., and Bjorklund, S.A., "Collaborative Learning vs. Lecture/Discussion: Students' reported learning gains", *Journal of Engineering Education,* Vol. 90, No.1, pp. 123-130.

[7] Felder, R.M., Felder, G.N., and Dietz, E.J., "A longitudinal study of engineering student performance and retention. V. Comparisons with traditionally-taught students", *Journal of Engineering Education,* Vol. 98, No. 4, October 1998, pp. 469-480.

[8] Soloman, B.A., and Felder, R.M., "Index of Learning Styles Questionnaire", http://www.engr.ncsu.edu/learningstyles/ilsweb.html, accessed on 3/8/2005.

[9] Brickell, J.L., Porter, D.B., Reynolds, M.F., and Cosgrove, R.D., "Assigning students to groups for engineering design projects: A comparison of five methods", *Journal of Engineering Education,* Vol. 83, No. 3, July 1994, pp. 259 - 262.

[10] Trytten, D.A., "Progressing from Small Group Work to Cooperative Learning: A case study from Computer Science", *Journal of Engineering Education,* Vol. 90, No. 1, January 2001, pp. 85 – 91.

[11] Crouch,C.H., and Mazur, E., "Peer Instruction: Ten years of experience and results", *American Journal of Physics*¸ Vol. 69, No. 9, September 2001, pp. 970-977.

[12] Mazur, E., *Peer Instruction: A User's Manual,* 2nd edition, Upper Saddle River, New Jersey: Prentice Hall, 1997.

[13] Berry, C.A.. "ENGR 2000 – Circuits I course website", http://www.tnstate.edu/cberry/ENGR2000.htm, accessed on 3/8/2005.