Is There a Correlation between First Year Critical Thinking Assessment Test Performance and Retention among Civil Engineering Students?

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Abstract

A team of faculty from the Department of Civil Engineering at the University of Texas at Arlington received funding in 2010 to support a project entitled "Civil Engineering and Life Decisions: Choose Wisely." The aim of the project is to improve the decision making capabilities of students with emphasis on critical thinking and alternative analysis. This is being accomplished through the development and implementation of targeted modules for required courses in the first year through the senior year. Gains in critical thinking capabilities are measured using the Critical Thinking Assessment Test (CAT), which students complete at the beginning and end of their undergraduate programs. This paper focuses on the first semester assessment results as they pertain to retention in civil engineering.

By requiring faculty to grade the exams, the CAT gives them first-hand knowledge of students' strengths and weaknesses related to critical thinking, allowing them to make instructional modifications that should ultimately result in improved student learning. While previous studies have used the CAT to determine learning gains in specific science courses, this study seeks to show the correlation between first semester CAT performance and the likelihood that a student is retained in civil engineering. Further, researchers have shown the importance of advanced critical thinking skills in undergraduate education and in the workforce. They have also demonstrated the shortcomings of many programs – including engineering programs – in cultivating those capabilities in undergraduate students. However, studies directly correlating undergraduate engineering student retention and critical thinking assessment performance are not readily available.

This study uses first semester CAT scores, along with other parameters that are demonstrated indicators of student retention (e.g. SAT Math scores and grade point averages) to perform various statistical analyses that show the relationship between early CAT performance and retention, and the correlation between CAT scores and the aforementioned parameters. The results may be used to further substantiate the need for increased higher order thinking in engineering curricula, focusing on the need to improve critical thinking capabilities in first year engineering students.

Introduction

For decades, the engineering education community has researched factors contributing to the retention and attrition of engineering majors. Studies have consistently shown that a large fraction of students leave undergraduate engineering programs before the second year of

enrollment. Several factors have proven to be strong predictors of engineering student retention and success; some are pre-college attributes or measures, while others are observed during the first year of enrollment in an engineering program. Key pre-college indicators are related to quantitative ability, namely mathematics aptitude measured using ACT and/or SAT Math scores and not only enrolling in, but also performing well in advanced science (i.e. physics) and mathematics (i.e. calculus) courses in high school.[1-3] Additionally self-efficacy, determined from student survey responses to questions designed to gauge their confidence in their quantitative abilities, parental educational attainment and geographic location (i.e. urban versus rural home) have been found to impact engineering student persistence and achievement.[4,5] One of the primary first year indicators is grade point average (GPA), which is indicative of students' quantitative and analytical capabilities, as first year engineering curricula are dominated by mathematics, science and fundamental engineering courses that require these skills.[2,3,4,6] While social and academic integration have also been linked to improved engineering student retention,[7,8] those factors are not included in this paper.

The importance of critical thinking skills in undergraduate education and in the engineering workforce is well-documented, as are the shortcomings of many programs – including engineering programs – in cultivating those capabilities in undergraduate students.[9-15] Engineering design and decision making require higher order thinking capabilities than those typically gained or utilized in many science and engineering courses. Most of these courses plateau at the "application" level of Bloom's Taxonomy, with "plug and chug" equations and problems with a single "right" answer. Engineering design problems and decisions, on the other hand, are typically open-ended and have many possible solutions and many approaches to arriving at them.

Researchers at Tennessee Technological University (TTU) developed the Critical Thinking Assessment Test (CAT) as a tool for measuring students' critical thinking capabilities. By requiring faculty to grade the exams, the CAT gives them first-hand knowledge of students' strengths and weaknesses related to critical thinking, allowing them to make instructional modifications that should ultimately result in improved student learning. Previous studies have used the CAT to determine learning gains in specific science courses;[16,17] however, studies directly correlating undergraduate engineering student retention and critical thinking assessment performance are not readily available. This study seeks to show the relationship between first semester CAT performance and the likelihood that a student is retained in civil engineering. Additionally, the strength of correlation between CAT scores and both grade point averages (GPAs) and SAT Math scores will be discussed.

Significance of the Retention Problem

The demand for American scientists and engineers makes the understanding of causes of attrition and the development of strategies for improving retention important to the engineering community as a whole – including educators and practitioners. In order to improve its global

competitiveness, the United States must grow its science, technology, engineering and mathematics (STEM) workforce. Although the engineering sector has grown in past years, in 2012, engineers comprised only 1.2% of the U. S. workforce.[18] The U. S. Department of Labor forecasts growth in workforce needs among all of the major engineering disciplines (chemical, civil, electrical, industrial and mechanical); however, the projected demand for civil engineers is far greater compared to the other disciplines (Table 1).[19] This is largely due to the need for civil engineers to address issues related to the country's aging infrastructure and to the design and development of new infrastructure needed to support growing populations in many metropolitan areas and population sprawl in other areas.

Based on 2010 data, civil engineers held 262,800 jobs in the U.S. and the outlook is for 19% growth (an additional 51,100 jobs) from 2010 to 2020. It is important to note that this excludes jobs in environmental engineering, which is a major subdiscipline of civil engineering. For environmental engineers, the projected demand is even higher. In 2010, environmental engineers held 51,400 jobs, and the outlook is for 22% growth, which is faster than the average 14% expected for all other occupations, not just engineering.[19] Growth in the engineering workforce can only be achieved by successfully attracting talented students to engineering majors, retaining them and providing them with a relevant education that meets industry needs and expectations.

Table 1. Employment Data for Engineering Disciplines[19]

Engineering Discipline	Number of Jobs (2010)	Job Outlook (2010-2020)	Change in Employment (2010-2020)
Chemical	30,200	6%	1,800
Civil[a]	262,800	19%	51,100
Electrical[b]	294,000	9%	17,600
Industrial	203,900	6%	13,100
Mechanical	243,200	9%	21,300

[a] Excludes environmental engineering, [b] Includes electronics engineering

Background

Civil Engineering and Life Decisions: Choose Wisely

The Southern Association of Colleges and Schools (SACS) requires institutions to develop a Quality Enhancement Plan (QEP) as a part of its reaffirmation process. The QEP, according to SACS, is a "… carefully designed and focused course of action that addresses a well-defined topic or issue(s) related to enhancing student learning."[20,21] The university implemented its QEP, entitled "Active Learning: Pathways to Higher Order Thinking at UT Arlington" beginning in 2007 with the aim to "… improve students' capacity for top quality critical thinking: application, analysis, synthesis and evaluation."[22]

A team of faculty from the Department of Civil Engineering at the University of Texas at Arlington (UT Arlington) received support in 2010 from QEP funds to implement a project entitled "Civil Engineering and Life Decisions: Choose Wisely". The aim of the project is to improve the decision making capabilities of students with emphasis on critical thinking and alternative analysis. This is being accomplished through the development and implementation of targeted modules for required courses in the first year through the senior year. Gains in critical thinking capabilities are measured using the Critical Thinking Assessment Test (CAT), which students complete at the beginning and end of their undergraduate programs in CE 1105, Introduction to Civil Engineering, and CE 4383, Senior Project, respectively. This paper focuses on the first semester assessment results as they pertain to retention in civil engineering.

Institutional Landscape

UT Arlington is a Research University/High Research Activity institution with a current population of 33,311 students (25,678 undergraduates) based on Fall 2013 data.[23] Roughly 96% of first-time undergraduates are in-state students and about 20% of those students are enrolled in engineering.[24] All incoming freshman and transfer students who have completed fewer than 24 hours of coursework are advised in University College (UCOL), where they declare an intended major and pursue foundational coursework toward that major. When students transition from UCOL to the major departments, they are designated as XX_INT, where XX indicates the major, (e.g. CE_INT for civil engineering majors) until they satisfy requirements for admission to the Professional Program, where they complete upper division coursework.

During the first year of enrollment, students complete two introductory engineering courses – CE 1104, Introduction to Engineering, and CE 1105, Introduction to Civil Engineering. CE 1104 is cross-listed among all of the engineering disciplines (e.g. electrical engineering students enroll in EE 1104); students are given a multi-disciplinary introduction to the engineering profession and are required to complete a multidisciplinary design project during the semester. Each program offers its own version of 1105, which is a discipline-specific introduction to engineering.

Data Collection and Analysis

Students in CE 1105, Introduction to Civil Engineering, took the CAT at the beginning of each semester during which the QEP module was implemented. The CAT is a one hour exam consisting of fifteen questions that require short, essay-style responses. The questions are designed to assess student capabilities related to the top five levels of Bloom's Taxonomy – understanding, application, analysis, synthesis and evaluation.[6,25] This is accomplished through questions targeting specific skills such as the ability to:

> Separate factual information from inferences that might be used to interpret those facts, identify appropriate conclusions, understand the limitations of correlational data, identify evidence that might

> support or contradict a hypothesis, identify new information that is needed to draw conclusions...[6,25]

The exams were scored by at least two faculty (three if there was disagreement between the two scorers), and each question had a different scoring rubric. The total number of points possible was 38.

This study uses results for students in CE 1105 during the Fall 2010 or Spring 2011 semesters. The remaining data was obtained from UT Arlington Academic Analytics and Operations. This included SAT Math score, cumulative grade point average and semester-by-semester data for major to determine retention in civil engineering.

Results and Discussion

Sample Analysis

A total of 160 students were enrolled in CE 1105, Introduction to Civil Engineering, during Fall 2010 and Spring 2011. Because the QEP is a campus-wide initiative, multiple disciplines across the campus administered the CAT on multiple occasions. Exams are graded manually, after which they are shipped to TTU for validation. Due to delays in processing the large number of exams, not all of the CAT scores are available at the time of this writing. Our analysis was limited to the number of students for which we have graded CATs with validated scores, which was 33. (The remaining graded exams have been sent to TTU for validation; however, the scores are not available for inclusion in this analysis). Because of the small sample size, we have been careful in interpreting the results obtained and we have not looked at demographic differences among the students.

The first semester of each student's enrollment at UT Arlington was compared to the semester in which he/she was enrolled in CE 1105 to gauge the number of students who took the course during their first year of enrollment. This comparison showed that 81% (130/160) were enrolled in CE 1105 during their first year of enrollment at UT Arlington. For those students who first enrolled at the university in an earlier semester, it was assumed that they were in their first year of the civil engineering program. For example, a student may have enrolled as a non-CE major during a semester prior to Fall 2010 or Spring 2011, but later changed majors to CE, and thus were first year CE students when they enrolled in CE 1105, though not first year university students. This raised questions about whether or not there would be differences in the CAT scores among the two student designations. We computed an F statistic to compare the variances of the two groups (students enrolled in CE 1105 during the first year of university enrollment and students who were enrolled in the university previously), which yielded $F=1.28$ ($n_1=18$, $n_2=15$, $\alpha=0.05$); thus we failed to reject the null hypothesis, which was that the variances of the two groups were equal. We then computed a t-statistic to compare the means, which yielded $t=1.45$, and again, we failed to reject the null hypothesis (that the two means were equal) at the $\alpha=0.05$ significance level. These findings supported our decision to evaluate the two groups together.

A histogram showing the frequency distribution of the CAT scores revealed skewness. In order to ensure that the distribution of the data was normal or nearly normal despite the skewness, thus validating our use of parametric statistics, we used equation (1) to calculate Pearson's second coefficient of skewness:

$$sk_2 = \frac{3(mean-median)}{standard\ deviation} \qquad (1)$$

For a sample size n=30, the critical region for sk_2 is $-0.643 < sk_2 < 0.643$.[26] Our calculations yielded the value $sk_2 = -0.135$, which is not indicative of a non-normal distribution.

CAT Scores and Retention

The maximum possible CAT score was 38. Students' scores ranged from 4 to 27, with a mean of 16.72 and a standard deviation of 6.17. While assessing the CAT instrument, Stein et al administered one version of the exam to 100 STEM and non-STEM upper division students at six universities students and obtained a mean score of 21.02 out of 40 possible points with a standard deviation of 6.19.[4,25] We used this as our basis for comparing performance, and because of the difference in maximum scores, converted the means to percentages, giving a mean of 44% (16.72/38) for our sample and 53% (21.02/40) for the reference group.

Table 2 summarizes the probabilities calculated for students retained in civil engineering through the first and second years based on at or above average CAT performance. Year one and year two retention were measured using the semester of CE 1105 enrollment as a baseline, based on the assumption that the students were first year CE students as discussed previously. At or above average performance was determined by comparing our students' scores to the reference scores, which averaged 53%. Students who earned a score of 53% or greater and who were retained through the first year had a nearly 50% higher probability of being retained through year one and roughly 60% higher probability of being retained through year two than students who scored below 53% on the exam.

Table 2. Retention Probabilities Based on CAT Performance

Parameter	N	RY1	p(RY1)	RY2	p(RY2)
CAT Scores ≥ 53%	10	9	0.90	7	0.70
CAT Scores <53	23	14	0.61	10	0.44

N = number of students (total population = 33)
RY1 = number of students retained through year one
p(RY1) = probability of a student being retained through year one
RY2 = number of students retained through year two
p(RY2) = probability of a student being retained through year two

The following hypothesis test was conducted for both one year and two year retention and using a one-tailed test at the $\alpha = 0.05$ significance level:

- H_0: At or above average CAT performance does not improve retention
- H_1: At or above average CAT performance improves retention

The resulting z statistics indicated that for first year retention, we should reject the null hypothesis (z=1.67) and for second year retention, we should fail to reject the null hypothesis (z=1.40).

Correlation of CAT Scores with SAT Math Scores and Grade Point Averages

Pearson's correlation coefficient was calculated to determine the degree (or lack) of correlation of CAT scores with grade point averages and SAT Math scores. For this analysis, we used the first semester grade point averages, which we took to be the semester in which they enrolled in CE 1105. As shown in Table 3, CAT scores and GPAs for students who were retained through year one (RY1) showed a weak positive correlation, while those for students who were not retained through year one NRY1) showed a weak negative correlation. Likewise, CAT scores and GPAs for students who were not retained through year two (NRY2) showed a weak negative correlation. In contrast, the two variables showed a strong correlation for students who were retained through year two (RY2).

Table 3. Correlation of CAT Scores and Grade Point Averages

Population	r
Students retained through year one (RY1)	0.33
Students not retained through year one (NRY1)	-0.25
Students retained through year two (RY2)	0.71
Students not retained through year 2 (NRY2)	-0.19

Similarly, CAT scores were compared to SAT Math scores (Table 4). Not all students in the data set had SAT scores; students lacking SAT scores were excluded from this analysis. The n values are provided for clarity (a total of 13 of the students had both SAT scores and graded, validated CAT scores). Though we are careful of the conclusions drawn here due to sample size, it appears that the CAT scores and SAT Math scores, in most cases, have a stronger correlation than CAT scores and GPAs. In all cases, except one, the correlation was moderate. The exception is in the case of students who were not retained through year two; the correlation is a weak one. As expected, the correlation between the parameters for students who were not retained was negative, while the correlation was positive for those who were retained.

Table 4. Correlation of CAT Scores and SAT Math Scores

Population	r	n
Students retained through year one (RY1)	0.58	9
Students not retained through year one (NRY1)	-0.44	4
Students retained through year two (RY2)	0.46	8
Students not retained through year two (NRY2)	-0.22	5

It should be noted that while most of our students generally take the SAT, our dataset included scores for only 88/160 students enrolled in CE 1105 during the two semesters. This is because a large number of students are enrolled as transfer students, and their transfer records do not usually contain the standardized test scores.

Conclusion

Mean CAT scores of CE 1105, Introduction to Civil Engineering, students were lower than those of the reference group. One key factor contributing to this was the difference in populations; the reference group was comprised of upper division students while the CE 1105 course was comprised primarily of first year students. It was expected that upper division students would have stronger critical thinking capabilities than first year students. We are presently conducting a study to compare gains in critical thinking among our students using paired tests of first year CAT performance versus final year CAT performance. The final year data will give an additional basis of comparison to the reference group.

We offer the following observations based on our data:

- Students who scored at or above the average reference score on the CAT had higher probabilities of being retained in civil engineering than students who scored lower than this threshold. This result was significant at the 95% confidence level for students retained through year one; however, even though the probability was higher for students retained through year two, the results were not significant.
- The observed correlation between CAT scores and grade point averages for students who were retained in civil engineering through year two was a strong, positive one. Correlations between CAT scores and GPAs for all other students were weak (positive for students who were retained in civil engineering, negative for those who were not).
- The observed correlations between CAT scores and SAT Math scores were moderate (positive for students who were retained in civil engineering, negative for those who were not), with the exception of the case of students who were not retained through year two (which yielded low, negative correlation).

Due to the limited sample sizes involved, we are careful about attempting to draw broad conclusions from our analyses. However, this work does point to a positive relationship between first year CAT scores and retention among our civil engineering students. Additionally, it lays the groundwork for future studies, the results of which would be of interest to the broader engineering (not just civil engineering) community. Specifically, it may help to substantiate the need for strong emphasis on cultivating critical thinking skills early in engineering curricula. Future studies will include a larger sample size that should allow us to draw stronger

conclusions, to compare freshmen to transfer students and to analyze differences among demographic groups.

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