An Analysis of Two Interventions Designed to Improve Student Performance in Engineering Calculus

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Abstract

At the University of Louisville, a large, urban, institution in the southeast, undergraduate engineering students take their mathematics courses from the school of engineering. For freshman who struggle in their first engineering calculus course a long standing intervention has been to transfer these students to a remedial *Introduction to Calculus* course early in the semester, preventing them from likely failing math in the fall term of their freshman year. In an effort to reduce the number of students who transfer to *Introduction to Calculus*, the department collaborated with university academic support services to create a summer intervention program designed to strengthen students' algebra skills. Students were targeted for the summer program based on their score on an algebra readiness exam (ARE) developed by the department faculty. An analysis of the predictive validity of the ARE and the efficacy of the summer algebra intervention are reported in this paper. ARE scores were a significant predictor of retention and performance in the first engineering calculus course. Students with higher ARE scores were more likely to remain in the course and performed better on exams and quizzes than students with lower scores. Students who participated in the summer algebra intervention program demonstrated improvement in algebra skill prior to beginning their fall coursework and were more likely to remain in the engineering calculus course. Although there was some evidence that participation in the summer program led to improved performance in the engineering calculus course, further research is necessary to determine whether benefits associated with the summer program were due to higher motivation in the participants or due to the structure of the program itself.

Introduction

Within the J.B. School of Engineering, the Engineering Fundamentals Department is responsible for teaching all of the undergraduate engineering mathematics courses and a high priority is placed on a sequence of calculus-based courses: *Engineering Analysis I, II, and III*. This sequence of courses is uniformly taught using a rigorously developed set of learning objectives for each course.

Increasing retention of freshman engineering students has been a major focus of the Engineering Fundamentals Department since it was founded in 2007. An on-going retention study is seeking to learn more about the characteristics of entering students, to identify obstacles to their retention, and to devise interventions to improve retention. This analysis is an integral part of the department's overall retention effort.

Background and Purpose

It is well documented that retention of engineering students is related to their first fall semester GPA and that performance in a first mathematics course has a large impact on the first fall GPA[1]. Furthermore, entry-level calculus continues to be a challenge for many engineering students [2-5]. Nearly 30 years ago, Edge and Friedberg[6] reported that an algebra pretest and high school rank were the best combination of predictors of success in a first calculus course. This research coincides with the long held belief of the faculty in the Department of Engineering Fundamentals that weak algebra skills are a stumbling block for students entering the program. So strong has been this conviction, that in the first two weeks of *Engineering Analysis I* algebra concepts and functions are reviewed rather than beginning immediately with calculus concepts.

One remedy for entering freshman who struggle with *Engineering Analysis I* has been the offering of a remedial calculus course called *Introduction to Calculus*. Freshman performing poorly on the first two exams in *Engineering Analysis I* have been encouraged to transfer to *Introduction to Calculus*. This approach has allowed students to maintain a high GPA while strengthening fundamental math skills. *Introduction to calculus* is designed to review algebra, trigonometry, functions, and basic calculus concepts at a slower pace, and offering the course has prevented many D, F, and W grades in *Engineering Analysis I*. Historical data shows that the 6 year graduation rate for students who took *Engineering Analysis I* was slightly over 60%, whereas the 6 year graduation rate for those who had to take *Introduction to Calculus* was about half of that; *Introduction to Calculus* is an intervention, but many of those students still end up transferring out of the engineering college. Consequently, the department is interested in developing interventions prior to or concurrent with *Engineering Analysis I*. One approach, added within the last five years, is a summer algebra intervention program.

To determine which students to target for the summer intervention program, an algebra readiness exam (ARE) was developed by faculty and offered to incoming students during orientation. The ARE was intended to identify students in need of algebra review prior to starting *Engineering Analysis I*, and the summer program was intended to provide the needed review. Students who scored below 80 percent on the ARE were encouraged to participate in the algebra intervention program, though neither the ARE nor participation in the program were required. In the program's first two years, the number of students taking the ARE and participating in the program was low. However, there was some indication that the program was having a positive impact for those who participated. To encourage more students to take advantage of the program, in 2011, the ARE became a requirement for *Engineering Analysis I,* counting 5 percent of the final grade.

This paper describes initial steps taken by the department to empirically validate the use of the ARE as an assessment tool and to determine the efficacy of the summer algebra intervention program. The analysis focused on three main questions. First, how well did the ARE predict performance in the engineering calculus course? Second, did participation in the summer algebra intervention program improve participants' algebra skills? Third, if algebra skill improved, did this lead to improved performance in the engineering calculus course? After presentation of results, plans for the continued development of the program and improvements to our classroom research methodology are discussed.

Materials and Program Descriptions

Pre- and Post-Intervention Algebra Assessment Tools

Faculty from the Department of Engineering Fundamentals created the ARE based on years of experience with the errors that students frequently make in the first two weeks of *Engineering Analysis I*. Topics covered include basic algebra skills such as determining the equation of a straight line given point-slope information, solving two equations with two unknowns, solving simple and compound inequalities including ones with variables in the denominator, complex arithmetic, simplification of expressions, including finding common denominators involving complex fractions. These concepts were assessed in a 25 question multiple choice test.

The summer algebra intervention post-test (IPT) was created by the staff at a center on campus that specializes in providing academic and support services for undergraduates. They have expertise in designing remediation courses for mathematics for the entire university. The test was composed of 25 questions and delivered in MathXL®. The test consisted of 5 multiple choice responses and 20 open responses.

The ARE and the IPT were highly similar in that the same concepts were tested on 22 of the 25 questions. There were two differences across the tests. First, there were 3 questions on the IPT that covered concepts not tested on the ARE, but were part of the remediation materials and so were included for completeness. Second, the ARE and IPT differed in the types of responses expected from students. The ARE was composed entirely of multiple choice questions whereas the IPT was composed of multiple choice and open response (where students must enter the computed answer using the keyboard) questions. Faculty reviewed the IPT and ARE side-by-side and concluded that the IPT was considerably more difficult, primarily due to the fact that it required open responses.

Summer Intervention Program

The summer algebra intervention program was designed to provide a comprehensive review of college algebra. Instruction was individualized so that more of a student's time was focused on concepts missed on the ARE and items missed on exams taken while attending the program. Students were taught by an experienced algebra instructor with the assistance of a graduate engineering student and additional tutors.

The program had a $75 fee and was conducted onsite and online (in a self-guided format) for 5 weeks during the summer after orientation. For the onsite program, students received a binder of materials and sessions met four days a week, for two hours in the morning, in an onsite math computer center. A math resource center provided additional drop-in tutoring support on each of these days. For the online program, students worked independently using material provided on the Blackboard learning management system and a browser-based program, MathXL, on their computers. The onsite math computer center provided additional online tutoring support at night and on the weekend.

There were several requirements for successful completion of the program. Participants entered into a contract agreement promising that they had read the syllabus and understood that they had to:1) complete a pre assessment (ARE) and post assessment (IPT), 2) submit a signed and dated program agreement, 3) attend 80% of onsite classes or make four contacts (emails, calls or texts) with the facilitator for online classes, 4) complete a program evaluation, and 5) complete the homework assignments and tests with an 80% on both.

Engineering Analysis I

This lecture based course covered the development and use of differentiation and integration to solve engineering problems, including those involving motion, related rates, optimization, moments and centers of mass and it also includes an introduction to vector methods. In the approximately 15 week course, there were 13 homework assignments, 13 quizzes, and 13 exams concluding with a comprehensive final exam. The course was a four credit hour course that met five days a week; a portion of the class time was considered laboratory time due to the intensive problem solving done as part of the course.

Introduction to Calculus

This course reviewed algebra, trigonometry, analytic geometry, and introduced elementary calculus in preparation for *Engineering Analysis I*. The course did not begin until the third week of the semester. There were ten homework assignments, ten quizzes, and ten exams concluding with a comprehensive final exam.

Procedure

During summer orientation in June, students were advised to take the ARE to determine their preparedness for the *Engineering Analysis I* course. To provide incentive, students were also told that their score on the exam would constitute 5 percent of the course grade. On completion of the online exam, students with scores below 80 percent were given an electronic message suggesting they review intermediate and advanced algebra prior to entering *Engineering Analysis I*. At this time they were also provided information regarding the summer algebra intervention course. This information was followed up through email and with a formal letter.

Students entered the summer intervention program in early July and completed the program in 5 weeks. Upon completion of the program, students were given the IPT. At 3 weeks into *Engineering Analysis I*, students with scores below 55 percent on the first two exams were advised to move to the *Introduction to Calculus* course.

Participants

In the 2011-2012 academic year, 381 students entered the *Engineering Analysis I* course. At three weeks into the semester, 270 students chose to remain in the course, and 111 students transferred to the *Introduction to Calculus* course. There were 249 students in *Engineering Analysis I* and 84 students in *Introduction to Calculus* that met the criteria for inclusion in the data analysis (see Table 1). Students with missing ARE scores, and students who did not complete course requirements were excluded from the data analysis. Students who chose the summer algebra intervention course but did not complete it were also excluded from the analysis. Only 2 of the 48 students not meeting the requirements for inclusion had completed the summer intervention.

The number of students in in *Engineering Analysis I* and *Introduction to Calculus* who participated in the summer algebra intervention course is presented in Table 1. Prior to the beginning of the semester, 88 students (26.4%) completed the *summer algebra intervention course*, and 245 students (73.6%) chose not to participate in the course. Of the 88 students participating in the *summer algebra intervention course*, 73 (83%) remained in *Engineering Analysis I*, and 15 (17%) transferred to the *Introduction to Calculus* course. Of the 245 students choosing not to participate in the summer algebra intervention program, 176 (71.8%) remained in *Engineering Analysis I* and 69 (28.2%) transferred to the *Introduction to Calculus* course.

Results

Does performance on the ARE predict performance in Engineering Analysis I?

Linear regression analysis was used to measure the degree to which ARE scores could explain variability in exam and quiz scores in *Engineering Analysis I*. Only students who chose not to participate in the summer algebra intervention program were included in this analysis. If the summer intervention was successful, course performance was likely to be altered for students who participated. Typically, this would be handled by making participation in the summer program a factor in the analysis. However, the summer intervention group also had lower scores on the ARE than the group who did not participated, and it was decided that these two factors together would make interpretation of the results difficult. Furthermore, the ARE scores of the 176 students included in the analysis were well-distributed, ranging from 16 to 100 percent with a mean of 79.5 (SD = 15.96) and a median of 84.

Table 1. The number of students in the Fall 2011 cohort broken down by course, participation in the summer algebra intervention, and inclusion/exclusion in the data analysis.

Group	Engineering Analysis I	Introduction to Calculus	*Row Total*
Completed SI	73	15	88
Did not choose SI	176	69	245
Subtotal	*249*	*84*	*333*
Incomplete SI	1	6	7
Missing ARE	2	8	10
Course Incomplete	18	13	31
Subtotal	*21*	*27*	*48*
Total	*270*	*111*	*381*

SI = summer algebra intervention, ARE = algebra readiness exam

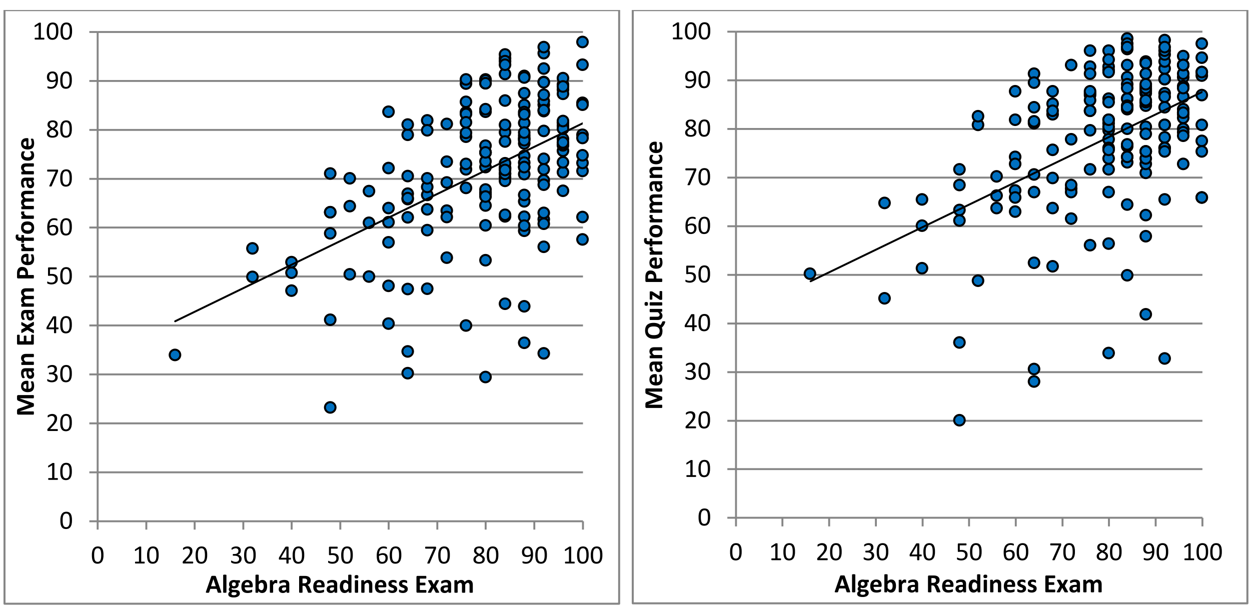

Figure 1. Mean exam performance (left) and mean quiz performance (right) as a function of algebra readiness exam scores for students in *Engineering Analysis I* who did not participate in the summer algebra intervention program. A regression line is presented in black. Filled circles represent individual student data.

Algebra readiness scores were significant predictors of performance in *Engineering Analysis I*. Students with higher ARE scores also performed better on exams and quizzes in the course (see Figure 1). In a linear regression analysis, ARE scores significantly predicted 26.2%

of the variance in mean exam performance, F(1, 175) = 61.64, p < .001, and 24.2 percent of the variance in mean quiz performance, F(1, 175) = 55.46, p < .001.

Do ARE scores and/or participation in the summer intervention program predict which students will remain in Engineering Analysis I and which students will transfer to Introduction to Calculus?

A logistic regression was performed to predict student continuance in *Engineering Analysis I* based on ARE scores and participation in the summer intervention program. The full model reliably distinguished between students remaining in *Engineering Analysis I* and those students moving to the *Introduction to Calculus*, predicting 77.5 percent of the outcome correctly, $\chi^2(2, N = 333) = 46.03, p < .001$. Individually, ARE and participation in the summer intervention program were both significant predictors of continuation in *Engineering Analysis I* (ARE, Wald statistic = 36.32, df = 1, p < .001, OR = 1.05; SI, Wald statistic = 11.03, df = 1, p = .001, OR = 3.20). As ARE scores increased, students were more likely to remain in *Engineering Analysis I*. Students who participated in the summer intervention program were also more likely to remain in *Engineering Analysis I*.

Does participation in the summer algebra intervention program improve performance in Engineering Analysis I?

In *Engineering Analysis I*, students who chose to participate in the summer algebra program performed 12 percentage points lower on the ARE that those who did not participate in the program (SI M = 58.9, NI M = 71.0; t(247) = 5.647, p < .001). After completing the summer program, student scores on the intervention post-test were 27 points higher than their pre-intervention scores on the ARE (ARE M = 58.9, RPT M = 86.3; t(72) = 13.458, p < .001; r = .13, p = .288). At the end of the semester, no significant differences in performance were found between the summer intervention group and the no intervention group on mean exam performance (SI M = 67.5, NI M = 71.5; t(247) = 1.906, p = .058) or mean quiz performance (SI M = 74.3, NI M = 78.1; t(247) = 1.841, p = .067).

Does participation in the summer algebra intervention program improve performance in Introduction to Calculus?

As a group, students choosing to transfer to the *Introduction to Calculus* course had lower performance on the ARE than the students who remained in *Engineering Analysis I* (EAI M = 67.5, IC M = 54.7; t(331) = 6.085, p < .001). However, within the *Introduction to Calculus* group, there are no difference found between the ARE scores of students who did and did not choose the summer intervention (SI M = 52.3, NI M = 55.3; t(82) = .609, p = .544). This stands in contrast to the *Engineering Analysis I* group where students choosing the intervention had lower scores. Still, for the students who chose the intervention in the *Introduction to Calculus* group, scores on the intervention post-test demonstrated improvement from the ARE and were essentially equal to the post-test scores of the group that remained in *Engineering Analysis I* (ARE M = 52.3, RPT M = 83.2; t(14) = 4.766, $p < .001$; r = .068, p = .810). Nevertheless, participation in the summer intervention program and the seeming improvement in algebra knowledge did not translate into improved mean exam performance (SI M = 58.5, NI M = 60.2; t(82) = .388, p = .699) or mean quiz performance (SI M = 55.7, NI M = 53.8; t(82) = .463, p = .645) over the no intervention group.

Table 2. Mean ARE scores, intervention post-test scores, and course performance scores for students in Engineering Analysis I and Introduction to Calculus who did and did not participate in the summer algebra intervention program.

Course	Group	n	ARE M (SD)	IPT M (SD)	Exams M (SD)	Quizzes M (SD)
Engineering Analysis I	SI	73	58.85 (15.25)	86.25 (10.50)	67.49 (15.12)	74.31 (15.09)
	NI	176	71.02 (15.58)		71.49 (15.04)	78.13 (15.08)
	All	249	67.45 (16.42)		70.32 (15.14)	77.01 (15.15)
Introduction to Calculus	SI	15	52.27 (22.50)	83.20 (12.85)	58.49 (17.81)	55.70 (17.66)
	NI	69	55.25 (15.84)		60.15 (14.36)	53.82 (13.43)
	All	84	54.71 (17.10)		59.85 (14.93)	54.16 (14.17)

SI = summer intervention, NI = no intervention, ARE = algebra readiness exam, IPT = intervention post-test

Discussion

Our long term goal of increasing student retention in the engineering program is focused on identifying factors affecting student performance and designing programs that provide students with the skills necessary for success. Initial efforts have been focused on early intervention programs for students with deficient algebra skills. We have used an empirical approach to evaluating our efforts in this area which has allowed us to differentiate aspects of the program that have been effective from those that require further development.

Our tool for assessing algebra skill, the ARE, served as a good predictor of performance in *Engineering Analysis I*. Students with higher scores performed better in the course and were more likely to remain in the course. This provides further confirmation that a solid foundation in algebra is necessary for success in more advanced mathematics courses [6]. It also serves as an important reminder that students entering an engineering program, a group assumed to have been successful in high school mathematics, may still have weaknesses in fundamental algebra. There are many possible explanations for this, including the fact that some high schools that do not cover algebra in a uniform manner, and in many cases it may have been a year or more since students' algebra skills were reinforced. In the future, it may be beneficial to extend our assessment of mathematics skill to include fundamental concepts in precalculus and trigonometry as well.

Although algebra knowledge accounted for one quarter of the variability in exam and quiz performance in our first semester engineering course, a significant amount of variability in performance was unexplained as can be seen in the dispersion of the data in Figure 1. To a large degree, this dispersion is coming from students who have high ARE scores but perform poorly in the course. This could be due to a couple of factors. Some students may have good ability but poor study habits or are unable to adjust to the rigors of engineering school. As with any online, un-proctored exam, there is a possibility that a few individual results are not honest representations of the student's ability.

In meeting long term retention goals, it will be important to consider additional factors affecting student performance. Recent studies have shown attitudes[7] and personality factors[8] to be related to first year success in engineering. Two factors currently being evaluated by these authors are motivational factors and learning strategies. Both have been found to significantly impact student performance and are promising avenues for successful intervention[9].

An evaluation of our summer algebra intervention program provided mixed findings with regard to its efficacy. On one hand, algebra scores increased significantly from a pre- to post-intervention test, and it seems reasonable to think that some of these large gains can be attributed to participation in the summer program. On the other hand, some portion of this increase in performance is likely due to practice effects[10]. These are well-documented improvements in performance related to task repetition that can occur in the absence of intervening training. In the future, we plan to distinguish improvements in performance associated with practice from improvements related to participation in the summer program by having our no intervention group take the intervention post-test. Using this methodology, performance gains in the no intervention group can be attributed to practice, and performance gains in the summer intervention group that are above and beyond those of the no intervention group can be attributed to the summer program.

At this point, it is unclear whether performance gains on the intervention post-test translated into improved performance in the fall semester engineering course. Students who participated in the summer program were more likely to remain in *Engineering Analysis I*. These same students performed equally well on semester exams and quizzes as their no intervention counterparts, despite their pre-intervention deficit in algebra knowledge. One concern with these data is whether these improvements are due to participation in the course or some other factor such as motivation. Although students with lower ARE scores were advised to take the summer intervention, the decision was left to the students, leaving open the possibility of a self-selection bias. In other words, students who chose to participate in the summer program may have been more highly motivated than those who did not choose to participate, making it difficult to attribute performance gains to participation in the course alone. Biases of this kind would typically be handled by randomly selecting students for participation in the summer intervention program. Unfortunately, experimental controls that are easy to implement in the laboratory are often not realistic options in classroom research. Alternatively, this situation could be addressed in the future by measuring a variety of potential group differences. This would allow group differences to be ruled out or offered as an additional explanation for group performance.

For students who participated in the summer program but nevertheless moved to *Introduction to Calculus*, there appeared to be no benefit from participation in the summer algebra intervention. Although these 15 students had the same large gains in pre- to post-intervention test scores as the group of students remaining in *Engineering Analysis I*, this seeming improvement in algebra knowledge did not result in any demonstrated benefits in the fall semester. This is not entirely surprising because the *Introduction to Calculus* course itself is an intervention, and those who did not participate in the summer program also had the opportunity to remediate any algebra skills as they were reviewed again in the course.

Conclusions and Future Directions

The department is encouraged by this initial empirical validation of efforts toward early identification and intervention for at risk students in the freshman engineering course. It is now possible to differentiate aspects of the program that have been successful from those that need strengthening in the future. First, the ARE was a good predictor of performance in fall coursework. However, it is clear that factors beyond algebra knowledge contribute to student success. Going forward, a major thrust of our research will focus on identifying these factors. Second, students in the summer algebra intervention program demonstrated immediate post-intervention gains in algebra knowledge. However, it is still unclear whether these gains translated into improved performance in fall coursework. Future research plans include improvements to methodology that will allow for long term evaluation of the summer algebra intervention program and its impact on retention.

The two interventions described in this study are concerned with one factor affecting first year retention, namely mathematics skill; however, there are many additional factors that are likely to contribute to student success and retention in engineering school. Identifying these factors is a long term process that requires the continued collection and tracking of all potential factors involved. As part of our efforts, a system has been put into place for on-going tracking of students. It involves the creation of a large data base that contains information such as demographic and performance information for entering cohorts of freshmen, motivational and learning strategies questionnaire results, and course performance results. As this first cohort completes their undergraduate program, analysis will reveal which of the collected factors is most relevant for long term retention. Although much work remains in reaching our long term goal of improving retention in the engineering program, this early study has provided valuable guidance in this endeavor.

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