AC 2007-1497: TESTING OUR ASSUMPTIONS: MATHEMATICS PREPARATION AND ITS ROLE IN ENGINEERING STUDENT SUCCESS

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Testing Our Assumptions: Mathematics Preparation and its Role in Engineering Student Success

Abstract

Two studies are presented that attempt to test commonly held assumptions regarding mathematics preparation as a predictor to success and retention in engineering programs. Many engineering educators, high school teachers and guidance counselors recommend that engineering programs should only be attempted by students who excel in accelerated and advance placement high school mathematics. The underlying assumption behind this belief is that success in high school mathematics is the best predictor of success as an engineering student and, by extension, a practicing engineer. Boise State University, as a metropolitan university in a region that is not supported by a community college system, is uniquely situated to test these assumptions. We have found that more than 30% of our successful students (those who earn bachelors degrees) began their college career at the eighth or tenth grade algebra level. Even more significantly, we found that the grade earned in their first college level mathematics class was significantly correlated to whether or not they persisted in engineering while the level at which they began mathematics study at the university was not. These results, if they prove to be representative, have significant implication for policy, admissions standards and program development to improve retention in engineering schools.

Introduction

Nearly every discussion about recruitment and retention of students in engineering involves, or focuses on, mathematics and student preparation in mathematics. Many of the recent studies that have been published about the looming crisis in American competitiveness cite mathematics preparation as a major, if not the only, area that must be improved[1, 2]. The common observation that college mathematics courses are responsible for the majority of attrition in engineering programs has led to the widely held assumption that lack of mathematics preparation is the underlying problem facing engineering education today. Surprisingly, there is little research to critically and quantitatively put that assumption to the test. An alternate hypothesis might be that students are discouraged by their experience in their college mathematics classroom for reasons that might or might not be related to performance. Over a six year period, in conjunction with a well-funded effort to develop student support programs, we have studied a number of factors to see how they correlate with student success in engineering.

Due to the nature of our institution, we provide access to students with a wide range of mathematics preparation, from those with advanced placement (AP) credit for two semesters of calculus to students who require developmental algebra at the eighth or tenth grade level. This population provides a unique opportunity to study this particular issue and we feel this paper will be of broad interest and have significant impact in the engineering education community.

Research Method

Two studies are reported on this paper: 1) A backward-looking survey of successful engineering students to see the level of mathematics at which they started college and 2) An analysis of factors correlated to student persistence. The first study began as an informal attempt to assess the range of math preparedness among our students in an effort to help direct our program development efforts. The second was performed to test a hypothesis formed while carrying out the informal studies. As we will demonstrate, a significant portion of our successful students began their college experience in developmental mathematics. We also found that attrition among students who began in calculus or came to the university with AP credit did not appear to be significantly different than those that began in precalculus courses. That observation led to an interesting hypothesis:

The performance of students in their first math class was more highly correlated to persistence than the level of mathematics at which they began their college studies.

Backward-Looking Survey of Successful Engineering Students

A previously published paper[3] reported on a pilot study. The results are summarized in Figure 1 which shows the break down by percentages and first college mathematics class taken by the 2004 graduates of our mechanical engineering (ME) program.

For two of these students, this was their 2nd degree so their first college-level course was not categorized. Of the remaining students, only one started the program with AP credit for calculus, and hence began the program in Calc II. Even more surprising, only eight of the students (less than one quarter) started at the typical starting point for engineering students, Calc I. The majority of students began one semester behind, in pre-calculus (made up of advanced algebra and trigonometry). Perhaps the must stunning statistic is that three students began their college studies in non-credit bearing developmental algebra. At this point, it bears pointing out that students graduating from this mechanical engineering program have one of the highest pass rates on the Fundamentals of Engineering exam in the nation (consistently near 90%).

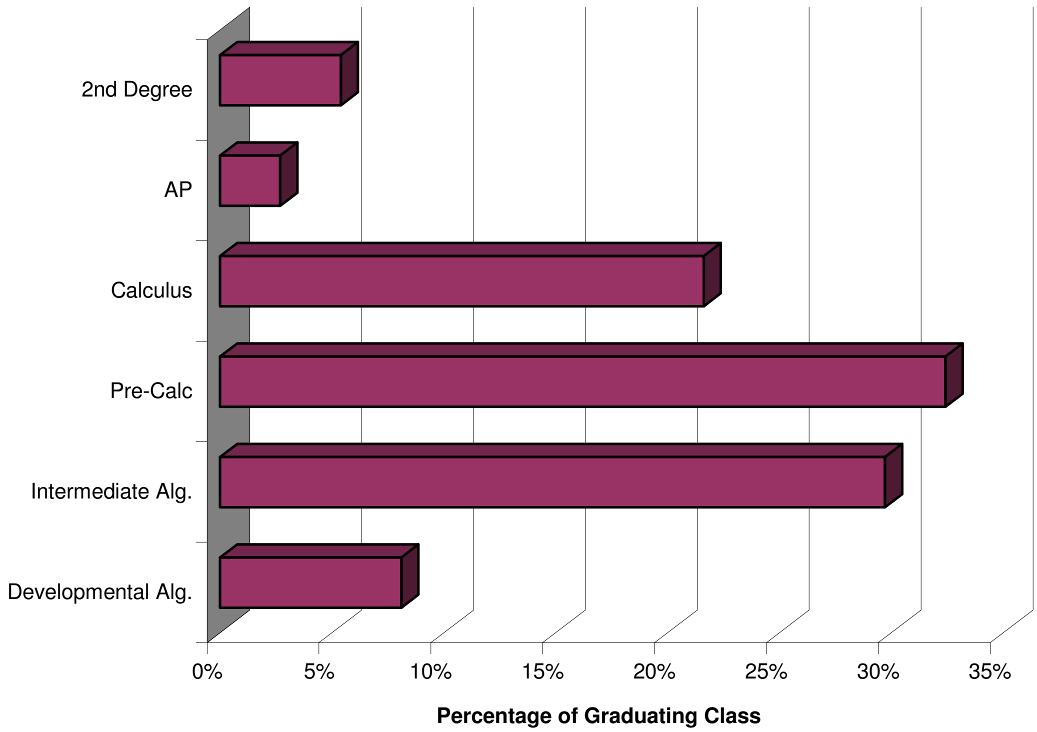

Figure 1: Make up of a 37-member graduating class in mechanical engineering as determined by their first college-level mathematics class.

More recently, all engineering majors were included in a similar study. For Fall 2005 and Fall 2006, the records of all students who declared engineering majors were analyzed to find the level of their first mathematics course. The results are summarized in Figure 2.

Note that the distribution is very similar to the 2004 ME graduating class indicating that this trend is consistent across the various majors and across the years. Students classified as 2nd degree students for the purposes of Figure 1 were not included in the data set shown in Figure 2.

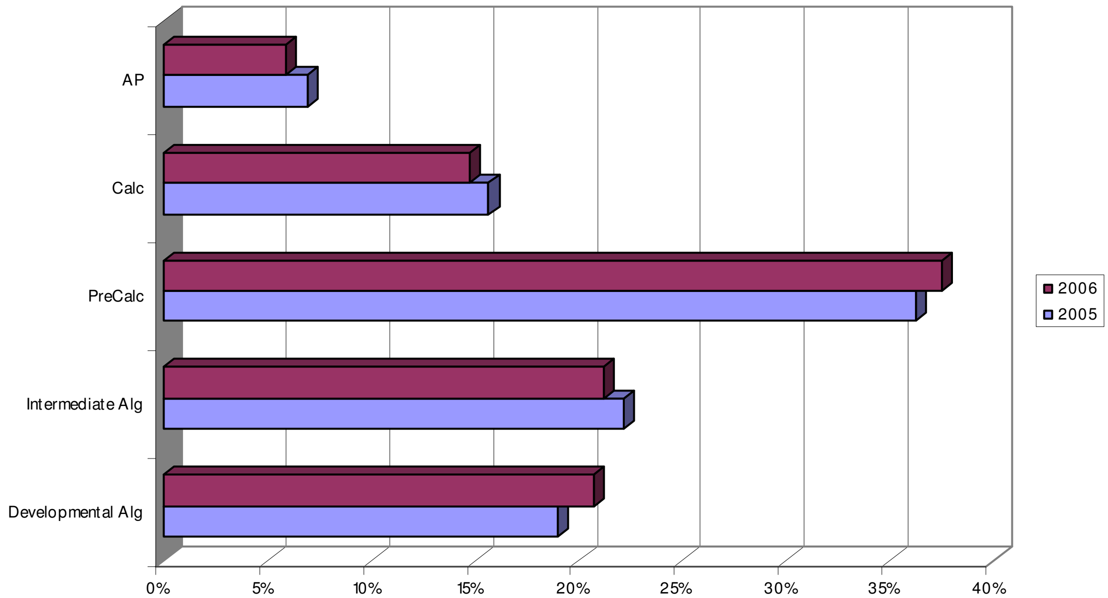

Figure 2: College wide distribution of first time math class for all engineering majors

Factor Analysis for Student Persistence

A total of 337 students were included in this study. They were students enrolled for the first time at the university and enrolled in a math class between fall of 2000 and fall of 2005. Students were considered to be retained if they were re-enrolled in college one year later and they still indicated engineering was their major.

The variables used to predict retention are summarized in Table 1.

Because the retention variable was bivariate, a logistic regression using the Statistical Analysis System (SAS) was employed to predict whether or not students returned to engineering. As a first step, the predictor variables and their interaction terms were submitted. When no interaction terms were significant, the analysis consisted of all predicator variables. For a final solution, step-wise regression was employed to select the best set of variables to predict retention. Results were considered statistically significant if the p-value was less than or equal to 0.05.

Table 1: Factors included in the analysis and how they were coded

Variable	Variable name	Coding
Major in a particular branch of engineering vs. undecided about type of engineering to pursue	GENRLENGR	1=general engineering 0=specific major
Gender	MALE	1=male, 0=female
Race/ethnicity	WHITE	1=White non-Hispanic, 0=other
Year of entry	YEAR	1=2000, 5=2005
Age	AGE	Age at beginning of school year being analyzed
Grade in first math course	FIRST_GRADE	0=F, 1=D, 2=C, 3=B, 4=A
First enrolled in elementary algebra	FIRST_025	1=yes, 0=no
First enrolled in intermediate algebra	FIRST_108	1=yes, 0=no
First enrolled in college algebra	FIRST_143	1=yes, 0=no
First enrolled in calculus	FIRST_170	1=yes, 0=no

Results

The group studied was 90% male and 73% identified themselves as white non-Hispanic. Ages ranged from 16 to 41 with an average age of 19.5. A total of 13% began in developmental algebra, 21% in intermediate algebra, 43% in college algebra (precalculus), and 17% in calculus. After one year, 57% were retained in engineering. Some of the students who were not retained in engineering switched to a non engineering major, while others left the university. The choices and paths of the students not retained in engineering are beyond the topic of this paper.

The logistic regression found no significant interaction effects. However, the study of main effects was more successful. The model was statistically significant (Wald χ^2 = 34.8, df = 10, p = 0.0001) and the results are summarized in Table 2 below.

The only statistically significant effects were a) the grade earned in the first math course ($p < 0.0001$) and b) race/ethnicity ($p = 0.05$).

Table 2: Analysis of Maximum Likelihood Estimates for all variables

Parameter	DF	Estimate	Std. Error	Wald χ^2	Pr > ChiSq
Intercept	1	1.35	0.97	1.92	0.17
General Engineer	1	0.46	0.32	2.12	0.15
Male	1	-0.41	0.40	1.09	0.30
White	1	-0.55	0.28	3.84	0.05
Year	1	-0.14	0.08	2.83	0.09
Age	1	-0.01	0.04	0.10	0.75
First grade	1	0.37	0.09	16.75	< 0.0001
First course: Elementary Algebra	1	-1.07	0.61	3.09	0.08
First course: Intermediate Algebra	1	-0.84	0.57	2.21	0.14
First course: College Algebra	1	-0.36	0.53	0.45	0.50
First course: Calculus	1	-0.42	0.58	0.52	0.47

Using the stepwise regression approach to select the best set of variables to predict retention resulted in the selection of only one variable: grade in first math course. With only one variable, the analysis is equivalent to a chi-square test ($\chi^2 = 37.65$, df = 4, $p < 0.0001$). The relationship between first grade and retention is shown in Table 3 below.

Table 3: Correlation of the grade in first math class to retention

Grade	Number receiving Grade	Percent retained
F (0)	72	29.2%
D (1)	45	48.9%
C (2)	83	67.5%
B (3)	87	73.6%
A (4)	50	60.0%
Total	337	57.3%

These results challenged our basic assumptions regarding the role of mathematics preparation and success in engineering school. They indicate that attrition would be roughly the same for students who start college placing into developmental algebra as those prepared for calculus. An implication of this is that the distribution of students based on their first college-level math class would be roughly the same, regardless of how much progress they've made in the program. To put it another way, the graphs shown in Figure 1, describing the distribution for graduates, should be roughly the same for first year students.   Figure 3 shows the distribution for the students making up the factor analysis study.

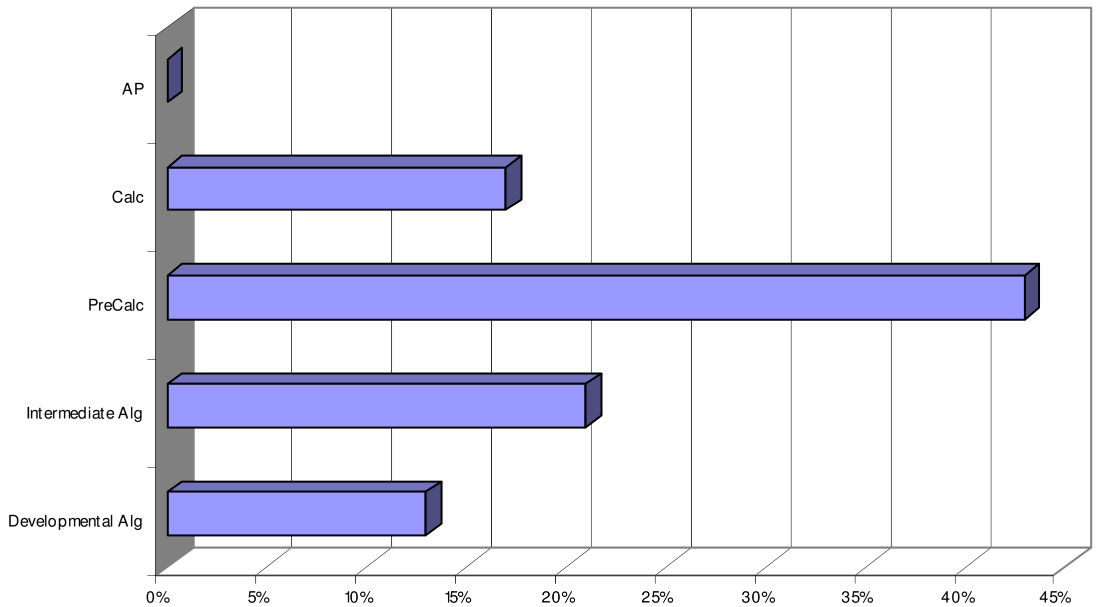

Figure 3: Distribution of first college-level math class for students in the factor analysis study

The similarity between Figures 1, 2 and 3, while not formally analyzed, is striking and lends support to the conclusions drawn from this study.

Conclusions

As the call for more and better-trained engineers continues (and increases), it is essential that we focus our limited resources in ways that make sense, according to empirical data. Widely held assumptions, no matter how common sense they appear on the surface, can and must be rigorously tested. The cost of not doing so is both direct (in the cost of programs that have little hope of succeeding to improve the situation) and indirect (lost opportunity represented by a population of people who have the potential of succeeding in engineering).

The results of this study, if they prove to be representative, have far reaching implication regarding the manner in which we allocate resources in outreach and recruiting. If we continue to focus the bulk of our efforts on high-performing high school mathematics students (i.e. AP Calculus enrollees), we should not be surprised if our results are the same as they always have been. On the other hand, if we tailor outreach efforts to bring encouragement and support to *all* students who show an interest, we may well make more progress. Similarly, it is essential that we constantly strive to keep open pathways through our educational systems that allows students who do not excel in mathematics in K-12 to find a way, through perseverance and hard work, into our engineering classrooms.

Acknowledgements

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