Relationship between High School Mathematical Achievement and Quantitative GPA

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Abstract

The demand for STEM graduates has increased, but the number of incoming freshmen who declare a STEM major has remained stagnant. High school courses, such as calculus, can open or close the gate for students interested in careers in STEM. The purpose of this study was to determine if high school mathematics preparation was a significant prerequisite for success in the pre-engineering curriculum at the post-secondary level. The College Freshman Survey was administered to a sample of 2,328 incoming freshman students, then their survey responses were matched with the grades and standardized test scores provided by the university's institutional research office. A multiple regression analysis was conducted to predict quantitative pre-engineering GPA. The most significant predictor of quantitative GPA was adjusted ACT math score. Other significant contributors to the models were calculus, algebra II, trigonometry, and algebra I grades. The results suggest that high school preparation in specific mathematics subjects does have a positive impact on success in pre-engineering education.

Keywords: grade point average, high school, mathematical achievement, pre-engineering curriculum

1. Introduction

1.1 The Problem

During the last decade, the number of STEM (i.e., Science, Technology, Engineering and Mathematics) jobs in the US has tripled, 7.6%, compared to non-STEM jobs, 2.6% (Langdon, McKittrick, Beede, Khan, & Doms, 2011). This growth is projected to continue on into 2018 (i.e., 17.0% compared to 9.8%, respectively). Engineering accounts for one-third of the current STEM jobs in 2010. As the economic infrastructure has transitioned from a manufacturing to more specialized services (e.g., technology), the demand for a more skilled workface has increased, particularly in the STEM fields (Langdon et al., 2011; Sargent, 2014).

In the middle of the 20th century, President John F. Kennedy inspired a nation of scientists and engineers to win the space race after the Soviet Union's launch of Sputnik in 1957. These motivated individuals are reaching retirement age in the beginning of the 21st century, yet the declining interest and increasing attrition rates have reduced the number of scientists and engineers to replace them. Between 2012 and 2022, 2.3 million scientists and engineers will be needed to meet growth and replacement needs (Sargent, 2014). This shortage of prepared scientists and engineers can be linked to preparation in mathematics and science at the K-12 level, particularly secondary education. Between 2003 and 2009, one out of every two students who entered a STEM field bachelor's degree program either switched majors to a non-STEM field or dropped out of post-secondary school (Chen, 2013). According to Wang (2013), the decision to pursue a degree within a STEM field is considered a longitudinal process. This process begins in secondary education and continues into postsecondary education. Researchers (e.g., Adelman, 2006) suggest that curriculum content, coursework exposure, and proficiency in math and science factor into whether students leave or persist a STEM field of study (Wang, 2013).

1.2 Review of Literature

While the number of engineering bachelor's degree grew 6% in 2014, the majority of that growth was from students transferring into engineering during their junior and senior year. The number of incoming freshman has remained relatively stagnant (Yoder, 2014). Over the past 60 years, the graduation rate among engineering

majors has remained stagnant at 50%, meaning one out of every two incoming freshmen will not graduate (Geisinger & Raman, 2013). With decreased interest and low retention rates, the projected number of engineering graduates will not meet the projected demand for the US workface (Sargent, 2014).

The majority of high school graduates enroll at a post-secondary institution immediately after high school completion; however, nearly half of those graduates took some type of remedial course after enrollment. The number of students taking Advanced Placement (AP) math or science courses has doubled since 2002, but the exam passage rate has declined or remained stagnant. More specifically, calculus AB dropped by 9% and biology dropped by 13% since 2002 (National Science Board [NSB], 2014). Geisinger and Raman (2013) conducted a meta-analysis to examine why students leave the field of engineering. They found factors that impacted the decision to leave included conceptual difficulties, lack of self-efficacy, and inadequate high school preparation. Wang (2013) found high school exposure to math and science had a significant effect on the intent to pursue a STEM field. Furthermore, this coursework selection and completion played a critical role in developing student interest in STEM fields.

The student's decision to persist or change occurs during the first year of study at the post-secondary level. Often, this decision is based on successful completion of a gateway course (e.g., calculus) because the culture in these STEM courses tends to be quantitatively oriented (Gainen & Willemsen, 1995). Chen and Weko (2009) conducted a study with longitudinal data and found stronger academic preparation increased the likelihood of students entering the STEM fields. The intensity of STEM coursework and type of math courses taken during the first year of college affected the probability of persistence in the STEM fields (Chen, 2013).

Mathematics requires fundamental knowledge of concepts and procedures; however, it requires critical and analytical thinking skills. These mathematical problem-solving skills allow the students to apply their fundamental knowledge in various contextual situations (DeWinter & Dodou, 2011). Students should practice problem-solving skills in real-life situations. By practicing these skills, the students could increase their engagement with the content of mathematics, increase their ability to think critically, and increase their performance on higher order cognitive questions (Mitchell, Hawkins, Stancavage, & Dossey, 1999; Wulf & Fisher, 2002). Anthony, Hagedoorn and Motlagh (2001) suggested problem solving and application skills could increase the likelihood of success in engineering (e.g., correlating the calculus and physics content). Litzinger and Marra (2000) defined the critical skills and attributes needed for lifelong learning as confident, flexible, logical, analytical, and self-aware. Unfortunately, traditional classroom instruction provides minimal preparation for inquiry-based learning or critical thinking during performance-based tasks. The learning experience should provide open-ended problems within a real-world context to give the students the opportunities to develop and practice these skills. Based on these reasons, there is a need to prepare the students from lifelong learning where they can solve contextual problems. Thus, they will be prepared for the ever-changing society (NSB, 2014).

Mathematics ability is the strongest predictor of success in the field of engineering (LeBold & Ward, 1988). A correlational study conducted by van Alphen and Katz (2001) with electrical engineering majors supports this notion. The researchers found that a strong relationship existed between admission to engineering and academic background. Likewise, Klingbeil, Mercer, Rattan, Raymer and Reynolds (2005) pointed to a lack of high school preparation as the most notable factor that influences success in engineering. Without a strong foundation in algebra, the doors are closed for subsequent mathematics courses (Edge & Friedberg, 1984; Klein, 2003). Courses, such as calculus, could open or close the gate for students interested in mathematical, scientific, and technological careers (Gainen & Willemsen, 1995). DeWinter and Dodou (2011) conducted a study with 1,050 engineering students using high school exam scores in liberal arts, natural sciences and mathematics, and languages to predict first-year Grade Point Average (GPA) and program completion. Natural sciences and mathematics (i.e., physics, chemistry and math) were the strongest predictors. The researchers concluded that engineering required the students to apply mathematical content knowledge because of the strong focus on physics. Therefore, there was a strong correlation between mathematical ability and academic success in engineering.

1.3 Purpose of the Study

Limited literature exists to examine the incoming freshman enrollment into the STEM fields (Wang, 2013). The purpose of this study was to determine if high school mathematics preparation was a significant prerequisite for success in the pre-engineering curriculum at the post-secondary level. Specifically, it was hypothesized that select mathematics subjects from the high school curriculum (e.g., calculus) would be significantly related to student performance in post-secondary quantitative subjects, which might be a necessary condition for success in engineering education.

2. Methods

2.1 Participants

The participants included a sample of 3,052 students who entered a university in the south eastern United States from the fall semester of 2000 through the fall semester of 2004. Table 1 displays the frequencies for each admission year. Of these cases, 2,328 participants were selected for the study because their survey responses were matched with the grades and standardized scores provided by the University Planning and Analysis Office. The participants who have an intended engineering major included 1,901 (81.7%) were male, and 427 (18.3%) were female. Of these participants, the racial classification of the group was 1,932 (83.0%) White, 259 (11.1%) Black, and 137 (5.9%) participants who reported they belonged to other racial groups. The majority of the participants (54.8%) reported a master's degree as their highest education level they expected to attain.

When asked to describe the place where they lived before enrolling in college, 746 (32.0%) participants reported small town, 676 (29.0%) reported suburbia, 550 (23.6 %) reported large town, 181 (7.8%) reported big city, and 175 (7.5%) participants reported rural. The participants in this study represented 40 of the 50 U.S. States. For specifically, 1,646 (70.7%) reported Alabama as their home state. Nearly 60% of the participants reported their high school rank to be in the top 20% of the graduating class. The range of graduating class size was less than 50 to more than 500 students with a median of 200.

Table 1. Frequencies by academic year

| Year | Entire Sample | | Sample Cases | |
	n	*%*	*n*	*%*
2000	609	20.0	466	20.0
2001	608	19.9	464	19.9
2002	626	20.5	453	19.5
2003	641	21.0	495	21.3
2004	568	18.6	450	19.3
Total	3,052	100.0	2,328	100.0

2.2 Measure

The College Freshman Survey (Halpin & Halpin, 1996), which consisted of 248 items, was the measurement tool used in this study. The beginning questions elicited demographic information, standardized test scores, and high school grades. For interest in high school courses, the participants rate their interest in each of the above subjects using a 4-point scale with 1, which denotes *Really Liked*, to 4, which denotes *Really Disliked*: algebra-calculus sequence, chemistry, physics, English, social studies, computer, and foreign language. The remaining questions (200 items) determine the importance of various subjects, rank of abilities, likelihood of various events, and agreement with various statements. The responses from these items were not utilized in this study.

2.3 Data Collection

The College Freshman Survey (Halpin & Halpin, 1996) was administered at a series of summer orientation session that were held on the university's campus from 2000 to 2004. The completed paper-pencil answer sheets were scanned into a text file. At end of each spring semester, the researchers requested pre-engineering quantitative course grades after the first attempt from institutional research. Those course letter grades, which in an Excel spreadsheet, were merged with the survey data to create the database within SPSS.

2.4 Research Question

What is the relationship between high school preparation and quantitative grade point average in a pre-engineering curriculum?

3. Results

3.1 Descriptives

Descriptives for the final grades and interest in the high school mathematics courses (i.e., algebra I, algebra II,

geometry, trigonometry, and calculus) were assessed. For 292 cases, the participants only took the SAT. The SAT quantitative and ACT math scores are highly correlated ($r = .79$; $p < .001$). To linear equate the SAT quantitative and ACT math scores, a multiple regression analysis was conducted (Peterson, Kolen, & Hoover, 1989). The predicted ACT math score was used for the participants who only took the SAT. The mean score for the adjusted ACT math was 26.59 with a standard deviation of 4.22 and ranged from 15 to 36. For high school grades, the participants' responses range from 1, which represented D+ or less, to 7, which represented A+. The seven-point scale was used to empirically weight the responses in order to account for the class not being taken in high school and to differentiate between A+, A, and A-. Table 2 displays the means and standard deviations for grades for each high school mathematics course. Table 3 displays the intercorrelations with the predictor variables.

Table 2. Means and standard deviations for grades for each high school mathematics course

Course	Grades	
	M	*SD*
Algebra I	5.65	1.38
Geometry	5.58	1.35
Algebra II	5.48	1.39
Trigonometry	5.00	1.59
Calculus	4.45	1.65

Table 3. Intercorrelations for the predictor variables

Variable	1	2	3	4	5	6	7
1. Adjusted ACT Math	--	.20**	.30**	.34**	.32**	.42**	.19**
2. Algebra I grade		--	.41**	.48**	.34**	.23**	.29**
3. Geometry grade			--	.55**	.40**	.32**	.28**
4. Algebra II grade				--	.52**	.41**	.41**
5. Trigonometry grade					--	.37**	.33**
6. Calculus grade						--	.28**
7. Interest in high school mathematics							--

Note. * $p < .05$; ** $p < .01$

The dependent variable of quantitative GPA in the pre-engineering curriculum was measured with at least two at quantitative courses in the pre-engineering curriculum. A quantitative course was defined as a college course whose conceptual foundation is based in mathematics (Gainen & Willemsen, 1995). The final letter grade in each quantitative course was coded using the four-point scale (i.e., A = 4, B = 3, C = 2, D = 1, F = 0) and was averaged together to create the quantitative grade point average. The mean score was 2.33 with a standard deviation of 1.03. A bivariate correlation was conducted to determine the relationship between the quantitative GPA and pre-engineering GPA. A strong positive relationship existed between the GPAs ($r = .87$; $p < .001$).

3.2 Explanation of Quantitative GPA

After the initial descriptives and correlations, a multiple regression analysis was conducted using quantitative GPA as the dependent variable. Adjusted ACT math, high school mathematics course grades, and high school mathematics course interest were used as independent variables. The R^2 for the full regression model was .31 (F (7, 2264) = 143.10; $p < .001$). The most significant predictor of quantitative GPA was the adjusted ACT math score ($t = 15.47$; $p < .001$). Other significant contributors to the models were calculus grades ($t = 10.22$; p

< .001), algebra II grades ($t = 3.76$; $p < .001$), trigonometry grades ($t = 3.71$; $p < .001$), and algebra I ($t = 2.01$; $p = .04$). Table 4 displays the summary of the full regression analysis including the zero-order correlations, semi-partial correlations, and structure coefficients for each predictor.

Table 4. Summary of full regression analysis for variables predicting quantitative GPA ($n = 1,184$)

Variable	r	sr	Structure Coefficient
Adjusted ACT Math	.46	.27	.84
Algebra I grade	.23	.04	.42
Geometry grade	.30	.03	.54
Algebra II grade	.34	.07	.62
Trigonometry grade	.32	.07	.58
Calculus grade	.42	.18	.76
Interest in high school mathematics	.19	-.01	.34

Note. $R^2 = .31$

As a follow-up procedure, a series of univariate analyses were conducted with the Bonferroni post hoc for each significant high school mathematics course (i.e., algebra I, algebra II, trigonometry, and calculus) using quantitative GPA as the dependent variable. In general, the participants who reported that they made an A+ or A in a high school mathematics course tended to have significantly higher quantitative GPAs compared to the other grade categories. The participants who reported that they did not take a specific high school mathematics course tended to have significantly higher quantitative GPAs compared to the participants who reported poor performance in high school mathematics courses. The results suggest that successful performance in high school mathematics significantly affects performance in college quantitative courses. In addition, the exposure to the content in high school does not increase academic performance in college quantitative courses. Table 5 though Table 8 display the mean differences for each high school mathematics course by grade category.

Table 5. Post hoc test results: mean differences for algebra i by grade category

| Grade Category | Mean difference | | | | | | |
	A+	A	A- to B+	B to B-	C+ to C-	D+ or less	Did not take
A+	--						
A	.27**	--					
A- to B+	.65**	.38**	--				
B to B-	.83**	.56**	.18	--			
C+ to C-	.90**	.63**	.25	.08	--		
D+ or less	.74	.47	.09	-.09	-.16	--	
Did not take	-.03	-.29	-.67**	-.85**	-.93**	-.76	--

Note. * $p < .05$; ** $p < .001$

Table 6. Post hoc test results: mean differences for algebra ii by grade category

Grade Category	Mean difference A+	A	A- to B+	B to B-	C+ to C-	D+ or less	Did not take
A+	--						
A	0.35**	--					
A- to B+	0.71**	0.35**	--				
B to B-	0.93**	0.58**	0.22*	--			
C+ to C-	1.13**	0.78**	0.43**	0.20	--		
D+ or less	1.25**	0.89*	0.54	0.32	0.11	--	
Did not take	0.31	-0.05	-0.40	-0.62	-0.83	-0.94	--

Note. * $p < .05$; ** $p < .001$

Table 7. Post hoc test results: mean differences for trigonometry by grade category

Grade Category	Mean difference A+	A	A- to B+	B to B-	C+ to C-	D+ or less	Did not take
A+	--						
A	0.27**	--					
A- to B+	0.86**	0.59**	--				
B to B-	1.03**	0.76**	0.17	--			
C+ to C-	1.19**	0.92**	0.33*	0.16	--		
D+ or less	1.17*	0.90	0.31	0.14	-0.03	--	
Did not take	0.69**	0.42**	-0.17	-0.34**	-0.50**	-0.48	--

Note. * $p < .05$; ** $p < .001$

Table 8. Post hoc test results: mean differences for calculus by grade category

Grade Category	Mean difference A+	A	A- to B+	B to B-	C+ to C-	D+ or less	Did not take
A+	--						
A	0.34**	--					
A- to B+	0.66**	0.32**	--				
B to B-	0.99**	0.65**	0.33**	--			
C+ to C-	1.28**	0.94**	0.62**	0.29	--		
D+ or less	1.96**	1.62**	1.30**	0.97**	0.69*	--	
Did not take	1.09**	0.75**	0.43**	0.10	-0.19	-0.87**	--

Note. * $p < .05$; ** $p < .001$

4. Discussion

Based the results of this study, ACT math scores were the most significant predictor of quantitative GPA according to the bivariate correlation, semi-partial, and structure coefficient. In addition to ACT math scores, the grades earned in the high school calculus course was a statistically significant contributor to the regression model. The post hoc tests revealed significant differences in quantitative GPA based on grade categories. The participants who earned an A+ in calculus had quantitative GPAs at least 1.00 higher compared to those participant who earned a B and lower. Similar mean differences were seen with algebra II and trigonometry.

Algebra I, algebra II, trigonometry, and calculus were also statistically significant predictors, which supports the findings of DeWinter and Dodou (2011), LeBold and Ward (1988), and van Alphen and Katz (2001).

The nation should equip students in K-12 education for tomorrow's demands in the workforce and society. With continuing advances in technology, students must have a solid foundation in mathematics to be productive members in their communities. External forces of society, economy, and profession challenge the stability of the engineering workforce. This instability affects recruitment of the most talented students into the engineering profession (NSB, 2014). Students cannot begin to develop their intellectual capacities when they enter college at the age of 18. Hence, these demands will require developing their mathematical skills earlier in the formal education years (Wang, 2013). To improve mathematics education at the K-12 level, the curriculum should make the learning experiences more meaningful and introduce the essence of engineering (National Academy of Engineering, 2005).

The nature of science, engineering, and mathematics college courses tends to be quantitatively oriented, and calculus tends to serve as the gateway course for academic success within these majors according to Gainen (1995). Therefore, mathematical ability is considered a critical factor for achieving success in engineering because it serves a foundation for the science curriculum (Heinze, Gregory, & Rivera, 2003). Based on the findings of this study, the College of Engineering and K-12 educational systems should increase their awareness of the relationship between high school mathematical preparation and academic success in the pre-engineering curriculum. Future research should examine mathematics curriculum in order to develop mathematical skills at the secondary level so the students will be better prepared for the quantitative courses within the pre-engineering curriculum and other quantitatively-oriented professions.

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