UNDERSTANDING THE TRANSITION BETWEEN HIGH SCHOOL AND COLLEGE MATHEMATICS AND SCIENCE

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Abstract

Mathematics and science education is gaining increasing recognition as key for the well-being of individuals and society. Accordingly, the transition from high school to college is particularly important to ensure that students are prepared for college mathematics and science. The goal of this study was to understand how high school mathematics and science course-taking related to performance in college. Specifically, the study employed a nonparametric regression method to examine the relationship between high school mathematics and science courses, and academic performance in college mathematics and science courses. The results provide some evidence pertaining to the positive benefits from high school course-taking. Namely, students who completed high school trigonometry and lab-based chemistry tended to earn higher grades in college algebra and general chemistry, respectively. However, there was also evidence that high school coursework in biology and physics did not improve course performance in general biology and college physics beyond standardized test scores. Interestingly, students who completed high school calculus earned better grades in general biology. The implications of the findings are discussed for high school curriculum and alignment in standards between high schools and colleges.

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Introduction

No matter where in the educational continuum transitions take place (i.e., elementary to middle school or high school to college), systems are needed to ensure that students are prepared and that academic and non-academic factors are considered. In particular, the transition from secondary to post-secondary education is one that is receiving greater attention as data suggests that close to 50% of all college freshman students either fail or are put on academic probation due to poor performance [1]. Further, a large portion of student failure and academic probation is due to failure in mathematics and science courses. Kuh states that "many high school seniors are not prepared academically for college-level work and have not developed the habits of the mind and heart that will stand them in good stead to successfully grapple with more challenging intellectual tasks" [2]. Often, college and university faculty do not consider high school standards to be congruent with college expectations [1, 3]. Hoyt and Sorensen argued that "lax and/or inconsistent standards may create student attitudes, behaviors, and expectations for performance that lead to failure in the college environment" [3].

The literature cites many factors that may affect first-year students' performance in mathematics and science, including academic preparation, congruence between high schools and institutions of higher education, alignment of secondary education standards and expectations in higher education, and several non-academic factors (i.e., pre-enrollment preparation, social relationships, financial issues, parent background and support) [4]. What is clear from existing data is that the transition between high school and college is not conducive to fostering student success for many graduating seniors. As Conley states, "The two systems—K-12 and post-secondary—evolved in relative isolation. Although each is clearly engaged in education, each has traditionally seen its purposes and goals as distinctly different from the other's" [5]. Studies show that sufficient academic preparation is essential for success in college. For example, students who complete higher-level mathematics and science courses are more likely to attend college, succeed in college-level mathematics and science courses, and graduate [6-8]. In a review of research in science education, Tai, Sadler, and Loehr specifically point to pedagogical approaches, critical concepts taught, the type of laboratory experience, the degree of lesson structure, instructional technology use, AP science instruction, and mathematical background as factors that predict success in science to varying degrees [9].

Research also suggests a lack of congruence between high schools and post-secondary institutions [1-3, 10]. Brown and Conley found that most state assessments do not align with college and university expectations and the *ACT National Curriculum Survey: 2005-2006* found that few teachers agreed with college educators on what is important to teach. College professors valued thinking skills over content knowledge while high school teachers valued the exact opposite. The ACT survey suggests that this is due to content knowledge making up most state standards. There is also a body of literature related to mathematical knowledge itself and its impact on science courses. Kuh found that students who do not take upper-level mathematics courses are less likely to complete a baccalaureate degree. Hoyt and Sorensen found that students who receive less than a C- in high school Algebra I, Algebra II, and/or Geometry are more likely to take college remedial math.

Recently, researchers and policymakers are examining the alignment between state assessments and standards, and courses in colleges and universities. In fact, according to the ACT National Curriculum Review, "Inadequate high school coursework may account for at least part of the remediation problem. Too few students may be taking enough high school math (up through Algebra II at a minimum)" [1]. Standards are also problematic as they do not match college and university needs [1]. The *ACT National Curriculum Survey* found the following in its research:

> High school teachers are being held accountable to teach students the content and skills listed in state standards. Given those expectations, it is not surprising that our survey found that high school teachers tend to rate more content and skills with higher importance and at greater frequency than do their post-secondary counterparts [1].

Finally, there are also the non-academic factors. Studies have examined behavior and relationship issues. Ferry, Fouad, and Smith found a correlation between family involvement and classes taken in high school [11]. The more parents were involved, the higher level the classes that were taken by their high school-aged children. Nonis and Hudson looked at study habits and found that the amount of time students spend studying is related to the number of mathematics and science classes that students take [12]. However, they found that the strongest predictor for college success is either the ACT (American College Test) or SAT (Scholastic Aptitude Test) score. K. Cockley, et al. compared African-American and Euro-American students and reported differences in self-concept among students which they felt contributed to success in higher education [13].

The aforementioned literature clearly supports the need to better understand the alignment between mathematics and science courses in high school and college. Previous research in this area has primarily examined the relationship between high school course-taking and post-secondary enrollment and performance on standardized test scores or high school grades on college grades [14-17]. Consequently, additional research is needed to understand the link between high school course-taking and academic performance in college. Accordingly, the goal of this study was to explicitly assess the value of high school course-taking on student performance in freshmen-level mathematics and science courses (i.e., general biology, general chemistry, college algebra, and physics). More specifically, the purpose of this study was to address two central questions. First, how well do standardized test scores predict students' performance in freshmen-level mathematics and science courses? Secondly, what is the contribution of high school course-taking to academic performance in college after controlling for students' standardized test scores? Moreover, a significant relationship between high school and college courses provides evidence for alignment between secondary and post-secondary education.

The following discussion is divided into three sections. The first section discusses the sample, variables, and statistical model used to assess the research questions. The second section presents results from a nonparametric regression and discusses the results in relation to the research questions. The last section discusses the implications of the results and provides concluding remarks.

Methods

Sample—Students for this study attended a public, urban university in the Rocky Mountain region. For purposes of this study, data were collected on students who completed one of four mathematics or science courses, namely general biology, general chemistry, college algebra, and physics, between Fall 2005 and Spring 2008. The study examined data from a total of 2,108 students (i.e., 878 students in general biology, 499 in general chemistry, 482 in college algebra, and 249 in physics).

Variables—Table 1 presents descriptive statistics for the variables of interest. Specifically, the dependent variable, course grade, was a twelve-point scale ranging from zero to eleven to represent letter grades on a +/- scale; e.g., 11 represents an A, 10 is an A-, 9 a B+, 8 a B, etc. Table 1 shows that the average course grades ranged between a C and C+ in Biology (e.g., a mean of 5.6) to a B- in Physics (e.g., a mean of 7.3). We also examined the relationship between students' standardized test scores (as indicated by ACT Mathematics and Science sub-test scores) and credits earned with course performance. In particular, credits earned was an important control variable to account for the fact that students differ in exposure to college classrooms. In fact, the average student completed biology (*M* = 37.1, *SD* = 32.2), chemistry (*M* = 55.0, *SD* = 34.0), and college algebra (*M* = 32.5, *SD* = 29.8) as sophomores whereas students who completed physics tended to be juniors (*M* = 76.7, *SD* = 35.4).

TABLE 1
Summary of Academic Performance, High School Course Credits, and Demographics by Course

	General Biology (*n* = 878)		General Chemistry (*n* = 499)		College Algebra (*n* = 482)		Physics (*n* = 249)	
Variable	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Course Grade[a]	5.6	4.0	6.3	3.5	6.0	3.6	7.3	3.6
ACT Math	21.4	4.3	22.1	4.1	22.2	3.5	22.6	3.9
ACT Science	21.8	3.7	22.4	3.9	22.5	3.5	22.6	3.8
Credits Earned	37.1	32.2	55.0	34.0	32.5	29.8	76.7	35.4
High School Course Credits[b]								
Algebra	1.68	0.73	1.63	0.73	1.74	0.68	1.54	0.73
Biology	1.52	0.71	1.55	0.77	1.39	0.69	1.49	0.74
Calculus	0.19	0.40	0.23	0.44	0.09	0.28	0.29	0.50
Chemistry	1.05	0.52	1.10	0.53	0.98	0.50	1.05	0.51
Geometry	0.90	0.43	0.88	0.43	0.90	0.40	0.87	0.45
Physics	0.61	0.62	0.68	0.62	0.62	0.61	0.72	0.64
Precalculus	0.31	0.44	0.34	0.44	0.29	0.42	0.37	0.46
Trigonometry	0.26	0.32	0.29	0.33	0.26	0.32	0.30	0.34
Demographics[c]								
Female	0.69	0.46	0.67	0.47	0.62	0.48	0.60	0.49
Asian/Pacific Islander	0.22	0.42	0.24	0.43	0.18	0.38	0.26	0.44
African-American	0.07	0.26	0.05	0.22	0.05	0.22	0.05	0.22
Hispanic	0.16	0.36	0.11	0.31	0.14	0.34	0.09	0.29

Note. *M* = Average, *SD* = standard deviation.
[a]Course grade is a 12-point scale ranging from 0 to 11where 0 is an F, 1 is a D, 10 is A-, and 11 is an A. [b]High school courses credits are taken from students' transcripts and represent the number of years. [c]Demographic variables are coded using zeros and ones, so that statistics represent percentages.

The primary variables of interest were students' completed mathematics and science high school course credits reflecting the goal that was to assess whether standards were congruent with academic expectations within University of Colorado Denver (UCD) classrooms. Table 1 presents the average number of course credits students completed in Algebra, Biology, Calculus, Chemistry, Geometry, Physics, Precalculus, and Trigonometry. For example, students in general biology completed nearly one and a half years of high school biology and students in general chemistry completed approximately one year of chemistry in high school. If students finished a high school course, it was assumed that they received a D or higher in that course. This study examined courses taken, not performance in such courses, because specific high school course grades were unavailable. Nevertheless, if a student passed a course, according to the state, the student met the standards at a minimum level or higher and we assume the student possessed at least minimum skills.

The bottom portion of Table 1 summarizes the gender and race/ethnicity of the sample by course. Moreover, gender and race were quantified using reference coding. For example, the female variable equaled one for females and zero for males, Asian/Pacific Islander (API) equaled one for Asian/Pacific Islander students and zero otherwise, African-Americans (AFA) equaled one for African-American students and zero otherwise, and Hispanics equaled one for Hispanic students and zero otherwise. Note that White students were the reference group for the race/ethnicity comparisons. Table 1 shows that females consisted of nearly 60% of the students within each class and non-Whites comprised roughly 40% within each class.

Statistical Model—The dependent variable of interest, course grades, was an ordinal measure of course performance that was inherently non-normally distributed. Typically, the use of coarse measures, such as course grade, can result in attenuated, or smaller effects; however, some research suggests that coarse measures are less problematic when the variable has ten or more scale points [18]. Recall that course grades used in this study had twelve scale points.

Given the non-normal nature of course grades, a nonparametric regression technique was employed; specifically, a mixed-rank nonparametric regression model developed by Puri and Sen, for estimating and testing the relationship between each variable and course grades [19]. The Puri and Sen method allows researchers either to rank transform the predictors and dependent variable or simply to use the original variables. In this study, course grades were studied on the metrics defined in the previous section and the predictors were included into the model with their original metrics. Additionally, the relationship between each predictor and the dependent variable can be tested for statistical significance by computing the Puri and Sen test statistic, $PS_p = (n-1)\Delta R_p^2$, where ΔR_p^2 is the change in R^2 associated with adding variable p to the model. The mixed-rank method considers testing multiple coefficients as multiple tests, so it is appropriate to use a Bonferroni adjustment to control the family-wise type I error rate. In this study, the family-wise type I error was set at a 5% level (i.e., $\alpha = 0.05$), so each PS_p was compared with a test statistic from the χ^2 with one degree of freedom denoted as $\chi^2_{1-\frac{0.05}{P},1}$ where P is the number of variables in the model.

Results

Table 2 summarizes the results of the nonparametric regression models for the four classes. The following section discusses statistically significant relationships and presents estimates and statistical significance levels in parentheses. It is important to note that no variables significantly related to performance in physics, so results for physics are not discussed. One explanation for the absence of any significant relationships for physics could be that students who completed physics tended to be upper-level students who had enough distance from high school that pre-collegiate factors did not significantly differentiate performance levels. Consequently, it is possible that the physics results could differ in samples that consist mostly of freshman and sophomore students and future research should explore the extent to which pre-collegiate academic preparation (i.e., test scores and coursework) predicts performance in college physics for freshman and sophomore students. Additionally, there was no evidence that demographic characteristics significantly contributed to predicting course performance beyond academic variables. Consequently, the models discussed in this section did not include gender or race/ethnicity in the models. Overall, the models accounted for 19.2%, 20.7%, and 10.6% of the total student variation in course performance in general biology, general chemistry, and college algebra, respectively.

TABLE 2
Summary of Course Grade Regression Models

	General Biology (R^2 = 0.192)			General Chemistry (R^2 = 0.207)			College Algebra (R^2 = 0.106)			Physics (R^2 = 0.138)		
	EST	*PS*	Sig.	EST	*PS*	Sig.	EST	*PS*	Sig.	EST	*PS*	Sig.
ACT Math	0.19	16.66	**	0.33	29.29	***	0.21	11.39	**	0.12	1.70	
ACT Science	0.08	2.24		-0.01	0.02		-0.07	1.34		-0.02	0.03	
Total Credit Hours	0.04	28.59	***	0.02	9.36	*	0.02	5.26		0.02	3.04	
High School Course Credits												
Algebra	- 0.14	0.44		-0.03	0.01		0.46	2.80		-0.41	1.14	
Biology	0.26	1.81		-0.27	1.63		-0.09	0.15		0.53	2.43	
Calculus	1.03	8.44	*	0.10	0.07		1.46	5.40		0.57	1.07	
Chemistry	0.38	2.04		1.01	10.98	*	0.55	2.72		0.37	0.44	
Geometry	0.13	0.14		0.25	0.37		-0.86	4.07		0.85	1.83	
Physics	-0.13	0.34		-0.22	0.62		0.02	0.01		0.78	3.71	
Precalculus	0.21	0.41		0.96	6.44		0.78	3.66		0.61	1.13	
Trigonometry	0.81	3.59		0.71	1.93		1.51	8.31	*	1.40	3.11	

Note. *PS* denotes the Puri and Sen test statistic where $PS_p = (n-1)\Delta R_p^2$ for variable *p*. There was no evidence of course grade differences by demographic characteristics (e.g., gender and race/ethnicity) after controlling for academic variables.

Table 2 shows that several variables significantly related to performance in general biology. Specifically, ACT Math scores ($b = 0.19$; $p < 0.01$), total credits earned ($b = 0.04$; $p < 0.001$), and high school calculus credits completed ($b = 1.03$; $p < 0.05$) positively related to grades in general biology. For instance, after controlling for the other variables in the model, a five-point difference in ACT Math Scores corresponded to nearly a one grade-level difference in biology (e.g., $0.19 \cdot 5 = 0.95$ or about a one-point change in course grade). Additionally, completing thirty semester credit hours (which is equivalent to transitioning from a freshman to a sophomore) prior to taking general biology was associated with approximately a 1.17 point difference in students' course grade level. Stated differently, we would expect a sophomore to earn, on average, one grade level higher than a freshman, a junior to earn, on average, one grade level higher than a sophomore, etc. High school calculus also impacted performance in general biology. In fact, students who completed one year of high school calculus tended to perform one grade level higher than their peers who had no calculus in high school.

Table 2 shows that the findings for general chemistry were similar to those for general biology. Specifically, ACT Math ($b = 0.33$; $p < 0.001$) and total credits earned ($b = 0.02$; $p < 0.05$) related to course grades. Interestingly, ACT Math scores were more related to performance in general chemistry than in general biology and total credits earned were less influential on general chemistry course grades. For example, a five-point difference in ACT Math scores was associated with a 1.65 grade-level difference in chemistry and completing thirty college credit hours was only associated with two-thirds of a difference in chemistry grades. The chemistry findings differed from general biology in another significant way because students who completed chemistry in high school ($b = 1.01$; $p < 0.05$) tended to perform better in general chemistry. That is, students who completed a year of chemistry with a lab in high school tended to earn a grade level higher than students who had no lab-based chemistry in high school.

The third column of Table 2 presents findings for college algebra. In fact, only two variables related to performance in college algebra: ACT Math scores ($b = 0.21$; $p < 0.01$) and high school credits completed in high school trigonometry ($b = 1.51$; $p < 0.001$). Again, a five-point difference in ACT Math scores related to a grade-level difference in course performance similar to general biology. The findings for college algebra also demonstrate the strongest relationship with high school course credits. Specifically, students who completed a year of trigonometry tended to achieve grades 1.5 grade levels higher than their peers with no trigonometry. Recall that Table 1 shows the average grade in college algebra was 6.0, or roughly a C+. Consequently, one way to think about the impact of completing a year of trigonometry is that students with high school trigonometry tended to earn approximately a B- to a B, on average.

Discussion

High school course selection significantly predicted outcomes in gateway mathematics and math classes, which suggests several considerations for policymakers and education communities. Specifically, this study supports the need to further examine required coursework and would suggest the following recommendations.

First, high schools should better align mathematics and science courses with post-secondary courses to increase the skill level of all students and improve the likelihood of student success in college mathematics and science courses. Second, this research indicates a significant relationship between higher-level mathematics courses and college success. Specifically, high school calculus correlated with higher success in biology, and high school trigonometry correlated with high success in college algebra. These findings not only support the need for sufficient mathematics preparation in high school, but it supports the need to identify college bound students early (in middle school) and to encourage them to take higher-level mathematics courses the last two years of high school.

Finally, success in high school chemistry positively related to success in college chemistry. Many students are not required to take chemistry, only three years of science with a variety of selection around which courses to enroll. Our findings suggest that all high school students who are planning on careers in the sciences, which require success in general college chemistry, should complete a lab-based high school chemistry course. Additionally, the significant relationship between high school chemistry and general chemistry in college suggests that high school and college chemistry courses were more aligned than the other science disciplines studied. That is, students who successfully completed a lab-based course in high school tended to earn better grades in college chemistry. A similar finding was identified for college algebra. Future research should study the alignment between high school and college courses in chemistry and mathematics to learn about best practices to transfer to other disciplines, such as biology and physics.

In conclusion, this study suggests that high school course selection improves college academic success in some disciplines. More research is needed to understand reasons as to why chemistry and college algebra exhibited greater alignment with high school courses.

Additionally, future researchers should examine the alignment between high school and college mathematics and science courses at the state and national levels in an effort to develop effective policies.

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