Journal of Pre-College Engineering Education Research (J-PEER)

Volume 10 | Issue 1 Article 7

2020

The Influence of Student Enrollment in Pre-College Engineering Courses on Their Interest in Engineering Careers

Kelly A. Miller
Harvard University, kmiller@seas.harvard.edu

Gerhard Sonnert
Harvard University, gsonnert@cfa.harvard.edu

Philip M. Sadler
Harvard University, psadler@cfa.harvard.edu

Recommended Citation

Miller, K. A., Sonnert, G., & Sadler, P. M. (2020). The Influence of Student Enrollment in Pre-College Engineering Courses on Their Interest in Engineering Careers. *Journal of Pre-College Engineering Education Research (J-PEER), 10*(1), Article 7.
https://doi.org/10.7771/2157-9288.1235

The Influence of Student Enrollment in Pre-College Engineering Courses on Their Interest in Engineering Careers

Abstract

Pre-college student enrollment in engineering courses increases every year in the United States, yet little is known about the relationship between taking these courses and subsequent science, technology, engineering, and mathematics (STEM) career interest. Through multinomial logistic regressions, and while controlling for student background variables and prior STEM career interest, this study addresses two research questions: (1) Does completing a pre-college engineering course increase the likelihood of an engineering career interest at the end of high school? (2) Does completing a pre-college engineering course have a different influence on career interest in engineering than on career interest in other STEM fields (namely science, technology, and mathematics)? The study uses data from the Outreach Programs and Science Career Intentions survey (N 5 15,847), a large U.S. sample of college students enrolled in mandatory English courses. Our analysis reveals that the relationship between completing a pre-college engineering course and interest in a STEM career appears to be field-specific. Students completing a pre-college engineering course were two times more likely to want to pursue an engineering career than those without such a course, after controlling for a host of other relevant variables. By contrast, taking a pre-college engineering course was not associated with heightened interest in other science, technology, or mathematics careers. These findings suggest that high schools should offer engineering courses as an effective way to foster students' career interest in engineering. This effect appears to apply similarly to all students, independent of gender, race/ethnicity, and other background variables.

Keywords

pre-college engineering, engineering career interest, STEM career interest

Document Type

Article

Available online at http://docs.lib.purdue.edu/jpeer

Journal of Pre-College Engineering Education Research 10:1 (2020) 90–102

The Influence of Student Enrollment in Pre-College Engineering Courses on Their Interest in Engineering Careers

Kelly A. Miller, Gerhard Sonnert, and Philip M. Sadler

Harvard University

Abstract

Pre-college student enrollment in engineering courses increases every year in the United States, yet little is known about the relationship between taking these courses and subsequent science, technology, engineering, and mathematics (STEM) career interest. Through multinomial logistic regressions, and while controlling for student background variables and prior STEM career interest, this study addresses two research questions: (1) Does completing a pre-college engineering course increase the likelihood of an engineering career interest at the end of high school? (2) Does completing a pre-college engineering course have a different influence on career interest in engineering than on career interest in other STEM fields (namely science, technology, and mathematics)? The study uses data from the Outreach Programs and Science Career Intentions survey ($N = 15{,}847$), a large U.S. sample of college students enrolled in mandatory English courses. Our analysis reveals that the relationship between completing a pre-college engineering course and interest in a STEM career appears to be field-specific. Students completing a pre-college engineering course were two times more likely to want to pursue an engineering career than those without such a course, after controlling for a host of other relevant variables. By contrast, taking a pre-college engineering course was not associated with heightened interest in other science, technology, or mathematics careers. These findings suggest that high schools should offer engineering courses as an effective way to foster students' career interest in engineering. This effect appears to apply similarly to all students, independent of gender, race/ethnicity, and other background variables.

Keywords: pre-college engineering, engineering career interest, STEM career interest

Introduction

Between 2013 and 2023, the United States was forecasted to experience an extreme shortage of science, technology, engineering, and mathematics (STEM) professionals (Atkinson, 2013; President's Council, 2010). The number of workers trained for STEM careers is insufficient to meet the country's rising need for those who are technically trained and scientifically literate (National Research Council, 2011). Almost 26 million jobs (20% of all jobs) in the United States require significant STEM knowledge and skill in at least one field (Rothwell, 2013). Studies show that a recent decrease in graduation rates in STEM fields (Coble & Allen, 2005; Cullinane, 2009; Dagley, Georgiopoulos, Reece, & Young, 2016) will exacerbate the STEM worker shortage. This shortfall of STEM-trained workers is a serious problem because it will hamper the ability of the United States to compete globally in an ever more technologically advanced and science-driven economy (Anderson & Kim, 2006; Chen & Weko, 2009; Dowd, Malcom, & Bensimon, 2009).

http://dx.doi.org/10.7771/2157-9288.1235

Because more students need to be interested in pursuing degrees in STEM fields in order to meet the growing demand for STEM workers, a strong focus has recently been placed on programs designed to increase the attainment of STEM degrees at both the bachelor and graduate levels (Augustine, 2005). Many national, state, and private agencies and foundations have developed and promoted programs intended to improve the overall quality of STEM education to both attract more students to STEM fields and better prepare them for the increasing technological demands of the 21st century (Kuenzi, 2008; White House, 2010). To boost student interest in STEM, many schools have developed activities and programs that promote discovery and innovation within the school curricula (e.g., Project Lead the Way, 2011). In this article, we focus specifically on the engineering courses that are increasingly being offered in high schools and investigate their impact on student career intentions.

i) STEM Career Choice

Research has shown that important factors in determining STEM career choice include student self-perception and identity (Hazari, Sonnert, Sadler, & Shanahan, 2010) and the development of student interest and engagement (Fouad & Smith, 1996; Fouad, Smith, & Zao, 2002; Lent, Brown, & Hackett, 1994; Tai, Liu, Maltese, & Fan, 2006). Self-perceptions and interests that inform career choices have been found to start developing at an early age and to be relatively stable throughout middle school and high school (Tracey & Robbins, 2005). Sadler, Sonnert, Hazari, and Tai (2012) found that the strongest predictor of STEM career interest at the end of high school was interest at the beginning of high school. The odds of students reporting a career interest in STEM at the end of high school were nine times higher for those who also reported interest in STEM careers at the beginning of high school than for those who did not report such an interest (Sadler et al., 2012). Sadler and colleagues also found that parental influences (such as parents' level of education or having a parent with an engineering- or science-related career) positively influenced student interest in a STEM career before high school, but were not significant predictors of STEM career interest at the end of high school (Sadler et al., 2012). Nevertheless, high-school coursework and out-of-school experiences have also been shown to have a profound impact on career choice (Dabney et al., 2012; Miller, Sonnert, & Sadler, 2018; Olson, 2009; Riegle-Crumb et al., 2011).

ii) Self-efficacy, Academic Preparedness, and Social Cognitive Career Theory

Student self-efficacy, defined as a student's belief in his/her own ability to be successful at a specific task, has been shown to be a strong predictor of college major concentration (Lent et al., 2008; Porter & Umbach, 2006). Tightly connected to STEM self-efficacy is academic preparedness. Students with high self-efficacy in STEM are more likely to enroll in STEM classes in high school, which improves their level of preparedness, and, in turn, their self-efficacy. Bandura (1977) theorized that an individual develops self-efficacy for a specific task through social and personal experiences. There are four categories of experiences: mastery experiences, vicarious learning experiences, social persuasion experiences, and an individual's physiological and affective state (Bandura, 1994, 1997). Mastery experiences are recurrent episodes of failure or success that students experience through active participation. Vicarious experiences involve observations of peers or role models performing a specific task. Social persuasion includes the verbal and nonverbal judgment of peers and teachers. Finally, a student's physiological and affective state refers to their mood, stress, anxiety, etc., during the performance of a task. Students draw on all four of these categories as sources of information in building their self-efficacy (Bandura, 1997; Britner & Pajares, 2006), and one can imagine that each of these could be affected by participation in a pre-college engineering course.

Academic preparedness, as measured both by which science and mathematics classes students take and by their performance in those classes, has been shown to be the strongest predictor for students' choice to pursue STEM in college (Crisp, Nora, & Taggart, 2009; Freehill, 1997; Levine & Wyckoff, 1991; Song & Glick, 2004). Many studies have shown the importance of high-school mathematics and science courses on students' decisions to pursue majors in STEM (Engberg & Wolniak, 2013; Gaertner, Kim, DesJardins, & McClarty, 2014; Trusty, 2002; Tyson, Lee, Borman, & Hanson, 2007). Poor preparation in mathematics and science is strongly connected to failure in engineering education (Budny, LeBold, & Bjedov, 1997). Conversely, completing advanced mathematics and science courses in high school predicts students' pursuit of STEM in college (Gottfried, 2015).

Research has shown that specific pre-college curricular programs designed to increase student participation in engineering, like Project Lead the Way, improve retention of engineering students from freshman to sophomore year (Utley, 2013). Research has also shown that specific pedagogies in high-school classes can increase student interest in STEM majors in college: Lee (2013), for example, found that using computer-based learning activities in pre-college math courses increases students' math self-efficacy which leads to an increase in the number of students interested in STEM majors in college.

Social Cognitive Career Theory (Lent et al., 1994) is a useful framework for understanding how both self-efficacy and academic preparedness are connected to career interest. According to Social Cognitive Career Theory, interests are a function of a person's self-efficacy beliefs and their outcome expectations. If persons believe that the pursuit of a specific

http://dx.doi.org/10.7771/2157-9288.1235

career will lead to desirable outcomes and that they will perform well, then they will express interest in that career. When persons have positive experiences with activities related to a specific career and develop skills and expertise to do well in it (through academic preparedness, for example), it is more likely that those persons will develop strong self-efficacy and positive outcome expectations for that career. The model also implies that, when persons are not exposed to positive experiences that help develop self-efficacy and positive outcome expectations specific to a particular career, they are unlikely to be interested in pursuing that career.

iii) Pre-college Engineering Education

In the efforts to improve STEM education in elementary and secondary schools, little attention was paid, historically, to the issue of engineering education. Engineering has not traditionally been thought of as a subject in K–12 education (National Academy of Sciences, 2009). In 2006, the National Academy of Engineering and the National Research Council Center for Education established the Committee on K–12 Engineering Education to study the state of engineering education in American schools and to determine which "policies, programs, and practices at the local, state, and federal levels might lead to the meaningful inclusion of engineering in K–12 education in the United States" (National Academy of Sciences, 2009, p. 21). Since then, the role and influence of engineering education before college have increased substantially (Carr, Bennett, & Strobel, 2012; Community for Advancing Discovery Research in Education, 2013). Many schools across the United States have now incorporated engineering into their curriculum, and active research on high-school engineering programs is also growing (Committee on Integrated STEM Education, 2009; Community for Advancing Discovery Research in Education, 2013). Despite the growth in pre-engineering curriculum and research, according to a 2010 report, less than 10% of the school-age population was involved in formal pre-college engineering education between 1995 and 2010 (Committee on Standards for K–12 Engineering Education, 2010). With some notable exceptions (Project Lead the Way, 2011; Salzman & Lowell, 2007), research on the impact of these pre-college engineering courses on college and career outcomes is lacking. The laudable exception is Phelps, Camburn, and Min (2018), who published a study on the relationship between high-school engineering and engineering technology (E&ET) course completion and choosing a STEM major in a two- or four-year college. They found that students who completed three E&ET credits were 1.60 times more likely to enroll in a STEM major in a four-year institution, compared with students who did not take any E&ET courses (Phelps et al., 2018).

We wish to add to these findings and augment the knowledge base about pre-college engineering by examining three complementary aspects in terms of the employed controls, the choice, and the specificity of the outcome variable. First, while the Phelps et al. (2018) study controlled for many demographic and academic preparedness variables, it did not control for students' prior STEM interest, which has been shown to be the most important predictor of interest in STEM at the end of high school. We want to identify the net impact of taking a pre-college engineering course on career interest, controlling for the level of pre-high-school interest in engineering. Controlling for prior interest could possibly reduce the effect found in this study.

Second, whereas the study of Phelps et al. looked at STEM program enrollment, we use a slightly different outcome variable: career interest. Third, because Phelps and colleagues focused on the relationship between pre-college engineering course completion and enrollment in STEM in general, they did not determine whether there was a relationship between taking a high-school engineering class and interest in engineering, specifically.

Research Questions

The purpose of this study is to explore the connection between student enrollment in pre-college engineering courses and STEM career interest, particularly interest in engineering. It addresses the following two research questions: First, controlling for student background variables and prior STEM career interest, does completing a pre-college engineering course increase the likelihood of an engineering career interest at the end of high school? Second, does completing a pre-college engineering course have a different influence on career interest in engineering than on career interest in other STEM fields (namely science, technology, and mathematics)?

Methods

i) Survey and Sample

The data for this study come from a large sample of students enrolled in both four-year and two-year programs at American institutions of higher learning that participated in the Science, Technology, Engineering, and Mathematics Talent

Expansion Program (STEP) of the National Science Foundation. Students in this study completed the Outreach Programs and Science Career Intentions (OPSCI) survey, funded by the National Science Foundation in the context of the STEP initiative. We collected the data in Fall 2013, administering this survey mostly to freshmen (79.7%) enrolled in English courses that were required by the institution. In this way, we were able to target students with a wide range of career interests (both in and outside of STEM). Recruitment emails were sent to English Department Chairs at 150 institutions across the United States, soliciting involvement in the study. Of these, 104 institutions did not respond. Out of the 46 institutions that did respond, 27 (59%) participated with at least one instructor. Of the 535 instructors who initially agreed to participate in the study, 414 followed through and returned 15,847 completed student surveys. Most of the 27 institutions were four-year public institutions, except for three institutions that were two-year community colleges and two institutions that were private. Aside from the three community colleges, all of the institutions offered engineering and STEM bachelor-level majors. The students completed the surveys in class and on paper, and therefore there was virtually complete student participation.

Prior to the data collection, a pilot test of the OPSCI survey was conducted with 67 students at a single university. The test–retest reliability was determined with a subset ($N = 57$) of these students who completed the survey twice, two weeks apart. The Pearson correlation coefficient between the test and retest responses was used to determine the reliability for the questions with responses on a continuous scale. For questions with categorical responses, Cohen's kappa was calculated as a measure of reliability. The mean of the correlation coefficients was 0.73 and the mean of the Cohen's kappas was 0.59. A kappa between 0.60 and 0.79 is considered substantial (Landis & Koch, 1977), and our survey is very close to that range.

ii) Dependent Variable: Career Interest at the End of High School

The question from the survey that is central for this analysis asks about students' career intentions at various stages in their education up to that point (see Figure 1). Specifically, Question 1 on the survey asks *"Which of the following describes what you want(ed) to be in middle school, high school (beginning and end), and college?"*

The question is followed by a list of 29 different professions. Students were told to mark all that applied. For the purpose of our analysis, we grouped the 29 professions into one of three categories: engineering careers (choices h–p), science, technology, and mathematics careers (choices c–g, q–u, and w), and non-STEM careers (choices a, b, v, and x–aa). The underlying definition of STEM corresponds to that used by the National Science Foundation (Bray, 2010). Previous research has shown that self-reported surveys involving recall of prior experiences are reasonably reliable.[1]

We use career interest at the end of high school as our dependent variable. At the end of high school, 61% of the respondents expressed interest in a non-STEM career, 17% expressed interest in an engineering career, and 22% expressed interest in a career in science, technology, and mathematics, or STM (i.e., STEM minus engineering).

iii) Independent Variable of Interest: Pre-college Engineering Courses

Question 13 from the survey asks students if they took a high-school engineering class, and, if they did, to indicate the level (regular, honors, advanced, International Baccalaureate, and dual enrollment). Dual enrollment refers to the situation where high-school students enroll in college or university courses concurrently while attending high school. Out of the 15,847 respondents, 1,237 (8.5%) indicated that they had taken a pre-college engineering course. Of the students who took a pre-college engineering course, the majority (73%) took a regular engineering class in high school. Of the remaining, 18% took an honors engineering class (in high school), 4% took an advanced engineering class, 1% took an International Baccalaureate engineering class, and 4% took an engineering course through dual enrollment. For the purposes of this study, we collapsed the four levels into a single dichotomous variable: having taken a pre-college engineering course, or not.

[1]Accurate recall by subjects is essential and possible, even though those unfamiliar with the research literature often view self-reporting as inherently unreliable. Self-report surveys (even concerning such touchy subjects as drug usage) can be reasonably reliable (Oetting & Beauvais, 1990). The shape of the "forgetting curve" for such data is very nearly linear for recall of information similar to that which we will collect and is remarkably low, decreasing at a rate of only 3% each year in a study lasting 12 years. Bradburn (2000) explains that recall of this information encoded in an organized fashion can be quite reliable, especially if contextual cues are included in the survey instrument. The accuracy and reliability of self-report depend primarily on context, relevance, and survey clarity (Bradburn, 2000; Niemi & Smith, 2003; Pace, Barahona, & Kaplan, 1985). In a recent review of existing research on self-report, Kuncel, Credé, and Thomas (2005) conclude that self-report may be characterized as particularly accurate in samples where the surveys address issues relevant to the respondents. As such, our surveys are conducted in fall-semester college classes where the new college students' reflections on their prior experience are commonplace. In addition, the students' own instructors administer the surveys. We have generally conducted reliability studies of students taking our surveys twice, two weeks apart. Comparisons of their responses found them to be highly reproducible (Tai, Sadler, & Loehr, 2005).

http://dx.doi.org/10.7771/2157-9288.1235

ABOUT YOUR CAREER PLAN DEVELOPMENT

1. Which of the following describes what you want(ed) to be in middle school, high school (beginning and end), and in college? Mark all that apply. Leave blank those that don't apply.	Middle School	Beginning of High School	End of High School	Beginning of first semester of College
a. Medical professional (e.g. doctor, dentist, vet)				
b. Health professional (e.g. nurse, pharmacist)				
c. Biologist				
d. Earth/ Environmental scientist				
e. Astronomer				
f. Chemist				
g. Physicist				
h. Engineer (in general)				
i. Mechanical engineer				
j. Electrical engineer				
k. Civil engineer				
l. Chemical engineer				
m. Bio/Medical engineer				
n. Environmental engineer				
o. Industrial engineer				
p. Engineering technologist				
q. Computer scientist/ Programmer				
r. Other scientist				
s. Mathematician, statistician				
t. Science teacher				
u. Math teacher				
v. Other teacher				
w. Social scientist (e.g. psychologist, sociologist)				
x. Business person (e.g. entrepreneur, manager)				
y. Lawyer				
z. English/ Language Arts specialist				
aa. Sports-related (e.g. athlete, coach)				

Figure 1. Question 1 on career interest from the OPSCI survey.

iv) Key Control Variable: Prior Interest in STEM

Because we are examining the influence of taking an engineering course during high-school years on career interest at the end of high school, we used interest in STM and interest in engineering during middle school, as well as the same career interests at the beginning of high school, as control variables. Although student interest in STEM careers remains relatively stable during high school, significant numbers of students switch from being interested in STEM to disinterested (and vice versa) over the high-school years (Sadler et al., 2012). In addition, the survey contained a rating-scale question about students' interest in science during middle school (from 0 "not interested at all" to 5 "extremely interested"). This variable was also included as a control.

v) Other Control Variables: Demographic and Background Factors

Interest in a STEM career depends on many factors, in addition to interest in STEM during middle school or at the beginning of high school and the potential influence of taking a pre-college engineering course. Consequently, we control for a number of demographic and background factors in our statistical models.

A strong predictor for pursuit of a STEM career is academic preparedness, as measured by both which science and mathematics courses students take and their performance in these courses (Crisp et al., 2009; Freehill, 1997; Levine & Wyckoff, 1991; Song & Glick, 2004). Therefore, we control for a number of academic-preparedness variables. These control variables include whether or not students took high-school calculus or high-school physics, the number of other high-school STEM classes taken (excluding calculus and physics), and their Scholastic Aptitude Test (SAT) mathematics score. If students took the American College Testing (ACT)[2] mathematics test instead, that score was mapped onto the SAT scale, using a concordance published by the College Board (1999).

Given that another strong predictor for the pursuit of a STEM career is the career of the students' parents and the level of encouragement and support for science that students receive at home, we also control for students' backgrounds related to their families. These background variables include whether STEM was involved in the father's and/or mother's career, whether the father and/or the mother was encouraging of a STEM career, and a five-point rating scale about the general level of home support for science (from "not supportive" to "very supportive"). Lastly, we also controlled for demographic variables like gender (male = 1; female = 0) and race/ethnicity (Black, Asian, other, Hispanic, and White [reference group]).

All non-dichotomous control variables were standardized before being entered in the models.

vi) Analysis

We first built a logistic regression model to quantify the relationship between interest in STEM (any sub-discipline) and having taken a pre-college engineering course (controlling for background and demographic variables discussed). Then we built two multinomial regression models (Models I and II in Table 1) to quantify the relationship between career interest in engineering and STM, respectively, and having taken a pre-college engineering course. With these models, we calculated the odds ratio for interest in a career in engineering (Model I) and for interest in a career in STM (Model II), compared with the baseline condition of interest in neither engineering nor STM for students who took pre-college engineering courses, compared with those who did not (and controlling for the background and demographic variables discussed above).

Many factors that we used as controls in our models covary with the variable of interest. For example, students who take a pre-college engineering course are much more likely to also be interested in an engineering career at the beginning of high school. The first two columns of Table 2 show the differences between the students who did and did not take pre-college engineering. The third column shows the levels of significance for two-tailed *t*-tests between the two samples. This table shows that 39.9% of the students who took pre-college engineering were interested in an engineering career at the beginning of high school, compared with 10.9% of the students who did not take pre-college engineering ($p < 0.001$). Table 2 shows that there are significant differences between the two samples for most of the control variables used in our models. Given this, in the final stage of the analysis, we built two additional multinomial regression models (Models III and IV in Table 1) with the same variables as the first two, but using a matched sample to control for inherent differences between the population of students who took pre-college engineering and those who did not. To do this, we used propensity score matching by applying the psmatch2 command in STATA (Leuven & Sianesi, 2018). This technique tries to force covariates to be as similar as possible between two samples by choosing to include paired members from each sample who are similar

[2] Both ACT and SAT scores are standardized tests used for college admissions and merit-based scholarships in the United States. Colleges allow students to take either for admissions. Both tests generally cover the same content. The biggest difference between them is that the SAT has one mathematics section for which students are not allowed to use calculators.

Table 1
Summary of multinomial logistic regression models (reference group: no interest in engineering or STM).

	Model I	Model II	Model III	Model IV
	Unmatched		Matched	
	Interest in engineering	**Interest in STM**	**Interest in engineering**	**Interest in STM**
N	15,847	15,847	2,368	2,368
	OR	**OR**	**OR**	**OR**
Constant	0.04***	0.19***	0.06***	0.19***
Took pre-college engineering course	2.12***	1.01	1.95***	1.03
Interest in engineering beginning of high school	8.98***	1.37**	9.24***	1.52*
Interest in STM beginning of high school	1.23**	1.42***	1.42*	1.71***
Interest in engineering middle school	1.30**	1.22*	1.12	1.14
Interest in STM middle school	1.84***	3.11***	1.59***	3.04***
Interest in science middle school	1.24***	1.10***	1.33***	1.11
ACT/SAT mathematics score	1.53***	1.05	1.51***	1.05
Took calculus	1.28**	1.02	1.03	1.00
Took physics	1.52***	1.17**	1.60*	1.15
Number of STEM courses (excluding physics and calculus)	0.89**	0.98	0.84*	0.88
Mother/father encouraged STEM	1.75***	1.18**	1.71***	1.38
Mother/father career involved STEM	0.83*	0.97	0.84	0.93
Level of home support	1.02	1.04	1.02	1.03
Mother/father education	0.97	0.92**	0.95	0.89
Gender (male = 1)	2.93***	1.21***	2.15***	1.21
Race (reference: White)				
Black	1.34*	0.80**	1.36	0.86
Asian	1.06	1.06	0.84	0.97
Other	1.59***	1.06	1.70	1.17
Hispanic	1.17	0.90	0.84	0.78

***$p < 0.001$, **$p < 0.01$, *$p < 0.05$.

to each other on all the included covariates. Using a matched sample allows us to make stronger causal claims between the independent variable of interest (having taken a pre-college engineering course) and the outcome variable (end-of-high-school interest in an engineering career). The last three columns of Table 2 show the difference (and levels of significance) between the matched population of students who did and did not take pre-college engineering. From this we can see that there are almost no significant differences between the (matched) students who did and did not take pre-college engineering.

Finally, we tested all interactions in both the matched and unmatched models and found no significant interactions in either model.

Results

i) STM and Engineering Interest in Middle School and the Beginning of High School, Compared with the End of High School

Figure 2 displays a Sankey diagram to aid in the comparison of the numbers of students interested in a STM- and engineering-related career in middle school, at the beginning of high school, and at the end of high school. It shows a net gain of students interested in engineering from middle school to the beginning of high school to the end of high school. For STM, the number of interested students increases from middle school to the beginning of high school and then decreases slightly between the beginning and end of high school.

During high school, more students switch from being uninterested in STEM to interested in both engineering and STM than those who switch from being interested to uninterested.

Using only the matched sample, we calculated the percentages of students interested in engineering at the end of high school, conditional on their prior interest in engineering and their taking an engineering course. Of the students who were not interested in engineering at the beginning of high school and who did not take engineering in high school, 15.2% became interested by the end of high school. Of the students who were not interested in engineering at the beginning of high school and who did take engineering in high school, 28.6% became interested by the end of high school. Of the students who were already interested in engineering at the beginning of high school and who did not take engineering in high school,

Table 2
Comparison of matched and unmatched predictors with significance testing.

	Took pre-college engineering	Did not take pre-college engineering		Took pre-college engineering	Did not take pre-college engineering	
	(n = 1,184)	(n = 14,663)	Sig.	(n = 716)	(n = 730)	Sig.
Gender (male = 1)	69.9	42.1	***	70.0	73.2	-
Race/ethnicity						
White	51.0	52.4		51.0	53.0	-
Black	7.8	10.0	*	7.8	7.9	-
Asian	15.7	9.0	***	15.7	12.7	*
Other	7.1	3.2		8.1	8.9	-
Hispanic	15.5	18.4	*	15.5	15.5	-
Interest in engineering career in middle school	29.2	8.3	***	29.2	31.5	-
Interest in STM career in middle school	25.2	21.1	**	25.2	23.4	-
Interest in engineering career at beginning of high school	39.9	10.9	***	39.9	42.8	-
Interest in STM career at beginning of high school	40.4	45.6	***	40.4	37.3	-
Interest in science in middle school	3.5	3.0	***	3.5	3.5	-
ACT/SAT mathematics score	576.0	528.7	***	576.0	573.5	-
Took calculus	26.1	12.3	***	26.1	23.5	-
Took physics	77.1	42.0	***	77.1	71.7	**
Number of STEM courses (excluding physics and calculus)	5.8	3.0	***	5.8	5.2	***
Mother/father encouraged STEM	32.7	23.8	***	32.8	33.3	-
Mother/father career involved STEM	36.0	33.5	-	36.0	37.4	-
Level of home support	3.3	3.2	**	3.3	3.3	-
Mother/father education	3.4	3.3	**	3.4	3.5	-

***$p < 0.001$, **$p < 0.01$, *$p < 0.05$.

64.3% remained interested at the end of high school. Of the students who were interested in engineering at the beginning of high school and who did take engineering in high school, 72.4% remained interested at the end of high school.

In the subsequent sections, we model the relationship between taking an engineering course during high school and interest in STEM, engineering, and STM at the end of high school, controlling for student interest at the beginning of high school and during middle school.

ii) STEM Career Interest and Completion of a Pre-college Engineering Course

Based on a logistic regression model predicting interest in any STEM-related career at the end of high school (not shown), students who take pre-college engineering have 1.95 times the odds ($p < 0.0001$) of being interested in a career in engineering, compared with students who did not take pre-college engineering.

Because the focus of this article lies in determining the relationship between taking pre-college engineering and interest in pursuing a career specifically in engineering or some other STEM-related field, we estimated multinomial logistic regression models with a three-level dependent variable: career interest in engineering and career interest in STM, which are compared with the baseline level of no career interest in STEM. The independent variable is a dichotomous variable—taking a pre-college engineering course or not.

Models I and II are based on the entire sample, whereas Models III and IV are based on a sample that matches each student who took pre-college engineering with a counterpart who did not take pre-college engineering, but resembled that student on all other model variables, as explained above. Table 1 summarizes the odds ratios of each model for both levels of the dependent variable. Table 2 summarizes the differences between the unmatched and matched samples for students who took pre-college engineering, compared with students who did not take pre-college engineering. Two-tailed t-tests were performed to compare the two populations in both the unmatched and matched samples. In the unmatched sample, for example, 70% of the students who took pre-college engineering are male, compared with 42% of the students who did not take pre-college engineering ($p < 0.001$). In the matched sample, on the other hand, there is no longer any statistically significant difference in gender composition between the group that took pre-college engineering and the group that did not (70% vs. 73% males). Table 2 shows that, in the matched sample, with the exception of three variables (Asian, took physics, and the number of

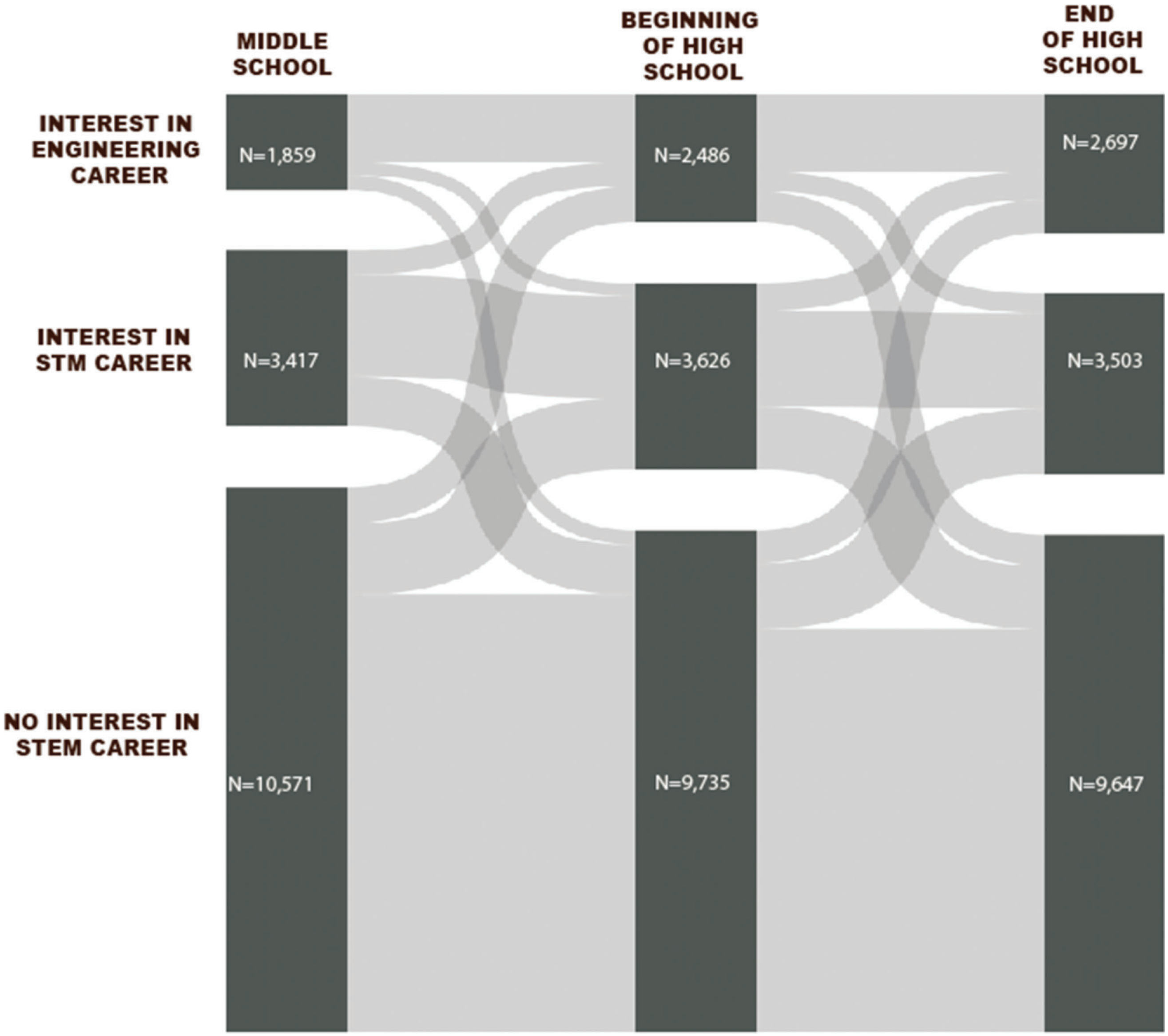

Figure 2. Sankey diagram comparing the number of students interested in an engineering- and STM-related career in middle school, at the beginning of high school, and at the end of high school.

STEM courses taken), all of the statistically significant differences between the group who took pre-college engineering and the group who did not in the unmatched sample disappear.

For all models presented in Table 1, we control for the prior interest variables (interest in engineering and STM careers at the beginning of high school and in middle school, science interest in middle school), preparedness variables (STEM courses taken and ACT/SAT mathematics score), and background variables (parents' careers, levels of education, and general level of home support for science) described earlier.

Table 1 provides a summary of the odds ratios (and significance levels) for each model. Based on the odds ratios of Model I (unmatched sample), students who take a pre-college engineering course have 2.12 times ($p < 0.001$) higher odds of being interested in a career in engineering (as opposed to a non-STEM career) than students who did not take pre-college engineering, after controlling for the other predictors present in the model. The strong predictive relationship between interest in a career in engineering and having taken a pre-college engineering course persists in Model III (based on the matched sample). Model III indicates that students who take a pre-college engineering course have 1.95 times ($p < 0.001$) higher odds of being interested in pursuing a career in engineering than students who did not take pre-college engineering. Table 2 also shows that there is no statistically significant relationship between interest in a career in STM and taking a pre-college engineering course, regardless of whether we look at the unmatched model (Model II) or the matched model (Model IV). Especially in light of the refined controls of the matched sample model, these results indicate that taking pre-college engineering specifically boosts students' career interest in engineering, but has no significant impact on career interest in other STEM disciplines.

It is worth mentioning that, in the matched sample, male students have 2.15 times higher odds of being interested in engineering than female students. The matched sample also shows that students interested in engineering at the beginning of high school have 9.24 times higher odds of being interested in engineering at the end of high school than students not interested in engineering at the beginning of high school. While these data suggest that pre-high-school interest in engineering is important, the strength of this study is that, after controlling for pre-high-school interest, we still see that taking a pre-college engineering class in high school is a statistically significant predictor for interest at the end of high school and thus makes a difference in young persons' career plans.

We found no significant interactions between taking a pre-college engineering course and gender, race/ethnicity, or any other control variable. This supports the conclusion that taking an engineering course in high school has a similarly large effect on engineering career interest across the whole student population, independent of gender, race/ethnicity, academic preparation, and interest in a STEM career at the beginning of high school.

Conclusions and Implications

The purpose of this study was to investigate the influence of taking a pre-college engineering course on STEM career interest, specifically in engineering. Three results of the logistic and multinomial regression models shed light on how completion of a pre-college engineering course influences STEM career interest.

First, we find that students who take a pre-college engineering course have 1.95 times higher odds of being interested in pursuing a career in STEM (in general), as opposed to a non-STEM career, than do students who did not take a pre-college engineering course. Our finding of a positive relationship between taking a pre-college engineering course and career interest in general STEM dovetails with that made by Phelps and colleagues (2018), who found that students were 1.60 times as likely to enroll in a STEM major in college if they took three pre-college engineering credits, compared with students who did not take any pre-college engineering. Because our study controls for prior STEM interest, we are able to better measure the direct effect of taking a pre-college engineering class on career interest, disentangling the effect of the course itself from prior interest in STEM, which almost certainly motivated many students to take engineering courses in the first place.

Second, we find that students who take a pre-college engineering course have 2.12 times higher odds of being interested in pursuing a career in engineering specifically (as opposed to a non-STEM career) than do students who did not take pre-college engineering. Third, there appears to be no significant relationship between taking a pre-college engineering course and interest in pursuing a career in other, non-engineering-related STEM fields (i.e., STM). The fact that our study looks precisely at career interest in engineering and separates it from interest in other STM careers allows us to uncover the specificity of the relationship between pre-college engineering courses and subsequent career interest. Whereas students who take pre-college engineering are more likely to be interested in an engineering career, they are not more likely to be interested in a STM career. This specificity is interesting and unobserved in previous studies. Some might have expected that a pre-college engineering course would provide a general boost for STEM career interests (including non-engineering fields); others might have thought that exposing students to pre-college engineering experiences would reduce interest in other fields in STEM. However, we see, through our matched model, that pre-college engineering has no significant impact on STM interest (in either direction). Whereas Phelps and colleagues (2018) found an overall increase in odds for STEM enrollment globally, our smaller "grain size" suggests that the odds ratio reported in that study is some kind of a weighted average of a higher odds ratio for engineering and a fairly constant odds ratio for STM.

As mentioned, according to Social Cognitive Career Theory, self-efficacy plays a crucial role in explaining the specific relationship between pre-college engineering courses and engineering career interest. It is possible that taking a pre-college engineering course has a positive effect on students' self-efficacy in engineering specifically (through both mastery and vicarious experiences, for example). Self-efficacy has been shown to predict both academic and career-related choices (Lent et al., 1994), and, therefore, improving self-efficacy within a specific content domain may increase the likelihood of someone choosing a career associated with that domain.

We acknowledge that this study has some limitations. It is a correlational study; hence causation is not clearly proven. Although we have carefully controlled for many relevant predictors of interest in a STEM career by creating a matched sample, we cannot say with certainty that taking a pre-college engineering course causes students to be interested in a career in engineering. Additionally, the survey instrument itself imposes some limitations on this study. For example, the survey did not ask students whether an engineering course was actually available for them to take during high school. For that reason, we are not able to control for access to a pre-college engineering course. It is possible that many of the students who were interested in engineering at the beginning of high school but did not take an engineering course during high school might have taken such a course, had it been available to them.

We also do not know what motivates students to take pre-college engineering. By using a sample that is matched on all control variables, we have managed, to a certain extent, to deal with inherent differences between students who took pre-college engineering courses and those who did not. Despite this, we know little about the factors that influence a student's decision to take pre-college engineering courses in the first place. Further research on student motivation would add insight to this.

In conclusion, this study provides evidence that supports pre-college engineering courses as an effective way to foster career interest in engineering during the high-school years. The specificity of the relationship between course type and career interest should be of particular interest to the policy makers and school administrators who promote pre-college engineering courses with hopes of attracting more students to pursue careers in STEM. Encouraging students to take engineering in high school, for example, may do nothing to influence their career interest in non-engineering-related STEM fields. Overall, while some might not consider the effect found in this research to be a major one, educators and policy makers introducing engineering classes into the high-school curriculum can be reasonably assured that their efforts are having a positive impact on students' career choices when it comes to engineering, and that the shortage of trained workers in engineering could be mitigated by encouraging more high-school students to take engineering courses.

Acknowledgments

This work was supported by the National Science Foundation [grant number 1161052]. Any opinions, findings, and conclusions in this article are the authors' and do not necessarily reflect the views of the National Science Foundation. Without the excellent contributions of many people, the OPSCI project would not have been possible. We thank the members of the OPSCI team: Wendy Berland, Zahra Hazari, Tyler Scott, and Annette Trenga. We would also like to thank several STEM educators and researchers who provided advice or counsel on this project: Rocco Cieri, Katherine Dabney, Connie Della-Piana, Robert Andrew Kolvoord, Chandra Muller, Matthew Ohland, Harriet Page, Barbara J. Speziale, and Christos Zahopoulos. Last but not least, we are grateful to the many college English professors and their students who gave up a portion of a class to provide data.

Author Bios

Kelly A. Miller is a senior preceptor in applied physics at the School of Engineering and Applied Sciences at Harvard University. Her research interests broadly include physics and engineering education. More specifically, she is interested in student self-efficacy and the use of technology and interactive teaching strategies in college STEM education. She is the co-founder of Perusall, a social annotation software used to help support flipped classrooms.

Gerhard Sonnert is a lecturer on astronomy at Harvard University and a research associate in the Harvard College Observatory. His research interests include astrosociology, space exploration, gender in science, science education, science policy, history of science, and migration.

Philip M. Sadler directs the CFA's Science Education Department and is F.W. Wright Senior Lecturer in Astronomy. He has taught pre-college math, science, and engineering, undergraduate science, and graduate teaching courses. He has won the JRST Annual Award, the AAS Education Prize, and the AAPT Millikan Medal.

References

Anderson, E., & Kim, D. (2006). *Increasing the success of minority students in science and technology*. Washington, DC: American Council on Education.

Atkinson, R. (2013). A short and long-term solution to America's STEM crisis. The Hill. <http://thehill.com/blogs/congress-blog/technology/287435-a-short-and-long-term-solution-to-americas-stem-crisis>.

Augustine, N. R. (2005). *Rising above the gathering storm: Energizing and employing America for a brighter economic future*. Retrieved March 19, 2008, from mdworkforce.com

Bandura, A. (1977). Self-efficacy: Toward a unifying theory of behavioral change. *Psychological Review*, *84*(2), 191–215.

Bandura, A. (1994). Self-efficacy. In Ramachaudran V. S. (Ed.), *Encyclopedia of human behavior* (Vol. 4, pp. 71–81). New York, NY: Academic Press.

Bandura, A. (1997). *Self-efficacy: The exercise of control*. New York, NY: Macmillan.

Bradburn, N. (2000). Temporal representation and event dating. In Stone A. A, Turkan J. S, Bachrach C. A, Jobe J. B, Kurtzman H. S, & Cain V. S. (Eds.), *The science of self-report* (pp. 49–61). Mahwah, NJ: Lawrence Erlbaum Associates.

Bray, J. H. (2010). *Psychology as a core science, technology, engineering, and mathematics (STEM) discipline*. Washington, DC: American Psychological Association.

Britner, S. L., & Pajares, F. (2006). Sources of science self-efficacy beliefs of middle school students. *Journal of Research in Science Teaching*, *43*(5), 485–499.

Budny, D., LeBold, W., & Bjedov, G. (1997, November). Assessment of the impact of the freshman engineering courses. In *Proceedings Frontiers in Education 1997, 27th Annual Conference. Teaching and Learning in an Era of Change* (Vol. 2, pp. 1100–1106). IEEE.

Carr, R. L., Bennett IV, L. D., & Strobel, J. (2012). Engineering in the K–12 STEM standards of the 50 U.S. states: An analysis of presence and extent. *Journal of Engineering Education*, *101*(3), 539–564.

Chen, X. (2009). Students Who Study Science, Technology, Engineering, and Mathematics (STEM) in Postsecondary Education. Stats in Brief. NCES 2009-161. National Center for Education Statistics.

Chen, X., & Weko, T. (2009). Students who study science, technology, engineering, and mathematics (STEM) in postsecondary education. Washington, DC: U.S. Department of Education, NCES, 2009-161. http://nces.ed.gov/pubs2009/2009161.pdf

Coble, C., & Allen, M. (2005). *Keeping America competitive: Five strategies to improve mathematics and science education*. Denver, CO: Education Commission of the States. Retrieved October 9, 2010, from http://www.ecs.org/clearinghouse/62/19/6219.pdf

Committee on Standards for K–12 Engineering Education. (2010). *Standards for K–12 engineering education*. Washington, DC: National Academies Press.

Committee on K–12 Engineering Education. (2009). *Engineering in K–12 education: Understanding the status and improving the prospects*. Washington, DC: National Academies Press.

Community for Advancing Discovery Research in Education. (2013). *Engineering: Emphasizing the "E" in STEM education*. Boston, MA: Education Development Center.

Crisp, G., Nora, A., & Taggart, A. (2009). Student characteristics, pre-college, college, and environmental factors as predictors of majoring in and earning a STEM degree: An analysis of students attending a Hispanic serving institution. *American Educational Research Journal*, *46*(4), 924–942.

Cullinane, J. (2009). *Diversifying the STEM pipeline: The Model Replication Institutions Program*. Washington, DC: Institute for Higher Education Policy.

Dabney, K. P., Tai, R. H., Almarode, J. T., Miller-Friedmann, J. L., Sonnert, G., Sadler, P. M., & Hazari, Z. (2012). Out-of-school time science activities and their association with career interest in STEM. *International Journal of Science Education, Part B*, *2*(1), 63–79.

Dagley, M., Georgiopoulos, M., Reece, A., & Young, C. (2016). Increasing retention and graduation rates through a STEM learning community. *Journal of College Student Retention: Research, Theory & Practice*, *18*(2), 167–182.

Dorans, N. J. (1999). Correspondences between ACT™ and SAT® I scores. *ETS Research Report Series*, *1999*(1), i–18.

Dowd, A. C., Malcolm, L. E., & Bensimon, E. M. (2009). *Benchmarking the success of Latina and Latino students in STEM to achieve national graduation goals*. Los Angeles, CA: University of Southern California.

Engberg, M., & Wolniak, G. C. (2013). College student pathways to the STEM disciplines. *Teachers College Record*, *115*(1), 103–104.

Fouad, N. A., & Smith, P. L. (1996). A test of a social cognitive model for middle school students: Math and science. *Journal of Counseling Psychology*, *43*(3), 338–342.

Fouad, N. A., Smith, P. L., & Zao, K. E. (2002). Across academic domains: Extensions of the social-cognitive career model. *Journal of Counseling Psychology*, *49*(2), 164–172.

Freehill, L. M. (1997). Education and occupational sex segregation: The decision to major in engineering. *Sociological Quarterly*, *38*(2), 225–249.

Gaertner, M. N., Kim, J., DesJardins, S. L., & McClarty, K. L. (2014). Preparing students for college and careers: The causal role of algebra II. *Research in Higher Education*, *55*(2), 143–165.

Gottfried, M. A. (2015). The influence of applied STEM coursetaking on advanced mathematics and science coursetaking. *Journal of Educational Research*, *108*(5), 382–399.

Hazari, Z., Sonnert, G., Sadler, P. M., & Shanahan, M. C. (2010). Connecting high school physics experiences, outcome expectations, physics identity, and physics career choice: A gender study. *Journal of Research in Science Teaching*, *47*(8), 978–1003.

Kuenzi, J. J. (2008). Science, technology, engineering, and mathematics (STEM) education: Background, federal policy, and legislative action. *Congressional Research Service Reports*, 35. https://digitalcommons.unl.edu/crsdocs/35

Kuncel, N., Credé, M., & Thomas, L. (2005). The validity of self-reported grade point averages, RICs, and test scores: A meta-analysis and review of the literature. *Review of Educational Research*, *75*(1), 63–82.

Landis, J. R., & Koch, G. G. (1977). An application of hierarchical kappa-type statistics in the assessment of majority agreement among multiple observers. *Biometrics*, *33*(1), 363–374.

Lee, A. (2013). Determining the effects of pre-college STEM contexts on STEM major choices in 4-year postsecondary institutions using multilevel structural equation modeling. *Journal of Pre-College Engineering Education Research (J-PEER)*, *3*(2), 3.

Lent, R. W., Brown, S. D., & Hackett, G. (1994). Toward a unifying social cognitive theory of career and academic interest, choice, and performance. *Journal of Vocational Behavior*, *45*(1), 79–122.

Lent, R. W., Sheu, H., Singley, D., Schmidt, J. A., Schmidt, L. C., & Gloster, C. S. (2008). Longitudinal relations of self-efficacy to outcome expectations, interests, and major choice goals in engineering students. *Journal of Vocational Behavior*, *73*(2), 328–335.

Leuven, E., & Sianesi, B. (2018). PSMATCH2: Stata module to perform full Mahalanobis and propensity score matching, common support graphing, and covariate imbalance testing. https://EconPapers.repec.org/RePEc:boc:bocode:s432001

Levine, J., & Wyckoff, J. (1991). Predicting persistence and success in baccalaureate engineering. *Education*, *111*(4), 461–468.

Miller, K., Sonnert, G., & Sadler, P. (2018). The influence of students' participation in STEM competitions on their interest in STEM careers. *International Journal of Science Education, Part B*, *8*(2), 95–114.

National Research Council. (2011). *Successful K–12 STEM education: Identifying effective approaches in science, technology, engineering, and mathematics*. Washington, DC: National Academies Press.

Niemi, R., & Smith, J. (2003). The accuracy of students' reports of course taking in the 1994 National Assessment of Educational Progress. *Educational Measurement: Issues and Practice*, *22*(1), 15–21.

Oetting, E. & Beauvais, F. (1990). Adolescent drug use: Findings of national and local surveys. *Journal of Consulting and Clinical Psychology*, *58*, 385–394.

Olson, S. (2009). *Strengthening high school chemistry education through teacher outreach programs: A workshop summary to the chemical sciences. Roundtable*. Washington, DC: National Academies Press.

Pace, C. R., Barahona, D., & Kaplan, D. (1985). *The credibility of student self-reports*. Los Angeles, VA: Center for the Study of Evaluation.

Phelps, L. A., Camburn, E. M., & Min, S. (2018). Choosing STEM college majors: Exploring the role of pre-college engineering courses. *Journal of Pre-College Engineering Education Research*, *8*(1), 1–24.

Porter, S. R., & Umbach, P. D. (2006). College major choice: An analysis of person–environment fit. *Research in Higher Education*, *47*(4), 429–449.

President's Council of Advisors on Science and Technology. (2010). Prepare and inspire: K–12 education in science, technology, engineering, and mathematics (STEM) for America's future. Washington, DC. https://nsf.gov/attachments/117803/public/2a--Prepare_and_Inspire--PCAST.pdf

Project Lead The Way. (2011). Our history.

Riegle-Crumb, C., Moore, C., & Ramos-Wada, A. (2011). Who wants to have a career in science or math? Exploring adolescents' future aspirations by gender and race/ethnicity. *Science Education*, *95*(3), 458–476.

Rothwell, J. (2013). *The hidden STEM economy*. Washington, DC: The Brookings Institution. Retrieved from https://www.brookings.edu/research/the-hidden-stem-economy/

Sadler, P. M., Sonnert, G., Hazari, Z., & Tai, R. (2012). Stability and volatility of STEM career interest in high school: A gender study. *Science Education*, *96*(3), 411–427.

Salzman, H., & Lowell, B. L. (2007). Into the eye of the storm: Assessing the evidence on science and engineering education, quality, and workforce demand. https://files.eric.ed.gov/fulltext/ED498867.pdf

Song, C., & Glick, J. E. (2004). College attendance and choice of college majors among Asian-American students. *Social Science Quarterly*, *85*(5), 1401–1421.

Tai, R. H., Liu, C. Q., Maltese, A. V., & Fan, X. (2006). Planning early for careers in science. *Science*, *312*(5777), 1143–1144.

Tai, R. H., Sadler, P.M., & Loehr, J. F. (2005). Factors influencing success in introductory college chemistry. *Journal of Research in Science Teaching*, *42*(9), 987–1012.

Tracey, T. J., & Robbins, S. B. (2005). Stability of interests across ethnicity and gender: A longitudinal examination of grades 8 through 12. *Journal of Vocational Behavior*, *67*(3), 335–364.

Trusty, J. (2002). Effects of high school course-taking and other variables on choice of science and mathematics college majors. *Journal of Counseling & Development*, *80*(4), 464–474.

Tyson, W., Lee, R., Borman, K. M., & Hanson, M. A. (2007). Science, technology, engineering, and mathematics (STEM) pathways: High school science and math coursework and postsecondary degree attainment. *Journal of Education for Students Placed at Risk*, *12*(3), 243–270.

Utley, J., Ivey, T., Weaver, J., & Self, M. J. (2019). Effect of Project Lead the Way Participation on Retention in Engineering Degree Programs. *Journal of Pre-College Engineering Education Research (J-PEER)*, *9*(2), 3.

White House. (2010). President Obama to announce major expansion of "Educate to Innovate" campaign to improve science, technology, engineering and mathematics (STEM) education. The White House. https://obamawhitehouse.archives.gov/the-press-office/2010/09/16/president-obama-announce-major-expansion-educate-innovate-campaign-impro